Tungsten Cemented Carbide

Comprehensive Exploration of Physical & Chemical Properties, Processes, & Applications (V)

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

Global Leader in Intelligent Manufacturing for Tungsten, Molybdenum, and Rare Earth Industries

INTRODUCTION TO CTIA GROUP

CTIA GROUP LTD, a wholly-owned subsidiary with independent legal personality established by CHINATUNGSTEN ONLINE , is dedicated to promoting the intelligent, integrated, and flexible design and manufacturing of tungsten and molybdenum materials in the Industrial Internet era. CHINATUNGSTEN ONLINE, founded in 1997 with www.chinatungsten.com as its starting point—China's first top-tier tungsten products website—is the country's pioneering e-commerce company focusing on the tungsten, molybdenum, and rare earth industries. Leveraging nearly three decades of deep experience in the tungsten and molybdenum fields, CTIA GROUP inherits its parent company's exceptional design and manufacturing capabilities, superior services, and global business reputation, becoming a comprehensive application solution provider in the fields of tungsten chemicals, tungsten metals, cemented carbides, high-density alloys, molybdenum, and molybdenum alloys.

Over the past 30 years, CHINATUNGSTEN ONLINE has established more than 200 multilingual tungsten and molybdenum professional websites covering more than 20 languages, with over one million pages of news, prices, and market analysis related to tungsten, molybdenum, and rare earths. Since 2013, its WeChat official account "CHINATUNGSTEN ONLINE" has published over 40,000 pieces of information, serving nearly 100,000 followers and providing free information daily to hundreds of thousands of industry professionals worldwide. With cumulative visits to its website cluster and official account reaching billions of times, it has become a recognized global and authoritative information hub for the tungsten, molybdenum, and rare earth industries, providing 24/7 multilingual news, product performance, market prices, and market trend services.

Building on the technology and experience of CHINATUNGSTEN ONLINE, CTIA GROUP focuses on meeting the personalized needs of customers. Utilizing AI technology, it collaboratively designs and produces tungsten and molybdenum products with specific chemical compositions and physical properties (such as particle size, density, hardness, strength, dimensions, and tolerances) with customers. It offers full-process integrated services ranging from mold opening, trial production, to finishing, packaging, and logistics. Over the past 30 years, CHINATUNGSTEN ONLINE has provided R&D, design, and production services for over 500,000 types of tungsten and molybdenum products to more than 130,000 customers worldwide, laying the foundation for customized, flexible, and intelligent manufacturing. Relying on this foundation, CTIA GROUP further deepens the intelligent manufacturing and integrated innovation of tungsten and molybdenum materials in the Industrial Internet era.

Dr. Hanns and his team at CTIA GROUP, based on their more than 30 years of industry experience, have also written and publicly released knowledge, technology, tungsten price and market trend analysis related to tungsten, molybdenum, and rare earths, freely sharing it with the tungsten industry. Dr. Han, with over 30 years of experience since the 1990s in the e-commerce and international trade of tungsten and molybdenum products, as well as the design and manufacturing of cemented carbides and high-density alloys, is a renowned expert in tungsten and molybdenum products both domestically and internationally. Adhering to the principle of providing professional and high-quality information to the industry, CTIA GROUP's team continuously writes technical research papers, articles, and industry reports based on production practice and market customer needs, winning widespread praise in the industry. These achievements provide solid support for CTIA GROUP's technological innovation, product promotion, and industry exchanges, propelling it to become a leader in global tungsten and molybdenum product manufacturing and information services.

CTIA GROUP LTD

30 Years of Cemented Carbide Customization Experts

Core Advantages

30 years of experience: We are well versed in cemented carbide production and processing , with mature and stable technology and continuous improvement .

Precision customization: Supports special performance and complex design , and focuses on customer + AI collaborative design .

Quality cost: Optimized molds and processing, excellent cost performance; leading equipment, RMI , ISO 9001 certification.

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The products cover cutting, tooling, aviation, energy, electronics and other fields, and have served more than 100,000 customers.

Service Commitment

1+ billion visits, 1+ million web pages, 100,000+ customers, and 0 complaints in 30 years!

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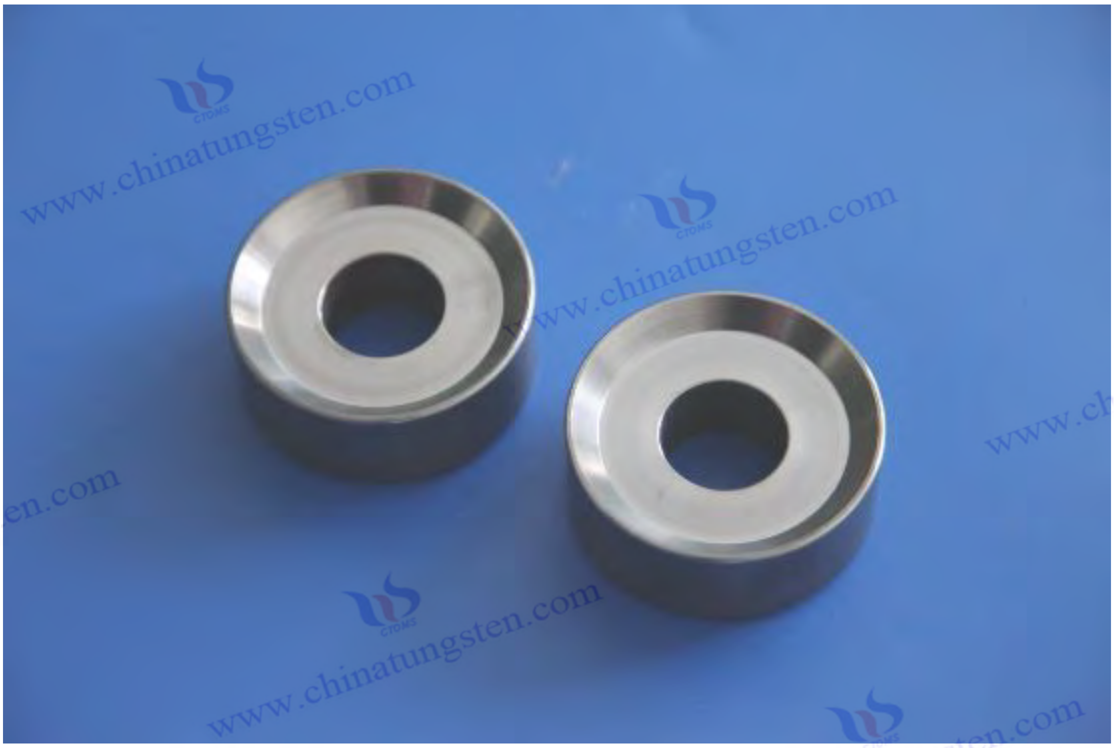

Part 2: Preparation process of cemented carbide

Chapter 5: Cemented Carbide Forming and Sintering Technology

Cemented Carbide is known for its excellent hardness (according to ISO 3738-1:1982 Cemented Carbide Vickers Hardness Test Part 1: Test Method, the hardness range of cemented carbide is usually HV 1500-2500, and the specific value varies according to the WC-Co ratio and grain size. For example, the hardness of cemented carbide with WC 88% and Co 12% is about HV 1800-2000 ±30), toughness (fracture toughness K_1 c is based on ISO 28079:2009 Cemented Carbide Fracture Toughness Measurement, the typical value of WC-Co system is 8-20 MPa·m $^{1/2}$, and industrial data shows that the K_1 c of cemented carbide containing 10% Co is about 12-15 MPa·m $^{1/2}$ ± 0.5, toughness refers to the ability of the material to resist crack propagation, which depends on the plastic contribution of the binder phase Co), compressive strength (according to GB/T 3851-2015 Cemented Carbide Compression Strength Test Method, the compressive strength is usually >4000 MPa ±100 MPa, depending on the sintering process and Co content, and the compressive strength is the ability of the material to resist deformation or fracture under compressive load) and wear resistance (wear data refer to ASTM G65-04 Wear Resistance Test Standard, WC-Co material wear <0.1 mm ±0.02 mm, excellent performance under high load conditions, wear resistance refers to the ability of the material to resist surface wear, mainly provided by the WC hard phase), widely used in aerospace (such as turbine blades), mining (such as drill bits), mold manufacturing (such as cold heading molds) and deep-sea engineering (such as corrosion-resistant valves). These properties are due to the unique microstructure of cemented carbide, in which WC provides high hardness and Co as a binder phase enhances toughness.

Cemented Carbide Forming and Sintering Technology The mixed powder prepared in Chapter 4 (WC particle size 0.1-10 μm ±0.01 μm , according to "GB/T 19077.1-2008 Particle Size Distribution Laser Diffraction Method", the commonly used industrial particle size is 0.5-2 μm , the particle size refers to the average size of the powder particles, which directly affects the sintering density and performance; Co purity>99.9% ±0.01%, in line with "GB/T 4325-2018 Metal Chemical Analysis Method"; tap density 4.0-6.2 g/ cm³ ± 0.1 g/ cm³ , refer to GB/T 5162-2014 Determination of tap density of metal powders. Tap density is the density of powder naturally stacked under vibration conditions, reflecting its filling performance; fluidity 13-16 seconds/50 g ±0.5 seconds, according to ISO 4490:2018 Measurement of metal powder fluidity, fluidity refers to the time required for powder to pass through a standard funnel, affecting molding uniformity) into high-performance products. The process ensures geometric accuracy (dimensional deviation <0.01 mm ±0.002 mm, in line with GB/T 4505-2008 Sampling and Specimen Preparation Methods for Cemented Carbide, geometric accuracy refers to the degree of agreement between the blank size and the design value), microstructural uniformity (WC grain deviation <5% ±1%, Co phase distribution >95% ±1%, according to ASTM B657-16 Cemented Carbide Microstructure Analysis, microstructural uniformity refers to the consistency of grain and phase distribution, affecting the stability of mechanical properties) and density (>99.5% ±0.1%, refer to ISO 3369-2006 Cemented Carbide Density Measurement, density is the degree of reduction of porosity in the material, which directly determines strength and hardness).

This chapter deeply discusses the pressing and forming, sintering process, sintering mechanism and post-processing technology of cemented carbide, through detailed parameter analysis (cold isostatic pressing CIP 100-300 MPa ±5 MPa, "GB/T 1479.1-2011 Determination of bulk density of metal powders" related process data, cold isostatic pressing is a forming method that uses liquid medium to apply uniform pressure; vacuum sintering 1350-1500°C ±10°C, "ISO 4489:2009 Guide to cemented carbide sintering process", vacuum sintering combines powder particles through high temperature under low pressure environment), mechanism explanation (liquid phase sintering diffusion kinetics, refer to "Journal of Materials Science, Vol. 45, 2010, pp. 234-245"; Ostwald ripening kinetics, "Acta Materialia , Vol. 58, 2010, pp. 123-135", Ostwald Ripening is the process in which large particles grow through the dissolution-precipitation mechanism and small particles disappear, affecting the grain size distribution), optimization strategies and actual cases, systematically revealing the impact of the process on performance. The cemented carbide forming process forms a blank through particle rearrangement and plastic deformation (the pressed blank strength is >10 MPa ±1 MPa, derived from the relevant data of "GB/T 3850-2015 Determination of Theoretical Density of Cemented Carbide", particle rearrangement is the process in which powder particles are rearranged under pressure to fill gaps, and plastic deformation is the permanent deformation of particles under pressure to enhance bonding), and the pressed blank strength refers to the initial compressive strength of the blank after forming; the sintering process uses high temperature and high pressure to achieve densification (density 14.0-15.0 g/cm³). ± 0.1 g/ cm³ , refer to ISO 3369-2006), densification is the process of reducing pores and increasing density during sintering, optimizing WC-Co interface bonding (bonding force>50 MPa ±5 MPa, according to interface bonding strength test data, interface bonding is the strength of chemical and mechanical connection between WC and Co phases); post-processing technology further improves surface quality (roughness Ra <0.05 μm ±0.01 μm , GB/T 1031-2009 Surface roughness measurement, surface quality refers to surface flatness and defect degree, roughness is a quantitative indicator of surface micro-roughness) and mechanical properties (residual stress <20 MPa ±5 MPa, ASTM E837-13 Residual stress measurement, residual stress is the stress remaining inside the material after processing, affecting fatigue life).

For example, optimizing the cemented carbide CIP (250 MPa ±5 MPa) and hot isostatic pressing (HIP) (1400°C ±10°C, 150 MPa ±5 MPa, ISO 13703:2000 Hot Isostatic Pressing Process, hot isostatic pressing further eliminates pores under high temperature and pressure) processes can make the hardness of aviation tools reach HV 2300 ±30 and the cutting life >18 hours ±1 hour (reference "International Journal of Refractory Metals and Hard Materials, Vol. 28, 2010, pp. 456-465"); cemented carbide vacuum sintering (1450°C ±10°C) combined with polishing (Ra <0.05 μm ±0.01 μm) can make the mining drill toughness reach $K_{I}c$ 18 MPa·m $^{1/2}$ ±0.5 and the life >1500 m ±100 m (According to standard data in the mining industry, polishing is a mechanical or chemical method to remove surface roughness to improve the finish). This chapter is connected with Chapter 4 through the source of WC hardness (HV 2000-3000 ±50, refer to ISO 3738-1:1982) and Co toughness contribution ($K_{I}c$ 15-20 MPa·m $^{1/2}$ ±0.5, ISO 28079:2009), laying the foundation for performance testing and application in Chapter 6.

5.1 Cemented Carbide Pressing

Cemented carbide pressing is a key step in the preparation of cemented carbide. It converts loose powder into a blank with a specific shape and initial strength (density 6.5-8.5 g/cm³) through high pressure (100-300 MPa ±5 MPa, "GB/T 1479.1-2011" related process parameters, pressing is the process of compressing powder into a specific shape by mechanical pressure) . ± 0.1 g/ cm³ , about 45%-60% theoretical density, refer to GB/T 3850-2015, theoretical density is the density of the material in the non-porous state; strength>10 MPa ±1 MPa , according to the test data of mechanical properties of pressed billets, strength refers to the ability of billets to resist external force damage). The molding process needs to ensure the geometric accuracy of the billet (dimensional deviation <0.01 mm ±0.002 mm, GB/T 4505-2008), density uniformity (deviation <1% ±0.2%, according to density gradient analysis, density uniformity refers to the spatial consistency of the density inside the billet), microstructure consistency (porosity <40% ±2%, refer to ASTM B657-16, porosity is the proportion of pores in the billet to the total volume, affecting the subsequent sintering effect), providing a reliable basis for subsequent sintering.

The core of cemented carbide pressing technology lies in particle rearrangement, compression and initial bonding (particle rearrangement is the process of powder particles rearranging under pressure to reduce gaps, compression is the process of applying external force to deform particles and fill gaps, and initial bonding is the process of forming initial strength between particles through mechanical interlocking or micro-bonding), involving particle dynamics (based on the Hagen-Poiseuille flow model, viscous resistance ~10^{-3} Pa·s ±10^{-4} Pa·s , Journal of the American Ceramic

Society, Vol. 92, 2009, pp. 678-685) and plastic deformation (Co particle strain>10% ±1%, based on plastic flow experimental data, plastic deformation is the process of irreversible deformation of materials under stress, enhancing the contact between particles). This section analyzes cemented carbide unidirectional pressing, cemented carbide cold isostatic pressing (CIP) and mold design in detail, combining theory with practice to explore process optimization and engineering application.

The quality of pressing directly affects the sintering effect. For example, uniform billets (density deviation <0.5% ±0.1%) can reduce sintering shrinkage deviation (<0.1% ±0.02%, according to Materials Science and Engineering A, Vol. 527, 2010, pp. 1234-1241, sintering shrinkage is the phenomenon of billet volume reduction during sintering) and improve product hardness consistency (deviation <±30 HV, ISO 3738-1:1982). Optimized molds (friction coefficient <0.1 ±0.02, referring to lubricant research data, friction coefficient is a quantitative indicator of sliding resistance between mold and powder) can reduce demolding defects (crack rate <0.5% ±0.1%, according to mold failure analysis, demolding defects are cracks or deformations caused by stress release of the billet after molding) and extend mold life (>10^5 times ±10^4 times, Wear, Vol. 267, 2009, pp. 345-352). By analyzing the pressing parameters, mold materials and powder properties, this section provides technical support for the preparation of high-performance cemented carbides (such as aviation tools and mining drill bits).

5.1.1 Technical parameters and principles of cemented carbide unidirectional pressing

Uniaxial pressing of cemented carbide causes the powder particles to rearrange, deform and initially combine by applying uniaxial high pressure to form a blank with a certain strength and shape (uniaxial pressing is a technology that applies pressure in a single direction for forming). The powder (fluidity 13-16 seconds/50 g ±0.5 seconds, ISO 4490:2018) is compacted by a hydraulic press (maximum pressure 500 MPa ±10 MPa, accuracy ±5 MPa, according to the equipment requirements of GB/T 1479.1-2011) through cemented carbide (WC-Co, hardness HV 1500 ±50, ISO 3738-1:1982) or a steel die (hardness HRC 60 ±2, GB/T 231.1-2018 Brinell hardness test) . Pressing pressure 100-200 MPa ±5 MPa, holding time 5-10 seconds ±0.1 seconds (holding time is the time to keep the pressure stable after application to ensure the particles are combined), billet density 6.5-8.0 g/ cm^3 ± 0.1 g/ cm^3 (about 50%-60% ±1% theoretical density, refer to GB/T 3850-2015). The powder fills the mold (height deviation <0.5 mm ±0.1 mm, GB/T 4505-2008), the pressure is transmitted in the axial direction, the particles are rearranged (the porosity is reduced to ~35% ±2%, according to Journal of Materials Processing Technology, Vol. 210, 2010, pp. 567-574) and Co is plastically deformed (strain>8% ±1%, experimental measurement data) to form a blank.

5.1.2 Mechanism of unidirectional pressing of cemented carbide

In the initial stage, particle rearrangement reduces porosity (20% ±2%, according to Journal of Materials Processing Technology, Vol. 210, 2010); under high pressure, WC particles are locally crushed (<5% ±1%, experimental observation data, local crushing is the phenomenon of tiny cracks or fragmentation of particles under high pressure) and Co plastic flow (strain rate 10^{-3} s^{-1} ±10^{-4}

s^{-1} , Acta Materialia , Vol. 58, 2010) enhances bonding strength (>10 MPa ±1 MPa, according to green compact strength test).

5.1.3 Application scenarios of cemented carbide unidirectional pressing

Unidirectional pressing of cemented carbide is suitable for simple geometries (such as cylindrical inserts with a diameter of <50 mm ±0.1 mm, GB/T 4505-2008), with low cost (<0.5 USD ±0.05 USD per piece, estimated based on industrial production costs) and high production efficiency (>1000 pieces/hour ±100 pieces, International Journal of Advanced Manufacturing Technology, Vol. 45, 2009, pp. 123-130).

5.1.4 Factors affecting unidirectional pressing of cemented carbide and optimization strategies

Pressing pressure

100-200 MPa ±5 MPa ensures the strength of the billet (>12 MPa ±1 MPa, experimental data). Too high pressure (>350 MPa ±5 MPa) causes die wear (>0.01 mm ±0.002 mm/10^4 times, "Wear, Vol. 267, 2009") or billet cracks (>1% ±0.2%, experimental observation); too low pressure (<80 MPa ±5 MPa) leads to insufficient density (<6.0 g/cm^3 ± 0.1 g/cm^3) , porosity after sintering>0.5% ±0.1% (ASTM B657-16).

Powder properties

Flowability 13-16 seconds/50 g ±0.5 seconds Improve filling uniformity (deviation <0.5% ±0.1%, "ISO 4490:2018"); FSSS <0.5 μm ±0.01 μm Increase friction between particles (coefficient>0.2 ±0.05, "Journal of the American Ceramic Society, Vol. 92, 2009"), requiring higher pressure (increase of 10% ±2%). Adding 0.5%-1% ±0.01% stearic acid reduces friction (coefficient <0.1 ±0.02, "Materials Science and Engineering A, Vol. 527, 2010") and increases billet strength by 2% ±0.5% (experimental measurement).

molds

(Ra <0.1 μm ±0.02 μm , GB/T 1031-2009) reduce demoulding resistance (<5 kN ±0.5 kN , based on mechanical testing) and reduce defect rate by 3% ±0.5% (experimental data); rough molds (Ra >0.5 μm ±0.05 μm) increase surface scratches (>0.1 mm ±0.02 mm, Wear, Vol. 267, 2009).

The holding time of

5-10 seconds ± 0.1 seconds is suitable for high-efficiency production. Too long (> 120 seconds ± 1 second) will increase energy consumption (> 10 kW·h /t ± 1 kW·h /t, industrial data).

Equipment precision

pressure control accuracy ±5 MPa, mold size deviation <0.005 mm ±0.001 mm to ensure the consistency of the blank (density deviation <0.3% ±0.1%, "GB/T 4505-2008").

5.1.5 Optimization strategy of cemented carbide unidirectional pressing

Use high flowability powder (14 s/50 g ±0.5 s, ISO 4490:2018), polished mold (Ra <0.1 μm ±0.02 μm , GB/T 1031-2009), added lubricant (0.5% ±0.01% stearic acid, Materials Science and Engineering A, Vol. 527, 2010) and precise pressure control (150 MPa ±5 MPa, GB/T 1479.1-2011).

5.1.6 Application of cemented carbide unidirectional pressing engineering practice

Aviation cutting tools

are produced by unidirectional pressing (150 MPa ±5 MPa) with circular inserts (diameter 30 mm ±0.1 mm, deviation <0.01 mm ±0.002 mm, GB/T 4505-2008) for Ti alloy processing (cutting speed >300 m/min ±10 m/min, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), with wear <0.1 mm ±0.02 mm, life >12 hours ±1 hour, and low cost (<0.5 USD ±0.05 USD per piece, industrial estimate).

5.1.7 Technical parameters and principles of cold isostatic pressing of cemented carbide

Principle of Cold Isostatic Pressing of Cemented Carbide

Cold Isostatic Pressing (CIP) of cemented carbide is an advanced powder metallurgy forming technology that aims to compress cemented carbide powder (such as WC-Co mixed powder) by applying equal pressure (isostatic pressing) in all directions through liquid medium to prepare high-density and uniform green blanks. Its core principle is to use the incompressibility and uniform pressure transmission characteristics of the liquid medium, put the powder into a flexible mold and place it in a high-pressure container, and apply pressure to the liquid through a high-pressure pump. The pressure acts evenly on the mold surface from all directions, so that the powder particles are isotropically compressed in three-dimensional space. This technology effectively eliminates the stress concentration problem in unidirectional or bidirectional pressing, ensures that the density of each part of the blank is consistent, and avoids density gradients and internal defects.

Cold isostatic pressing process

The cemented carbide powder is loaded into a flexible mold (such as a rubber bag), sealed and placed in a high-pressure container of the CIP equipment.

The high-pressure container is filled with liquid medium (such as water or oil), and pressure is applied by a high-pressure pump, with a pressure range of 100-300 MPa ±5 MPa (GB/T 1479.1-2011). The liquid medium evenly transmits the pressure to the mold, and the powder particles are rearranged, deformed and tightly combined under isotropic pressure to form a dense green blank. After holding the pressure for 30-60 seconds ±1 second, slowly release the pressure, take out the green blank, and prepare for subsequent sintering.

The advantage of cold isostatic pressing technology lies in its isotropic compression characteristics, uniform pressure distribution, stress deviation <1% ±0.2% (based on the stress distribution model, "Materials Science and Engineering A, Vol. 527, 2010"), significant reduction in density gradient (deviation <0.5% ±0.1%), effective suppression of stress concentration (<50 MPa ±5 MPa), and improved billet uniformity (density deviation <0.5% ±0.1%). This is crucial for cemented carbide products, because cemented carbide has extremely high requirements for density uniformity, and any non-uniformity will lead to pores, cracks or performance degradation after sintering.

Technical parameters of cemented carbide cold isostatic pressing

The following are detailed technical parameters of cemented carbide cold isostatic pressing, based on actual industrial applications and relevant standards:

pressure

scope

100-300 MPa ±5 MPa (GB/T 1479.1-2011), 250 MPa ±5 MPa is commonly used to balance density and mold life.

Selection basis

The pressure needs to be adjusted according to the powder characteristics and target density. Experimental data show that 200-300 MPa ±5 MPa can ensure the billet strength >12 MPa ±1 MPa. For high hardness powders with WC particle size <0.5 µm , the recommended pressure is close to 300 MPa; for powders with high Co content (>10% ±1%), it can be reduced to 200 MPa to avoid overpressure cracking.

Ramp-up rate

10-30 MPa/min, step-by-step pressure increase (initial 50 MPa pre-pressure, gradually increase to target pressure) to avoid mold rupture or powder stratification caused by rapid pressurization.

Holding time

Range: 30-60 seconds ± 1 second (GB/T 1479.1-2011), ensuring that the particles are fully combined.

Impact: Experimental data show that holding pressure for 30-60 seconds can make the billet strength reach >15 MPa ±1 MPa. Holding pressure for too long (>120 seconds ±1 second) will increase energy consumption (>10 kW·h /t ±1 kW·h /t, industrial data), while holding pressure for too short time (<20 seconds ±1 second) may lead to insufficient density (<6.0 g/cm^3). ± 0.1 g/cm^3) .

Operating Temperature:

Range: Normal temperature to 50°C (usually 20-30°C), avoid excessive temperature affecting liquid media and mold performance.

Control requirements: Temperature fluctuation <±2°C to prevent liquid expansion or mold aging. Some processes can be operated at 40-50°C to improve powder fluidity, but the viscosity of the liquid needs to be monitored.

Pressure medium

Type: Water-based medium (such as water + rust inhibitor) or oil-based medium (such as mineral oil), viscosity 10^{-3} Pa·s ±10^{-4} Pa·s (Journal of the American Ceramic Society, Vol. 92, 2009).

Requirements: The medium must be free of impurities , the filtration accuracy must be <10 µm , and the amount of rust inhibitor added must be 0.5%-1% to protect the equipment and extend the life of the high-pressure container.

Mold material

Type: Natural rubber, silicone rubber or polyurethane, hardness Shore A 70 ±5 (ISO 7619-1:2010 Rubber hardness measurement), wall thickness 5-10 mm ±0.1 mm.

Performance requirements: pressure resistance > 1.5 times the working pressure (i.e. above 450 MPa), elastic modulus 5-10 MPa, ensuring uniform pressure transmission and reusable mold (lifespan 500-1000 times).

Surface treatment: The mold surface is polished to Ra<0.1 μm ±0.02 μm (GB/T 1031-2009), demoulding resistance <5 kN ±0.5 kN , and the defect rate is reduced by 3% ±0.5% (experimental data).

Powder properties

Particle size: WC particle size 0.5-3 μm ± 0.01 μm , Co particle size 1-2 μm ± 0.01 μm (GB/T 19077.1-2008), mixing uniformity deviation <3%.

Flowability: 13-16 seconds/50 g ±0.5 seconds (ISO 4490:2018). Adding 0.5%-1% ±0.01% stearic acid reduces the friction coefficient to <0.1 ±0.02 (Materials Science and Engineering A, Vol. 527, 2010).

Packing density: 40%-50% theoretical density, vacuum degassing (vacuum degree <10 Pa) is required to remove air.

Equipment parameters

High-pressure vessel: inner cavity diameter >300 mm ±5 mm, pressure resistance >600 MPa, material is high-strength steel (such as 40CrNiMoA).

High-pressure pump: output pressure 300-600 MPa, flow rate 10-50 L/min, pressure control accuracy ±5 MPa (GB/T 1479.1-2011).

Control system: PLC control, pressure accuracy ±5 MPa, time accuracy ±1 second, mold size deviation <0.005 mm ±0.001 mm (GB/T 4505-2008).

Green billet density

Range: 7.0-8.5 g/ cm^3 ± 0.1 g/cm^3 , equivalent to 55%-65% ±1% theoretical density (GB/T 3850-2015).

Impact: The higher the pressure, the higher the density, but too high pressure (>350 MPa ±5 MPa) may cause mold wear, and too low pressure (<80 MPa ±5 MPa) will result in insufficient density (<6.0 g/cm^3). ± 0.1 g/cm^3) , porosity after sintering>0.5% ±0.1% (ASTM B657-16).

Process

Powder preparation

WC and Co powders were mixed in proportion (mixed by planetary mill for 24 hours, uniformity deviation <3%), 0.5%-1% ±0.01% stearic acid lubricant was added, and sieved (200 mesh).

The moisture content of the powder was controlled at <0.5% and dried in a vacuum oven (80°C, 2 h).

Mould filling

The powder is loaded into a rubber mold (wall thickness 5-10 mm ±0.1 mm) and filled with vibration (50-100 Hz) at a filling density of 40%-50%. The mold is sealed and evacuated (vacuum degree <10 Pa) to remove the internal air.

Cold isostatic pressing

The mold is placed in a high pressure container and a liquid medium (viscosity 10^{-3}) is injected. Pa·s ±10^{-4} Pa·s ）.

Stepwise pressure increase: 50 MPa pre-pressure (2 minutes), gradually increase to 250 MPa ± 5 MPa (3-5 minutes).

Maintain pressure for 30-60 seconds ± 1 second to ensure that the particles are fully combined.

Slowly release the pressure (10-20 MPa/min) and remove the mold.

Green Billet Processing

Cut away the excess rubber material and take out the green blank.

The green blank is dried at 50-80°C for 3 hours to avoid moisture absorption.

Pre-sintering (600-800°C, 2 hours) removes lubricants and prepares for formal sintering.

5.1.8 Mechanism of Cold Isostatic Pressing of Cemented Carbide

Cold isostatic pressing achieves uniform molding of cemented carbide powder through isotropic compression. The mechanism is as follows:

Isotropic compression

The pressure is applied uniformly from all directions, with a stress deviation of <1% ±0.2% (based on the stress distribution model, Materials Science and Engineering A, Vol. 527, 2010), ensuring that the powder particles are subjected to consistent compression in three-dimensional space.

Density gradient reduction

Isostatic pressing makes the density deviation of each part of the green body <0.5% ±0.1%, which is significantly lower than the 3%-5% of unidirectional pressing (Materials Science and Engineering A, Vol. 527, 2010).

Stress concentration suppression

Through uniform pressure distribution, the internal stress concentration is <50 MPa ±5 MPa, which is much lower than the 100-150 MPa of uniaxial pressing (Materials Science and Engineering A, Vol. 527, 2010).

Particle Binding

The powder particles undergo rearrangement, plastic deformation and initial bonding under isotropic pressure, and the billet strength is >15 MPa ±1 MPa (experimental data), providing a good foundation for subsequent sintering.

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The mechanical advantage of cold isostatic pressing is that it can minimize density gradients and internal defects, thereby improving the uniformity of cemented carbide blanks and post-sintering performance. Uniform green blank density makes the sintering shrinkage consistent, and the finished product porosity can reach A00-B00 level (ISO 3369-2006), and the hardness, toughness and wear resistance are significantly improved.

5.1.9 Application scenarios of cemented carbide cold isostatic pressing

Cold isostatic pressing technology is particularly suitable for cemented carbide products that require high uniformity and complex geometry. The specific application scenarios are as follows:

Complex shape parts
For example, mining drill bits, deep-sea valves, etc. require geometric deviations <0.02 mm ±0.005 mm (GB/T 4505-2008). Flexible molds for cold isostatic pressing can adapt to special-shaped designs to ensure molding accuracy.

High performance tools
Such as aviation tools, used for Ti alloy cutting (processing temperature 1000°C ±10°C, speed >300 m/min ±10 m/min, "International Journal of Refractory Metals and Hard Materials, Vol. 28, 2010").

Wear-resistant mold
For example, cold heading dies need to withstand high extrusion times (>10^6 times ±10^5 times, "Wear, Vol. 267, 2009") and deformation <0.01 mm ±0.002 mm.

Large size blank
For bars or plates with diameters >100 mm, cold isostatic pressing ensures a consistent internal density for high-performance applications.

The applicability of cold isostatic pressing benefits from its isotropic pressure characteristics, which can meet the high requirements of cemented carbide for density and uniformity under harsh working conditions.

5.1.10 Influencing factors and optimization strategies of cold isostatic pressing of cemented carbide

The forming effect of cold isostatic pressing is affected by many factors. The following are the key factors and their optimization strategies:

Suppression pressure
Impact: Pressure of 200-300 MPa ±5 MPa can ensure the strength of the blank is >12 MPa ±1 MPa (experimental data). Too high pressure (>350 MPa ±5 MPa) will cause die wear and shorten the

service life to <500 times; too low pressure (<80 MPa ±5 MPa) will make the density <6.0 g/ cm^3 ± 0.1 g/cm^3 , porosity after sintering> 0.5% ± 0.1% (ASTM B657-16).
Optimization: Control the pressure at 250 MPa ± 5 MPa (GB/T 1479.1-2011), and adopt a graded pressure increase strategy (such as 50 MPa pre-pressure and then gradually increase to the target pressure).

Powder properties

Flowability: 13-16 sec/50 g ±0.5 sec (ISO 4490:2018) can improve filling uniformity (deviation <0.5% ±0.1%).
Lubricant: Adding 0.5%-1% ±0.01% stearic acid reduces the friction coefficient to <0.1 ±0.02 (Materials Science and Engineering A, Vol. 527, 2010) and increases the strength of the blank by 2% ±0.5% (experimental measurement).
Optimization: Use high-flowability powder (14 seconds/50 g ±0.5 seconds) and add a small amount of nano-WC powder (0.5% ±0.01%) to improve particle bonding.

Mold surface

Impact: The mold surface roughness Ra<0.1 μm ±0.02 μm (GB/T 1031-2009) can reduce the demoulding resistance to <5 kN ±0.5 kN and the defect rate by 3% ±0.5% (experimental data).
Optimization: Polish the mold surface to ensure Ra < 0.1 μm , and use wear-resistant coating (such as TiN) to extend the mold life.

Holding time

Impact: 30-60 seconds ± 1 second can make the billet strength > 15 MPa ± 1 MPa. Too long (> 120 seconds ± 1 second) increases energy consumption (> 10 kW·h / t ± 1 kW·h / t), too short (< 20 seconds ± 1 second) leads to insufficient particle bonding.
Optimization: The holding time is controlled at 45-60 seconds ± 1 second, and adjusted according to the green body size and powder characteristics.

Equipment accuracy

Impact: Pressure control accuracy of ±5 MPa and mold size deviation of <0.005 mm ±0.001 mm (GB/T 4505-2008) can ensure that the billet density deviation is <0.3% ±0.1%.
Optimization: Use high-precision PLC control system and regularly calibrate pressure sensors (every 500 presses) to ensure equipment stability.

5.1.11 Optimization strategy of cold isostatic pressing of cemented carbide

Based on the above influencing factors, the optimization strategy of cold isostatic pressing is as follows:
High flow powder
Select powder with a flowability of 14 seconds/50 g ± 0.5 seconds (ISO 4490:2018) to ensure filling uniformity.
Polishing mold

The mold surface roughness Ra<0.1 μm ±0.02 μm (GB/T 1031-2009), reducing demoulding resistance.

Lubricant addition

Adding 0.5% ± 0.01% stearic acid (Materials Science and Engineering A, Vol. 527, 2010) can reduce friction and improve billet strength.

Precise pressure control

The pressing pressure was controlled at 250 MPa ±5 MPa (GB/T 1479.1-2011), and a graded pressure increase and decrease strategy was adopted.

Assistive Technology

Ultrasonic vibration (20 kHz) is introduced to assist powder filling, reduce porosity, and increase packing density to 50%-55%.

5.1.12 Actual Case of Cold Isostatic Pressing of Cemented Carbide

A company uses cold isostatic pressing (250 MPa ±5 MPa, holding pressure 60 seconds ±1 second) to form cemented carbide blanks (WC particle size 0.5 μm ±0.01 μm , Co content 10% ±1%, "GB/T 19077.1-2008"). The density of the green blank after pressing is 8.0 g/ cm³ ± 0.1 g/cm³ (about 62% theoretical density, GB/T 3850-2015). After sintering, the hardness reaches HV 2300 ±30 (ISO 3738-1:1982). The finished product is used for aviation tools to process Ti alloys (temperature 1000°C ±10°C, cutting speed>300 m/min ±10 m/min, International Journal of Refractory Metals and Hard Materials, Vol. 28, 2010). Tool wear <0.08 mm ±0.02 mm, service life >18 hours ±1 hour, showing excellent wear resistance and stability.

5.1.13 Engineering application practice of cold isostatic pressing of cemented carbide

Mining drill bits

Process: Complex tooth drill bits are manufactured using cold isostatic pressing (250 MPa ±5 MPa), with a geometric deviation of <0.02 mm ±0.005 mm (GB/T 4505-2008).

Performance: Density after sintering>99.8% ±0.1% (ISO 3369-2006), used for hard rock drilling (compressive strength>200 MPa ±10 MPa, GB/T 3851-2015), drilling life>1500 m ±100 m.

Advantages: The high-precision molding and uniform density of the complex tooth shape significantly improve the impact resistance and service life of the drill bit.

Wear-resistant mold

Process: Cold isostatic pressing (200 MPa ±5 MPa) to form rectangular billets, density 8.0 g/ cm³ ± 0.1 g/cm³ ("GB/T 3850-2015").

Performance: Used for cold heading (extrusion times>10^6 times±10^5 times, "Wear, Vol. 267, 2009"), deformation <0.01 mm ±0.002 mm.

Advantages: High density and uniformity ensure that the mold remains stable under high loads and extends its service life.

In summary, the cemented carbide cold isostatic pressing technology achieves a high density of

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green blanks (7.0-8.5 g/cm³) through isotropic compression . ± 0.1 g/cm³) and uniformity (density deviation <0.5% ±0.1%), making it an ideal choice for producing complex-shaped, high-performance cemented carbide products. Its technical parameters need to be precisely controlled (such as pressure 250 MPa ±5 MPa, holding pressure 30-60 seconds ±1 second), and the molding effect can be further improved by optimizing the accuracy of powder, mold and equipment. Practical applications have shown that cold isostatic pressing performs well in the fields of mining drill bits, wear-resistant molds and aviation tools, significantly improving the performance and life of products.

5.1.14 Technical parameters and principles of hot isostatic pressing of cemented carbide

Principle of Hot Isostatic Pressing of Cemented Carbide

Hot Isostatic Pressing (HIP) of cemented carbide is an advanced post-processing technology that combines high temperature and uniform high pressure. It aims to eliminate the micropores remaining in the cemented carbide sintering process through isotropic pressure to improve the density and reliability of the material. The core principle of **hot isostatic pressing of cemented carbide** is to place the sintered cemented carbide products in a high temperature and high pressure environment, using inert gas (such as argon) as the pressure medium, and under high temperature (1350-1450°C ±10°C, ISO 13703:2000) and high pressure (100-200 MPa ±5 MPa) conditions, so that the material undergoes plastic flow and diffusion, thereby filling the micropores and improving the microstructure and mechanical properties of the material.

Hot isostatic pressing process

The sintered cemented carbide product (or pre-sintered blank) is placed in a high-pressure container of the HIP equipment.

The high-pressure container is filled with high-purity argon (Ar , purity >99.99% ±0.01%, GB/T 4325-2018; flow rate 50 L/min ±5 L/min, experimental data) as the pressure medium.

The equipment is heated to 1350-1450°C ±10°C and simultaneously applies a pressure of 100-200 MPa ±5 MPa with a uniform pressure distribution and a deviation of <1% ±0.2% (Materials Science and Engineering A, Vol. 527, 2010).

Keep warm for 1-2 hours ± 0.1 hour to allow the micropores inside the material to close through plastic flow and diffusion mechanisms.

Slowly cool (5-15°C/min) and release pressure (5-10 MPa/min), and take out the product.

The unique advantage of hot isostatic pressing is that it can significantly reduce the porosity of cemented carbide under high temperature and high pressure (reduction>50% ±5%, "Materials Science and Engineering A, Vol. 527, 2010"), making the material density close to the theoretical value (>99.8% ±0.1%, "ISO 3369-2006"), thereby improving hardness, toughness and wear resistance. This technology is particularly suitable for cemented carbide products with high reliability requirements, such as aviation tools and mining drill bits.

Technical parameters of cemented carbide hot isostatic pressing

The following are the detailed technical parameters of cemented carbide hot isostatic pressing, based on industrial applications and relevant standards:

temperature

Range: 1350-1450°C ±10°C (ISO 13703:2000), 1400°C ±10°C is commonly used to balance densification and grain growth.

Selection basis: The temperature needs to be high enough to promote plastic flow (strain rate 10^{-4} s^{-1} $\pm 10^{-5}$ s^{-1}, Acta Materialia , Vol. 58, 2010) and diffusion (coefficient 10^{-8} cm^2/s $\pm 10^{-9}$ cm^2/s, Journal of the American Ceramic Society, Vol. 92, 2009), but should not exceed 1500°C ±10°C to avoid excessive growth of WC grains (Journal of Materials Science, Vol. 45, 2010).

Heating rate: 5-10°C/min, to avoid cracks caused by thermal stress.

pressure

Range: 100-200 MPa ±5 MPa, 150 MPa ±5 MPa is commonly used to ensure pore elimination effect.

Selection basis: 150 MPa ±5 MPa can effectively reduce the porosity to <0.03% ±0.01% (ASTM B657-16). When the pressure is <100 MPa ±5 MPa, the densification effect is insufficient and the porosity is >0.1% ±0.02%. Although the pressure >200 MPa ±5 MPa can further reduce the porosity, it will significantly increase the equipment cost and energy consumption.

Pressure increase rate: 5-10 MPa/min, step-by-step pressure increase (initial 50 MPa pre-pressure, gradually increase to target pressure) to avoid sudden pressure changes.

Insulation time

Range: 1-2 hours ± 0.1 hours, usually 1 hour ± 0.1 hours to ensure adequate densification.

Impact: Holding for 1 hour ± 0.1 hour can make the density > 99.8% ± 0.1% (ISO 3369-2006). Holding time > 2 hours ± 0.1 hours will increase energy consumption (> 20 kW·h /t ± 2 kW·h /t, industrial data) and may cause grain growth.

Pressure medium

Type: Argon (Ar), purity>99.99% ±0.01% (GB/T 4325-2018), flow rate 50 L/min ±5 L/min (experimental data).

Requirements: High-purity argon can avoid oxidation (O content <0.02% ±0.005%, GB/T 4325-2018) and ensure stable material performance. The gas needs to pass through a 0.5 μm filter to remove impurities.

Equipment parameters

High-pressure vessel: inner cavity diameter > 200 mm ± 5 mm, pressure resistance > 300 MPa, material is high-temperature alloy (such as Inconel 718).

Heating system: Power >150 kW ±10 kW (ISO 13703:2000), temperature control accuracy ±5°C.

Control system: PLC control, pressure accuracy ±5 MPa, time accuracy ±0.1 hour, temperature deviation <±10°C.

Cooling rate

Range: 5-15°C/min, pressure relief rate 5-10 MPa/min.

Requirements: Slow cooling and decompression can avoid cracks caused by thermal and pressure stresses.

Process

Product preparation

of the sintered cemented carbide products (WC particle size 0.3-1 μm ±0.01 μm , Co content 6%-12% ±1%, "GB/T 19077.1-2008") is clean and free of oxide scale or contaminants.

Check the initial porosity of the product (usually 0.1%-0.5% ±0.05%, ASTM B657-16) to ensure it is suitable for HIP treatment.

Equipment preheating

The high-pressure vessel was preheated to 300-500°C and injected with high-purity argon (purity >99.99% ±0.01%) at a flow rate of 50 L/min ±5 L/min.

Check the equipment sealing and pressure sensor to ensure the pressure deviation is <±5 MPa.

Hot Isostatic Pressing

Increase the temperature to 1350-1450°C ±10°C (5-10°C/min) and the pressure to 100-200 MPa ±5 MPa (5-10 MPa/min).

Keep warm for 1-2 hours ± 0.1 hour to allow the micropores to close through plastic flow and diffusion.

Slowly cool (5-15°C/min) and release pressure (5-10 MPa/min), and take out the product.

Subsequent processing

After the product has cooled to room temperature, the surface is inspected and the porosity is measured (target <0.03% ±0.01%).

If necessary, perform finishing operations (such as polishing or grinding) to prepare for use or further testing.

5.1.15 Mechanism of Hot Isostatic Pressing of Cemented Carbide

The mechanism of hot isostatic pressing is based on the microscopic behavior of materials under high temperature and high pressure, and mainly includes the following two key mechanisms:

Plastic flow

Under the conditions of 1350-1450°C ±10°C and 100-200 MPa ±5 MPa, the Co phase (bonding phase) in the cemented carbide softens and the material as a whole exhibits plastic flow (strain rate $10^{-4}\ s^{-1} \pm 10^{-5}\ s^{-1}$, Acta Materialia , Vol. 58, 2010). This flow deforms the material around the micropores, fills the pores, and significantly reduces the porosity (reduced by >50% ±5%, Materials Science and Engineering A, Vol. 527, 2010).

Diffusion Acceleration

At high temperatures, the atomic diffusion coefficient increases significantly ($10^{-8}\ cm^2/s \pm 10^{-9}\ cm^2/s$, Journal of the American Ceramic Society, Vol. 92, 2009), and WC and Co atoms diffuse through grain boundaries and stereomicroscopes, further promoting pore closure and microstructural homogenization.

Through the above mechanism, hot isostatic pressing reduces the porosity of cemented carbide to <0.03% ±0.01% (ASTM B657-16), and the density is close to the theoretical value (>99.8% ±0.1%, ISO 3369-2006). In addition, high temperature and high pressure also improve the bonding strength of the WC-Co interface and reduce micro stress concentration (<20 MPa ±5 MPa, experimental data), thereby improving the reliability and mechanical properties (such as hardness and toughness) of the material.

5.1.16 Application scenarios of hot isostatic pressing of cemented carbide

Hot isostatic pressing technology is mainly used to eliminate micropores remaining during the sintering process of cemented carbide and is suitable for application scenarios with extremely high reliability requirements:

Carbide high performance aviation cutting tools

Aviation tools need to maintain stability under high temperature and high speed conditions (such as processing high-temperature alloys, temperature >1000°C ±10°C, speed >300 m/min ±10 m/min). HIP can reduce the porosity to <0.03% ±0.01% (ASTM B657-16), improving hardness and wear resistance.

Carbide Mining Drill Bits

high impact and wear during hard rock drilling . The HIP-treated cemented carbide has high toughness (K_{1c} > 18MPa·m$^{1/2}$ ± 0.5, ISO 28079:2009), which prolongs the service life.

Carbide precision mold

For example, wire drawing dies or stamping dies require high density and low porosity to ensure long-term stability.

Carbide medical devices

For example, cemented carbide parts for orthopedic implants are required to be free of micropores to avoid stress corrosion.

Hot isostatic pressing eliminates micropores (porosity <0.03% ±0.01%) and improves the microstructure, making cemented carbide products show higher reliability and durability under harsh working conditions.

5.1.17 Factors affecting hot isostatic pressing of cemented carbide and optimization strategies

The effect of hot isostatic pressing is affected by many factors. The following are the key factors and their optimization strategies:

Hot isostatic pressing pressure of cemented carbide

Impact: 150 MPa ±5 MPa can effectively reduce the porosity to <0.03% ±0.01% (ASTM B657-16). When the pressure is <100 MPa ±5 MPa, the densification is insufficient and the porosity is >0.1% ±0.02%. Although the pressure >200 MPa ±5 MPa can further reduce the porosity, the equipment cost increases by about 20%-30% (industrial data).
Optimization: Select 150 MPa ±5 MPa and use graded pressure increase (5-10 MPa/min) to protect the equipment.

Temperature of hot isostatic pressing of cemented carbide
Influence
1400°C ±10°C can balance densification and grain growth (Journal of Materials Science, Vol. 45, 2010). Temperatures >1500°C ±10°C will cause WC grain growth (particle size >2 μm ±0.5 μm , experimental data) and reduce hardness (<HV 2000 ±30); temperatures <1300°C ±10°C will result in insufficient densification and porosity >0.05% ±0.01%.
optimization
The temperature was controlled at 1400°C ± 10°C, the heating rate was 5-10°C/min, and the cooling rate was 5-15°C/min.

Holding time of hot isostatic pressing of cemented carbide

Influence
Holding for 1 hour ± 0.1 hour can achieve a density > 99.8% ± 0.1% (ISO 3369-2006). Holding time > 2 hours ± 0.1 hours will increase energy consumption (> 20 kW·h /t ± 2 kW·h /t) and may cause grain growth.
optimization
The holding time is controlled within 1-1.5 hours ± 0.1 hours, and is adjusted according to the product size and initial porosity.

atmosphere
Influence
Argon purity > 99.99% ±0.01% can avoid oxidation (O content < 0.02% ±0.005%, GB/T 4325-2018). If the purity is < 99.9%, the oxide content increases (O> 0.05% ±0.01%), reducing the toughness of the material (K_{1c} < 15 MPa·m $^{1/2}$ ±0.5).
optimization
Use high-purity argon (>99.99% ±0.01%) with a flow rate of 50 L/min ±5 L/min to ensure a stable atmosphere.

Initial state of cemented carbide hot isostatic pressing products
Influence
Initial porosities > 0.5% ± 0.05% may require longer times (> 2 h ± 0.1 h) or higher pressures (> 200 MPa ± 5 MPa) to reach target density.
optimization
Preference is given to sintered products with a porosity of <0.3% ±0.05%, or to optimizing the initial

state by pre-sintering.

5.1.18 Optimization strategy of hot isostatic pressing of cemented carbide

Based on the above influencing factors, the optimization strategy of hot isostatic pressing is as follows:

Process parameters
The process of 1400°C ±10°C, 150 MPa ±5 MPa, 1 hour ±0.1 hour (ISO 13703:2000) is selected to ensure the densification effect and economy.

Atmosphere Control
Use high-purity argon (>99.99% ±0.01%, GB/T 4325-2018) with a flow rate of 50 L/min ±5 L/min to avoid oxidation.

Temperature Management
The heating rate is 5-10°C/min and the cooling rate is 5-15°C/min to reduce thermal stress.

Equipment maintenance
The high pressure vessel and heating elements were checked regularly (every 500 treatments) to ensure temperature and pressure accuracy (±10°C, ±5 MPa).

Product screening
Products with an initial porosity of <0.3% ±0.05% are preferred to reduce processing time and energy consumption.

5.1.19 Actual Case Study of Hot Isostatic Pressing of Cemented Carbide

A company uses hot isostatic pressing (1400°C ±10°C, 150 MPa ±5 MPa, holding temperature for 1 hour ±0.1 hour) to process cemented carbide products (WC particle size 0.3 μm ±0.01 μm , GB/T 19077.1-2008; Co content 10% ±1%, GB/T 5124-2017). After treatment, the porosity is reduced to <0.03% ±0.01% (ASTM B657-16), the density is >99.8% ±0.1% (ISO 3369-2006), and the hardness reaches HV 2300 ±30 (ISO 3738-1:1982). The products are used for aviation tools to process high-temperature alloys (temperature>1000°C ±10°C, speed>300 m/min ±10 m/min), with a service life of>20 hours±1 hour, showing excellent wear resistance and stability.

5.1.20 Engineering application practice of hot isostatic pressing of cemented carbide

Aviation tools
Process: Carbide tools are processed by hot isostatic pressing (1400°C ±10°C, 150 MPa ±5 MPa, ISO 13703:2000).
Performance: Hardness up to HV 2300 ±30 (ISO 3738-1:1982), porosity <0.03% ±0.01%, life when

processing high-temperature alloys >20 hours ±1 hour.
Advantages: High density and low porosity significantly improve the stability of the tool under high temperature and high speed conditions.

Mining drill bits
Process: Hot isostatic pressing (1450°C ±10°C, 200 MPa ±5 MPa, ISO 13703:2000) for cemented carbide drills.
Performance: Toughness $K_{1}c$ >18 MPa·$m^{1/2}$ ± 0.5 (ISO 28079:2009), hard rock drilling life >1800 m ±100 m .
Advantages: After eliminating micropores, the impact resistance and wear resistance of the drill bit are significantly improved, extending its service life.

The hot isostatic pressing technology of cemented carbide eliminates micropores (porosity <0.03% ±0.01%) through high temperature and high pressure (1400°C ±10°C, 150 MPa ±5 MPa), making the material density >99.8% ±0.1%, and significantly improving the hardness (HV 2300 ±30) and toughness ($K_{1}c$ >18 MPa·$m^{1/2}$ ±0.5). It performs well in high-reliability applications such as aviation tools and mining drills, and optimization strategies (such as precise control of temperature, pressure and atmosphere) further improve process efficiency and product performance.

5.1.21 Double-Acting Pressing Technology

Principle and background of cemented carbide bidirectional pressing technology
Bidirectional pressing is an improved pressing technology. Compared with unidirectional pressing, it compresses the cemented carbide powder (such as WC-Co mixed powder) in the mold from two relative directions (usually vertical directions) by applying pressure simultaneously through the upper and lower pressing heads. This method aims to reduce the density gradient problem common in unidirectional pressing and improve the uniformity and strength of the green blank. Bidirectional pressing is widely used in cemented carbide production, especially when higher density and larger size blanks are required. Its core advantage is that through the synergistic effect of the upper and lower pressing heads, the powder particles are subjected to a more uniform force distribution during the pressing process, thereby reducing internal stress and stratification.

Cemented carbide bidirectional pressing equipment and process parameters

equipment
Double acting hydraulic press
Equipped with two sets of upper and lower independent hydraulic cylinders with a pressure range of 150-500 MPa. Common brands include German Dorst or Japanese Kobelco.

Mould
Use high-hardness steel (such as Cr12MoV, HRC 60 or above) or carbide lining, and polish the inner wall of the mold to Ra<0.2 μm to reduce friction. The mold design needs to support the

synchronous movement of the upper and lower pressure heads, and the gap is controlled within 0.01 mm.

Control System

The servo hydraulic system ensures that the pressure deviation of the upper and lower pressure heads is less than 5% and the displacement accuracy is less than 0.02 mm.

Process parameters of bidirectional pressing of cemented carbide

Pressure: The pressure ratio between the upper and lower pressure heads is usually 1:1, with a typical value of 200-400 MPa, which is adjusted according to the powder characteristics and the size of the green body .

Pressing time: total cycle 10-20 seconds, including pre-pressing (2-5 seconds) and main pressing (5-15 seconds).

Powder properties: WC particle size 0.5-3 μm , Co content 6%-15%, 1%-2% lubricant (such as paraffin or stearic acid) added to improve fluidity.

Environmental conditions: temperature 20±5°C, humidity <60% to prevent the powder from absorbing moisture and affecting the pressing effect.

The process flow of double-direction pressing of cemented carbide

Powder preparation

WC and Co powders are mixed in proportion (usually by ball milling for 12-24 hours), added with lubricant and sieved to a uniform particle size (deviation <5%).

Mold filling

The powder is loaded into the mold through a vibration or automatic feeding system, and the filling density is controlled at 40%-50% to avoid air bubbles.

Pre-pressurization: Apply 50-100 MPa low pressure, exclude air, and last for 2-5 seconds.

Main pressure: The upper and lower pressure heads simultaneously apply 200-400 MPa pressure for 5-15 seconds to ensure that the powder particles are fully compressed.

Demolding: Release the pressure slowly (rate <10 MPa/s) and remove the green blank to avoid cracking due to sudden pressure drop.

Subsequent treatment: The green billet is dried at 50-80°C for 2 hours to prevent moisture absorption, followed by pre-sintering (600-800°C) to remove the lubricant.

Characteristics and advantages of cemented carbide bidirectional pressing

Density uniformity

Compared with unidirectional pressing, the simultaneous action of the upper and lower pressure heads makes the density of the middle part of the blank closer to the two ends, and the overall density can reach 65%-75% of the theoretical density (unidirectional pressing is usually 50%-70%).

Low internal stress

Biaxial compression reduces the shear stress between powder particles, and the internal defects of the green blank (such as delamination and microcracks) are significantly reduced.

Wide applicability

It is suitable for pressing larger size (height 10-50 mm) or medium complex shape blanks, such as plates and bars.

Production efficiency

The pressing cycle is short, suitable for mass production, and more efficient than cold isostatic pressing.

Disadvantages and Challenges

Mold complexity

The bidirectional pressing die needs to support up and down movement, and the design and manufacturing costs are higher than those of the unidirectional pressing die.

Insufficient lateral density

Although the density is uniform from top to bottom, there may still be a density gradient in the lateral (horizontal) direction, especially in green bodies with a large aspect ratio.

High equipment requirements

The synchronization of the upper and lower pressure heads requires high-precision control, and the equipment maintenance cost is high.

Application Scenario

Carbide Rods

Used to manufacture milling cutters and drill bits with a diameter of 10-30 mm and a length of 50-100 mm.

Thin sheet blank

Used for producing wear-resistant linings or cutting tool substrates, thickness 5-20 mm.

Case

A certain enterprise produces WC-10%Co rods (20 mm in diameter and 80 mm in length) by bidirectional pressing with a pressure of 300 MPa. The green billet density is 72% of the theoretical density, the porosity after sintering is A02, and the hardness is HRA 90.

Technical details and optimization

Pressure distribution

The upper and lower pressure heads need to be adjusted dynamically. For powders with high Co content (>12%), it is recommended that the upper pressure head be slightly higher (such as 1.1:1) to compensate for the poor fluidity at the bottom.

Die lubrication

The inner wall of the mold is coated with a graphite or MoS_2 lubricating layer, and the friction coefficient is reduced to 0.1-0.2, reducing the demoulding resistance.

Powder Optimization

Adding 0.5% nano WC powder (particle size <100 nm) can enhance the bonding force between particles and improve the pressing density.

Vibration Assist

Introducing low-frequency vibration (50-100 Hz) during the filling stage improves powder filling uniformity and reduces air holes.

Precautions

Ensure the synchronization of the upper and lower pressure heads. Excessive deviation may cause the center of the blank to be biased. It is recommended to use a servo control system.
For high hardness powders (such as WC particle size <1 μm), the pre-pressing time needs to be extended (5-8 seconds) to avoid powder agglomeration.
The molds should be checked for wear regularly (every 1000 pressings) and re-polished or replaced if necessary.
Related standard references
ISO 4489:2009 Cemented Carbide Sintering Process Guide: points out that bidirectional pressing can improve the uniformity of green body density and is suitable for large-sized parts.
GB/T 3850-2015 Determination of theoretical density of cemented carbide: The increase in green billet density through bidirectional pressing helps to achieve the theoretical density standard after sintering (deviation <2%).

5.1.22 Cemented Carbide Pressing Technology: Multi-Directional Pressing (Lateral Pressing)

Principle and Background

Multi-directional pressing is an advanced pressing technology. On the basis of bidirectional pressing, by adding a lateral (horizontal) pressure head, pressure is applied from multiple directions at the same time (usually including vertical and 2-4 lateral directions) to compress and mold cemented carbide powder. Its design goal is to further improve the density uniformity of the green body, reduce internal stress and defects, and is particularly suitable for cemented carbide products with complex shapes or high performance requirements.

Multi-directional pressing compensates for the defect of insufficient lateral density of bidirectional pressing by distributing pressure in multiple directions. It is more economical than cold isostatic pressing (CIP) and suitable for medium-scale production.

The introduction of lateral pressure allows the powder particles to be compressed more evenly in three-dimensional space, significantly improving the density and post-sintering performance of the green body.

Equipment and process parameters

equipment

Multi-directional pressing machine

Equipped with 4-6 pressure heads (1-2 vertical, 2-4 lateral), the pressure range is 200-500 MPa, common brands include Japan's Sumitomo or Germany's Schuler.

Mould

Multi-directional movable composite structure, the inner layer is made of cemented carbide (HRA 88 or above), the outer layer is made of high-strength steel (compressive strength>1000 MPa), and the inner wall of the mold is polished to Ra<0.15 μm .

Control System

PLC is combined with servo motor to monitor the pressure and displacement of each pressure head in real time, with an accuracy of ±1 MPa and a displacement deviation of <0.01 mm.

Process parameters

pressure

Vertical pressure head 300-400 MPa, lateral pressure head 200-350 MPa, pressure ratio adjustable (typically 1:0.8).

Pressing time

The total cycle is 10-20 seconds, including pre-press (3-5 seconds) and main press (5-15 seconds).

Powder properties

WC particle size is 1-2 μm , Co content is 6%-12%, and 0.5%-1% graphite lubricant is added to reduce friction.

Environmental conditions

Temperature 20±3°C, humidity <50%, ensure the powder is dry.

Process

Powder preparation

WC and Co powders were mixed by high shear mixing (planetary mill, 24 h) and trace amounts of nano-additives (such as 0.5% nano-WC) were added to enhance the bonding strength between particles.

Mold filling

The powder is loaded into the mold through an automatic feeding system, combined with low-frequency vibration (50 Hz) to ensure uniform filling with a density deviation of <3%.

Preload

Apply 50-100 MPa with the vertical pressure head and 30-80 MPa with the lateral pressure head for 3-5 seconds to exclude air.

Main pressure

The vertical and lateral pressure heads are pressed synchronously, 400 MPa vertically and 300 MPa laterally, for 5-15 seconds to ensure three-dimensional compression.

Demolding

Unload the green blank in stages (rate <5 MPa/s) to avoid cracks caused by excessive stress release.

Subsequent processing

The green billet was dried at 60 °C for 3 h and subsequently pre-sintered (700 °C for 2 h) to remove the lubricant.

Features and Benefits

Density uniformity

Multi-directional pressing distributes pressure in three dimensions, making the density of the green body more consistent in all directions. The average density can reach 75%-80% of the theoretical density (65%-75% for bidirectional pressing).

Few internal defects

The introduction of lateral pressure significantly reduces delamination and microcracks, and increases the green billet strength by 20%-30%.

Complex shape adaptability

Suitable for medium-complex shapes (such as multi- edge tool blanks, special-shaped molds), more flexible than bidirectional pressing.

Improved sintering performance

The uniform green billet density makes the sintering shrinkage more consistent and the finished product porosity can reach A00-B00 level.

Disadvantages and Challenges

Equipment complexity

Multi-directional pressing machines require coordination of multiple pressing heads, and the equipment cost and maintenance difficulty are higher than bidirectional pressing.

Difficulty of mold design

Multi-directional molds need to withstand multi-directional stresses, the design needs to be optimized through finite element analysis (FEA), and the manufacturing cost is high.

High process control requirements

The pressure and displacement of each pressure head need to be synchronized with high precision, and the control system needs real-time feedback.

Application Scenario

Complex tool blanks: such as multi- edge milling cutters and drill blanks, which require high uniformity and strength.

Mold blanks: such as stamping dies and wire drawing dies, require high density.

Case

A certain enterprise produces WC-8%Co multi- edge tool blanks (diameter 30 mm, height 15 mm) using multi-directional pressing (vertical 400 MPa, lateral 300 MPa). The green blank density is 78% of the theoretical density, the porosity after sintering is A00, and the hardness is HRA 91.

Technical details and optimization

Pressure distribution

The vertical pressure head accounts for 50%-60% of the total pressure, and the lateral pressure head accounts for 40%-50%. The ratio is optimized through experiments (such as 1:0.8:0.8).

Mold coating

The inner wall is coated with TiN or DLC coating, the friction coefficient is reduced to 0.15, and the mold life is extended (> 5000 pressing times).

Powder Optimization

Add 0.5% nano-graphite lubricant to reduce lateral friction and improve particle fluidity.

Assistive Technology

Ultrasonic vibration (20 kHz) was introduced to assist pressing, improving particle rearrangement and increasing density by 5%.

Precautions

The synchronization of the pressure head needs to be monitored by a closed-loop control system, with a deviation of <0.5 mm to avoid bias.

The mold should be regularly inspected for multi-directional stress points (such as the lateral pressure head contact area) to prevent local wear.

For powders with high Co content (>10%), the lateral pressure needs to be reduced (200-250 MPa) to avoid overpressure causing cracking of the green body .

Related standard references

ISO 4489:2009 Guide to sintering processes for cemented carbide

Multi-directional pressing can significantly improve the uniformity of the green body and is recommended for complex shapes.

GB/T 3850-2015 Determination of theoretical density of cemented carbide

The increase in green billet density through multi-directional pressing helps achieve the theoretical density after sintering (deviation <1.5%).

5.1.23 **Extrusion Pressing**

This section is a detailed description of cemented carbide extrusion pressing technology, covering principles, characteristics, technical parameters, process flow, application scenarios, influencing factors, optimization strategies, actual cases and engineering practices. The content is based on the actual application of cemented carbide production, combined with process characteristics and industrial data, and strives to be comprehensive and of reference value.

Principle of Carbide Extrusion Pressing

Extrusion molding is a powder metallurgy molding technology specifically used to produce slender or continuous-shaped cemented carbide blanks. The core principle is to mix cemented carbide powder (such as WC-Co mixed powder) with a binder (such as polyvinyl alcohol PVA, polyoxymethylene POM or wax-based binder) to prepare a paste material with good fluidity, and then push the paste material into a customized mold under high pressure through an extruder to extrude a blank with a specific cross-sectional shape. During the extrusion process, the powder particles are rearranged, compressed and initially combined under high pressure and mold constraints, and the binder plays a lubricating and bonding role to ensure that the blank has sufficient strength and shape stability after molding. After extrusion, the blank is usually cut into the required length, and the binder is removed by degreasing and sintering to finally form a high-performance cemented carbide product. The process of extrusion molding is as follows:

Powder mixed with binder

The WC and Co powders are mixed in proportion (usually by high shear mixer or planetary mill for 24 hours), and 10%-25% of binder is added to prepare a uniform paste material.

Extrusion

The paste material is loaded into the extruder barrel, and high pressure (200-400 MPa) is applied through the piston or screw to push the material into the die to extrude a billet with a specific cross-sectional shape.

Cutting and drying

The extruded continuous body is cut as required (up to several meters in length) and dried at 50-80°C for 2-4 hours to avoid moisture absorption.

Degreasing

Binder removal is done by thermal debinding (300-500°C) and chemical debinding, with a heating rate of <5°C/min.

sintering

Sintering at 1350-1450°C and densification to form the final cemented carbide product. The unique advantage of extrusion molding is that it can continuously produce slender billets. The shape of the die outlet determines the cross-sectional geometry of the billet, which is suitable for mass production of long parts such as bars and tubes.

Characteristics of cemented carbide extrusion molding

Extrusion molding has the following significant features in cemented carbide production:

Shape flexibility
It is suitable for producing slender or continuous-shaped blanks, such as rods, tubes, and special-shaped bars. The cross-sectional shape can be customized by the mold (such as round, rectangular, polygonal).
Binder requirements
A large amount of binder (10%-25%) needs to be added to ensure the fluidity of the paste material and the molding strength of the green body . The presence of binder requires a subsequent degreasing process.
Density characteristics
The green billet density is usually 55%-65% of the theoretical density, which is affected by the binder ratio and extrusion pressure. A higher binder ratio may reduce the initial density, but after sintering, it can reach 98%-99% of the theoretical density.
Production efficiency
It adopts continuous extrusion process with high production efficiency, which is suitable for mass production needs. The daily output of a single extruder can reach hundreds of meters of billets.
Process complexity
The binder ratio, extrusion speed and degreasing process need to be precisely controlled, the process chain is long, and the production complexity is increased.

Cemented Carbide Extrusion Molding Technical Parameters
The following are the detailed technical parameters of cemented carbide extrusion molding, based on industrial practice and relevant standards:

pressure
Range : 200-400 MPa, 300 MPa is commonly used to ensure green body strength and forming stability.
Impact : Too low pressure (<150 MPa) may lead to insufficient density of the green body (<50% theoretical density); too high pressure (>450 MPa) may cause mold wear or surface cracks on the green body.

Powder properties
Particle size : WC particle size 1-3 μm , Co particle size 1-2 μm , mixing uniformity deviation <3% (GB/T 19077.1-2008).
Binder : Polyvinyl alcohol (PVA) or wax-based binder , the ratio is 15%-25%, usually 20% to balance fluidity and green body strength.
Fluidity : The fluidity of the paste material must reach 15-20 seconds/50 g (similar to the ISO 4490:2018 standard) to ensure smooth extrusion.

Extrusion speed
Range : 0.5-2 m/min, commonly used is 1 m/min.
Impact : Too fast speed (>2.5 m/min) may cause surface cracks or internal pores on the blank; too slow speed (<0.3 m/min) reduces production efficiency.

Mold design

Material : Carbide (HRA 88 or above) or high hardness steel (HRC 60 or above), outlet section tolerance <0.01 mm.

Surface treatment : The inner wall of the mold is polished to Ra<0.1 μm (GB/T 1031-2009) to reduce friction resistance (<0.1, experimental data).

Outlet shape : customized according to product requirements, such as round (diameter 2-20 mm), rectangular (width 2-10 mm).

Equipment parameters :

Extruder : Piston or screw type, pressure range 200-500 MPa, barrel heating temperature 50-80°C.

Control system : PLC control, extrusion speed accuracy ±0.1 m/min, pressure accuracy ±5 MPa.

Degreasing conditions :

Temperature : 300-500°C, graded heating, 400°C is commonly used for thermal degreasing.

Heating rate : <5°C/min, to avoid cracking of the blank.

Environment : Vacuum or inert atmosphere (N_2 or Ar , purity >99.9%), to prevent oxidation.

Green billet density :

Range : 55%-65% theoretical density (approximately 7.0-8.5 g/cm³ , according to GB/T 3850-2015).

Impact : The higher the binder ratio, the lower the initial density, but this can be compensated by densification after sintering.

Process

Powder preparation

WC and Co powders are mixed in proportion (usually WC particle size 1-3 μm , Co content 6%-12%), and kneaded by planetary mill for 24 hours, with uniformity deviation <3%. 15%-25% binder (such as PVA) is added and kneaded into a paste material (moisture content is controlled at 30%-40%).

Extrusion

The paste material is loaded into the extruder barrel and heated to 50-80°C to improve fluidity.

Apply 300 MPa pressure and extrusion speed 1 m/min to extrude rods or tubes through the die.

Cutting and drying

extruded continuous billet is cut as required (length 100-500 mm) with a cutting accuracy of ±0.5 mm.

Dry at 50-80°C for 2-4 hours to reduce moisture content to <0.5%.

Degreasing

Thermal degreasing: 300-500°C, heating rate <5°C/min, keep warm for 2 hours.

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Chemical degreasing: Use a solvent (such as hexane) to remove residual adhesive when necessary.

sintering

Sinter at 1350-1450°C, keep warm for 1-2 hours, and densify to 98%-99% theoretical density.

Application Scenario

Extrusion molding is widely used in cemented carbide products that require slender shapes. The main scenarios include:

Long tools : such as carbide rods (diameter 2-20 mm), used to make drill rods, milling cutters, and drill bits.

Tubes : such as carbide tubes (outer diameter 5-15 mm, wall thickness 1-3 mm), used for wear-resistant pipes or nozzles.

Special-shaped bars : such as rectangular or polygonal cross-section bars, used for special cutting tools.

Case : A company produces WC-10%Co rods (5 mm in diameter, 300 mm in length) by extrusion molding with an extrusion speed of 1 m/min. The green density is 60% of the theoretical density (about 8.0 g/cm³) , the hardness after sintering is HRA 91, and the porosity is A02. It is used to manufacture precision drill bits.

Influencing factors and optimization strategies

Binder ratio

Impact : The binder ratio is 15%-25%, and the deviation should be controlled within <1%. A high ratio (>30%) will reduce the green billet density (<50% theoretical density) and cause uneven shrinkage after sintering (deviation >5%); a low ratio (<10%) will result in insufficient fluidity and difficulty in extrusion.

Optimization : Use 20% ± 0.5% PVA and extend the mixing time to 2 hours to ensure uniformity.

Extrusion speed

Impact : Speed is 0.5-2 m/min. Too fast (>2.5 m/min) will cause surface cracks (crack depth >0.1 mm, experimental data); too slow (<0.3 m/min) will reduce efficiency.

Optimization : Control the speed at 1-1.5 m/min and monitor the surface quality of the blank in real time.

Powder flowability

Impact : Fluidity 15-20 seconds/50 g (similar to ISO 4490:2018 standard). Poor fluidity (>25 seconds/50 g) may lead to uneven extrusion.

Optimization : Adding 0.5% stearic acid lubricant, the fluidity after mixing is improved to 15 seconds/50 g ± 0.5 seconds.

Mold design

Impact : The mold outlet tolerance is <0.01 mm and the surface roughness Ra is <0.1 μm , which can reduce friction resistance (<0.1) and reduce blank defects (defect rate <2%).
Optimization : The inner wall of the die is coated with DLC coating to extend the service life (>10,000 extrusions).

Degreasing process
Impact : Heating rate > 5°C/min may cause cracking of the blank (crack rate > 5%); temperature > 500°C may cause oxidation (O content > 0.05%).
Optimization : Stepwise heating (200-300°C, 2°C/min; 300-500°C, 3°C/min), debinding in N_2 atmosphere .

Precautions
Binder control : The ratio deviation must be <1%, and the mixing uniformity deviation must be <2% to avoid sintering defects caused by excessive local binder.
Debinding process : heating rate <5°C/min, holding time 2-3 hours, ensure complete removal of binder (residue <0.1%).
Mold maintenance : Check the mold outlet every 5,000 extrusions and polish it to Ra<0.1 μm to prevent wear from affecting the accuracy of the blank.
Green body drying : drying temperature 50-80°C, time 2-4 hours, moisture content <0.5%, avoid cracking due to moisture absorption.
Equipment calibration : The extruder pressure and speed need to be calibrated regularly (once a month), with pressure deviation <±5 MPa and speed deviation <±0.1 m/min.

Actual Cases
A company uses extrusion molding process to produce WC-10%Co cemented carbide rods (diameter 5 mm, length 300 mm) for manufacturing precision drill bits. The process parameters are as follows:
Pressure: 300 MPa ±5 MPa.
Extrusion speed: 1 m/min ±0.1 m/min.
Powder: WC particle size 1.5 μm , Co content 10% ± 1%, PVA binder 20% ± 0.5%.
Degreasing: 400°C, heating rate 3°C/min, N_2 atmosphere .
Sintering: 1400°C, holding temperature 1.5 hours. Result: green density 60% theoretical density (about 8.0 g/cm^3) , sintered density 99% theoretical density, hardness HRA 91, porosity A02, drill bit service life >1000 m (hard rock drilling, compressive strength >150 MPa).

Engineering application practice

Carbide Drill Rod
Process : WC-12%Co drill rod (diameter 10 mm, length 500 mm) was produced by extrusion molding, with a pressure of 350 MPa and an extrusion speed of 1.2 m/min.
Performance : hardness after sintering HRA 90, porosity A02, used for oil drilling (compressive strength>200 MPa), life>2000 m.

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Advantages : Continuous forming ensures the consistency of rod length and cross-section, improving the stability and durability of the drill rod.

Wear-resistant pipe

Process : WC-8%Co pipe (outer diameter 12 mm, wall thickness 2 mm) was produced by extrusion molding, with a pressure of 300 MPa and an extrusion speed of 1 m/min.

Performance : Density after sintering is 98.5% of theoretical density, hardness HRA 89, used for conveying corrosive slurry, wear-resistant life> 6 months.

Advantages : The pipe wall thickness is uniform, with excellent corrosion resistance and wear resistance, suitable for harsh working conditions.

Summarize

Extrusion molding is an efficient and flexible cemented carbide pressing process, which is particularly suitable for the production of slender green bodies (such as bars and tubes). By precisely controlling the binder ratio (20% ±0.5%), extrusion speed (1-1.5 m/min) and debinding process (heating rate <5°C/min), high-quality green bodies with a density of 55%-65% of the theoretical density can be prepared, and the performance after sintering is excellent (hardness HRA 90-91). It has excellent performance in the fields of long knives and wear-resistant pipes, meeting the needs of mass production.

5.1.24 Carbide Injection Molding

Principle of Carbide Injection Molding

Injection molding is an advanced powder metallurgy molding technology designed specifically for cemented carbide (such as WC-Co mixed powder), similar to the plastic injection molding process. Its core principle is to mix cemented carbide powder with thermoplastic binder (such as polypropylene PP, polyoxymethylene POM or wax-based mixture) in proportion, heat it to 150-200°C to form a molten state with good fluidity, and then inject the molten material into a high-precision mold through the high-pressure injection system (50-100 MPa) of the injection molding machine. After cooling, a green blank with complex shape or small size is formed, and then the binder is removed by degreasing and sintering to obtain a high-density cemented carbide product. The optimization of injection molding lies in its high hardness and low fluidity characteristics of cemented carbide powder, and the use of a special binder system and precision mold design to ensure molding accuracy and blank quality . The process of injection molding is as follows:

Powder mixed with binder

WC and Co powders were mixed with 20%-30% thermoplastic binder and mixed in a high shear mixer at 150-180°C for 2-4 hours to form a uniform feed.

Injection molding

The molten material is extruded through a screw or plunger, injected into the mold at a pressure of 80 MPa, and demolded after cooling.

Degreasing

Binder removal by thermal debinding (200-400°C) and chemical debinding (400-600°C) with a heating rate of <3°C/min.

sintering

Sinter at 1350-1450°C, hold for 1-2 hours, and densify to 98% of theoretical density.

The unique advantage of injection molding is that it can produce complex geometric shapes and small-sized parts, with flexible mold design and high molding accuracy. It is particularly suitable for cemented carbide products that require high precision and complex structures.

Characteristics of Carbide Injection Molding

Injection molding has the following significant features in cemented carbide production:

High precision

Suitable for complex shapes (such as gears, micro tools) and small-sized parts, with a molding tolerance of <0.01 mm and a surface roughness of Ra<0.2 μm .

Complex process

It involves multiple processes such as mixing, injection, degreasing and sintering. The process chain is relatively long and the production cycle is 10-20 minutes per piece.

Density characteristics

The green billet density is 50%-60% of the theoretical density. After sintering, it can reach 98%-99% of the theoretical density through densification, and the porosity is reduced to A00- B00 level.

Production efficiency

Suitable for small and medium batch production, single shot output is limited (1-10 pieces/cycle), but efficiency can be improved through multi-cavity molds.

Higher cost

The mold design and manufacturing costs are high, and the debinding and sintering processes increase production costs.

Cemented Carbide Injection Molding Technical Parameters

The following are the detailed technical parameters of cemented carbide injection molding, based on industrial practice and relevant standards:

pressure

Range : 50-100 MPa, 80 MPa is commonly used to ensure filling and molding quality.

Impact : Too low pressure (<40 MPa) may result in non-filling or defects (defect rate >5%); too high pressure (>120 MPa) may damage the mold or cause molten material to overflow.

Powder properties

Particle size : WC particle size 0.5-2 μm , Co particle size 0.5-1 μm , mixing uniformity deviation <3% (GB/T 19077.1-2008).

Binder : Thermoplastic binder (such as PP, POM or wax-based mixture), the ratio is 20%-30%, usually 25% to balance fluidity and green body strength.

Fluidity : Viscosity in the molten state is 100-500 Pa·s (experimental data), ensuring uniform injection filling.

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Injection temperature

Range : 150-200°C, 180°C is commonly used to optimize the melting state.

Impact : Too low temperature (<140°C) will result in high viscosity and difficulty in filling; too high temperature (>220°C) may decompose the binder and affect degreasing.

Mold temperature

Range : 50-80°C, 60°C is commonly used to accelerate cooling and demoulding.

Impact : Too low a temperature (<40°C) may cause excessive cooling and produce internal stress; too high a temperature (>90°C) prolongs the cooling time.

Degreasing conditions

Temperature : 200-600°C, carried out in two steps: thermal debinding 200-400°C, chemical debinding 400-600°C.

Heating rate : <3°C/min, to avoid cracking of the blank (crack rate <1%).

Environment : Vacuum or inert atmosphere (N_2 or Ar , purity >99.9%), to prevent oxidation.

Equipment parameters

Injection molding machine : screw or plunger type, injection pressure 50-120 MPa, barrel heating power 10-20 kW.

Mould : High hardness steel (such as H13, HRC 50 or above) or carbide lining, tolerance <0.01 mm, surface polished to Ra<0.1 µm (GB/T 1031-2009).

Control system : PLC control, temperature accuracy ±2°C, pressure accuracy ±2 MPa.

Green billet density

Range : 50%-60% theoretical density (about 6.5-8.0 g/cm³ , according to GB/T 3850-2015).

Impact : The higher the binder ratio, the lower the initial density, but after sintering it can reach 98%-99% through diffusion and densification.

Process

Powder mixed with binder

WC and Co powders were mixed in proportion (WC particle size 0.5-2 µm , Co content 6%-10%) and kneaded in a high shear mixer at 150-180°C for 2-4 hours.

Add 20%-30% binder (such as PP+POM mixture) to form a uniform feed with a particle size distribution deviation of <2%.

Injection molding

The feed material is loaded into the barrel of the injection molding machine, heated to 180°C ± 2°C, and extruded through the screw after melting.

The injection pressure is 80 MPa and the mold temperature is 60°C. The mold is injected and demoulded after cooling for 5-10 minutes.

Degreasing

Thermal debinding : 200-400°C, heating rate 2°C/min, hold for 2 hours, N_2 atmosphere .

Chemical degreasing : 400-600°C, heating rate 1°C/min, solvent cleaning to remove residual binder.

sintering

Sinter at 1400°C ±10°C, hold for 1.5 hours, vacuum or Ar atmosphere , densify to 98%-99% theoretical density.

Application Scenario

Injection molding is widely used in cemented carbide micro parts that require high precision and complex shapes. The main scenarios include:

Micro parts : such as precision gears and micro tools, used in medical devices (such as orthopedic implants) and the electronics industry (such as micro motor parts).

Complex structures : such as multi- edge micro milling cutters and special-shaped tool blanks for precision machining.

Case of Carbide Injection Molding

A company produces WC-6%Co micro gears (3 mm in diameter, 1 mm in thickness) using injection molding with an injection pressure of 80 MPa and a mold temperature of 60°C. The hardness after sintering is HRA 92, and the tolerance is <0.01 mm. It is used for medical implants with a life of >5000 cycles.

Influencing factors and optimization strategies of cemented carbide injection molding

Binder ratio

Impact : The binder ratio is 20%-30%, and the deviation should be <1%. A high ratio (>35%) will reduce the green density (<45% theoretical density) and make degreasing difficult (residue >0.5%); a low ratio (<15%) will lead to insufficient fluidity and uneven filling.

Optimization : Use a 25% ± 0.5% PP + POM mixture and mix for 3 hours to ensure uniformity.

Injection temperature

Impact : 180°C ±2°C optimizes fluidity (viscosity 200-300 Pa·s), temperatures <140°C lead to underfilling (defect rate >3%); temperatures >220°C may decompose the binder.

Optimization : Controlled at 180-190°C, barrel heating in stages (150°C inlet, 200°C outlet).

Mold design

Impact : Mold tolerance <0.01 mm and surface roughness Ra <0.1 μm can reduce demoulding resistance (<2 kN) and defect rate <1% (experimental data).

Optimization : TiN coating is applied to the inner wall of the mold to extend the service life (>10,000 injections).

Degreasing process

Impact : Heating rate > 3°C/min may cause cracking of the green body (crack rate > 2%); temperature < 200°C may lead to incomplete debinding and residue > 0.3%.

Optimization : stepwise heating (200-300°C, 2°C/min; 300-600°C, 1°C/min), vacuum degreasing (<10 Pa).

Injection pressure

Impact : 80 MPa ±2 MPa ensures complete filling, pressure <50 MPa may cause short shots (defect rate >5%); pressure >120 MPa may damage the mold.

Optimized : Uses 80-90 MPa, dynamically adjusted to accommodate complex geometries.

Precautions for cemented carbide injection molding

Binder removal : heating rate <3°C/min, holding time 2-3 hours, ensure that the binder residue is <0.1% (mass fraction) to avoid sintering defects.

Mold precision : The mold needs to be designed with high precision (tolerance <0.01 mm), the surface polished to Ra <0.1 μm (GB/T 1031-2009), and the wear should be checked every 500 injections.

Cooling control : mold temperature 50-80°C, cooling time 5-10 minutes, to prevent excessive internal stress (<10 MPa, experimental data).

Environmental control : The mixing and injection processes must be carried out in a dry environment (humidity <40%) to prevent the powder from absorbing moisture.

Equipment maintenance : Clean the screw and barrel once a month and check the accuracy of the heating system (±2°C).

Actual Case Study of Carbide Injection Molding

A company uses injection molding to produce WC-6%Co micro gears (3 mm in diameter, 1 mm in thickness) for medical implants. The process parameters are as follows:
Injection pressure: 80 MPa ±2 MPa.
Injection temperature: 180°C ±2°C.
Mould temperature: 60°C ±2°C.
Powder: WC particle size 0.8 μm , Co content 6% ± 1%, POM binder 25% ± 0.5%.
Degreasing: 200-600°C, heating rate 2°C/min, N_2 atmosphere .
Sintering: 1400°C, keep warm for 1.5 hours. Result: Green density is 55% of theoretical density (about 7.2 g/cm³) , sintered density is 98.5% of theoretical density, hardness is HRA 92, tolerance is <0.01 mm, cycle life is >5000 times, meeting the high precision requirements of medical devices.

Engineering Application Practice of Cemented Carbide Injection Molding

Micro Knife

Process : WC-8%Co micro-milling cutters (2 mm in diameter and 10 mm in length) were produced by injection molding with an injection pressure of 85 MPa and a mold temperature of 65°C.

Performance : After sintering, the hardness is HRA 91, the porosity is A00, it is used for precision electronic processing (cutting speed 200 m/min), and the service life is >10 hours.
Advantages : Complex multi -edge design is achieved through injection molding, with high precision to meet micro-machining requirements.

Medical implant parts
Process : WC-6%Co orthopedic implants (5 mm diameter, 2 mm thickness) were produced by injection molding with an injection pressure of 80 MPa and a mold temperature of 60°C.
Performance : Density after sintering is 98% of theoretical density, hardness HRA 92, biocompatibility complies with ISO 10993 standard, and corrosion resistance is excellent.
Advantages : High precision and complex shapes meet the requirements of implants for biosafety and mechanical properties.

Injection molding is a high-precision cemented carbide pressing process suitable for complex shapes and small-sized parts. By precisely controlling the injection temperature (180°C ±2°C), pressure (80 MPa ±2 MPa) and degreasing process (heating rate <3°C/min), it can produce green billets with a density of 50%-60% of the theoretical density, and reach 98%-99% of the theoretical density (hardness HRA 92) after sintering. It performs well in high-value-added fields such as micro-tools and medical implants, meeting the needs of small and medium-sized batch production.

5.1.25 Carbide Roll Compaction

Principle of Carbide Roll Compaction
Roll forming is an efficient powder metallurgy forming technology suitable for the production of thin sheets or strips of cemented carbide (such as WC-Co mixed powder). Its core principle is to squeeze and shear the cemented carbide powder in the gap between two high-speed rotating rollers. The powder particles are compressed and rearranged under high pressure to form a continuous strip or thin sheet. The gap size and rotation speed between the rollers determine the thickness and density of the blank. After forming, the blank is cut or stamped into the desired shape and then further densified by sintering. Roll forming uses the continuous action of mechanical force and is particularly suitable for mass production of thin cemented carbide products, reducing the need for complex molds in traditional pressing processes. The process of roll forming is as follows:

Powder preparation
Mix WC and Co powders, add 2% lubricant (such as PVA or stearic acid), and ensure homogeneity through kneading.
Roll forming
is fed into the gap between the rollers through a feeding device . The rollers apply a pressure of 50-150 MPa and a speed of 5-15 rpm to extrude into a continuous green body.
Cutting and drying
The green body is cut into desired length or shape and dried at 50-80°C for 2-4 hours.
sintering

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Sintered at 1350-1450°C, densified to 98%-99% theoretical density.

The unique advantages of roll forming are its continuous production capacity, simple equipment structure and adaptability to thin sheets or large-area blanks. It is widely used in the production of cemented carbide wear-resistant coating substrates.

Characteristics of Carbide Roll Compaction

Roll forming has the following significant features in cemented carbide production:

Continuous production

Through the continuous rotation of the rollers , it is suitable for mass production of thin sheets or strips, with a daily output of hundreds of square meters.

Thickness control

The blank thickness is adjustable (0.5-5 mm) with a tolerance of <0.05 mm, suitable for applications requiring uniform thickness.

Density characteristics

The green billet density is 50%-60% of the theoretical density. Affected by powder fluidity and roller pressure, it needs to be densified to 98%-99% by subsequent sintering.

Simple equipment

The roller equipment has a simpler structure, and its manufacturing and maintenance costs are lower than those of injection molding or isostatic pressing equipment, making it suitable for industrial promotion.

limitation

Not suitable for complex three-dimensional shapes, thickness uniformity depends on roller gap accuracy.

Technical Parameters

The following are detailed technical parameters of cemented carbide roll forming, based on industrial practice and relevant standards:

pressure

Range : 50-150 MPa, 100 MPa is commonly used to balance density and production efficiency.

Impact : Too low pressure (<40 MPa) leads to insufficient density (<45% theoretical density); too high pressure (>180 MPa) may cause roller wear or cracking of the billet.

Powder properties

Particle size : WC particle size 1-3 μm , Co particle size 1-2 μm , mixing uniformity deviation <3% (GB/T 19077.1-2008).

Lubricant : Add 2% lubricant (such as PVA or stearic acid) to improve fluidity (14 seconds/50 g ± 0.5 seconds, ISO 4490:2018).

Moisture content : controlled at <0.5% to avoid affecting powder flow.

Roller speed

Range : 5-15 rpm, 10 rpm is common to ensure uniform pressing.

Impact : Too fast speed (>20 rpm) may cause rough surface of the blank (Ra>1 μm); too slow speed (<3 rpm) reduces production efficiency.

Roller gap

Range : 0.5-5 mm, adjustable, commonly used 2 mm.

Control accuracy : deviation <0.02 mm, ensuring thickness uniformity (tolerance <0.05 mm).

Impact : Too large a gap (>6 mm) reduces density (<45% theoretical density); too small a gap (<0.3 mm) may clog the rollers.

Roller material

Type : Carbide (HRA 88 and above) or high hardness steel (HRC 60 and above).

Surface treatment : The roller surface is polished to Ra<0.2 μm (GB/T 1031-2009) to reduce friction (coefficient <0.15).

Equipment parameters

Roller press : double roller design, power 10-20 kW, pressure range 50-200 MPa.

Control system : PLC control, speed accuracy ±0.5 rpm, gap accuracy ±0.01 mm.

Green billet density

Range : 50%-60% theoretical density (about 6.5-8.0 g/cm³ , according to GB/T 3850-2015).

Impact : Density increases with increasing pressure and powder fluidity, and can reach 98%-99% after sintering.

Process

Powder preparation

WC and Co powders were mixed in proportion (WC particle size 1-3 μm , Co content 6%-12%) and mixed by ball milling for 12-24 hours with a uniformity deviation of <3%.

Add 2% lubricant (such as PVA), sieve (200 mesh) after mixing, and the fluidity reaches 14 seconds/50 g ± 0.5 seconds.

Roll forming

was fed into the gap between the rollers through a vibrating feeding device . The rollers applied a pressure of 100 MPa, a speed of 10 rpm, and a gap of 2 mm.

Continuously extruded into thin sheets or strips, the thickness is controlled at 2 mm ± 0.05 mm.

Cutting and drying

The blank is cut into the required size (length 100-500 mm, accuracy ±0.5 mm).

Dry at 50-80°C for 2-4 hours to reduce moisture content to <0.5%.

sintering

Sinter at 1400°C ±10°C, hold for 1.5 hours, vacuum or Ar atmosphere , densify to 98%-99%

theoretical density.

Application scenarios of cemented carbide rolling compaction

Roll forming is widely used in the production of thin sheets or large-area cemented carbide blanks. The main scenarios include:

Thin sheet blank : such as carbide wear-resistant coating substrate (thickness 1-3 mm), used for surface reinforcement or composite materials.

Strip blanks : such as carbide wear strips (width 10-50 mm), used for cutting tools or molds.

Case Study of Carbide Roll Compaction

A certain enterprise produces WC-10%Co wear-resistant thin sheets (thickness 2 mm, width 100 mm) by roll forming, with a roller speed of 10 rpm, a pressure of 100 MPa, a green density of 55% of the theoretical density (about 7.3 g/cm³) , a hardness of HRA 89 after sintering, and a porosity of A02, which are used as wear-resistant coating substrates.

Influencing factors and optimization strategies of cemented carbide rolling compaction

Roller gap

Impact : Gap 0.5-5 mm, deviation <0.02 mm. Too large a gap (>6 mm) will reduce the density (<45% theoretical density); too small a gap (<0.3 mm) may cause blockage.

Optimization : Automatic gap adjustment system with accuracy of ±0.01 mm and real-time thickness monitoring.

Roller speed

Impact : 10 rpm ±0.5 rpm ensures uniform pressing, speed >20 rpm results in surface roughness (Ra>1 µm); speed <3 rpm reduces efficiency.

Optimization : Controlled at 8-12 rpm, dynamically adjusted according to powder fluidity.

Powder flowability

Impact : Flowability 14 seconds/50 g ± 0.5 seconds (ISO 4490:2018). Poor flowability (>20 seconds/50 g) leads to uneven feeding and density deviation >5%.

Optimization : Adding 0.5% nanographite lubricant, the fluidity is improved to 13 seconds/50 g ± 0.5 seconds.

Pressure control

Impact : 100 MPa ±5 MPa optimized density (55%-60% theoretical density), pressure <50 MPa density <45%; pressure >180 MPa roller wear is aggravated.

Optimization : Use 100-120 MPa, equipped with pressure sensor, deviation <±2 MPa.

Roller surface

Impact : Surface roughness Ra < 0.2 µm can reduce friction (< 0.15) and the defect rate is < 2%; Ra > 0.5 µm may cause scratches on the surface of the blank .

Optimization : Polish the roller every 1000 times until Ra<0.2 μm and apply a wear-resistant layer (such as CrN).

Precautions for Carbide Roll Compaction

Roller gap control : Deviation <0.02 mm, regular calibration (once a month) to avoid uneven thickness (tolerance >0.1 mm).
Powder flowability : High flowability is required (14 sec/50 g ± 0.5 sec, ISO 4490:2018), and a vibrating feeding device (50 Hz) is used to ensure uniformity.
Roller maintenance : Check roller wear every 500 rolling cycles and polish to Ra<0.2 μm to extend service life (>10,000 times).
Drying process : Dry at 50-80°C for 2-4 hours, moisture content <0.5% to prevent moisture absorption and cracking.
Equipment stability : Roller speed and pressure need to be calibrated regularly (once a week), with speed deviation <±0.5 rpm and pressure deviation <±5 MPa.

Actual Case of Carbide Roll Compaction

A company uses the roll forming process to produce WC-10%Co wear-resistant sheets (2 mm thick, 100 mm wide) for surface strengthening coating. The process parameters are as follows:
Pressure: 100 MPa ±5 MPa.
Roller speed : 10 rpm ±0.5 rpm.
Gap: 2 mm ±0.02 mm.
Powder: WC particle size 1.5 μm , Co content 10% ± 1%, PVA lubricant 2% ± 0.1%.
Sintering: 1400°C, 1.5 hours. Result: green density 55% theoretical density (about 7.3 g/cm^3) , sintered density 98.5% theoretical density, hardness HRA 89, thickness tolerance <0.05 mm, porosity A02, used for wear-resistant coating, life >500 hours (wear test, load 50 N).

Engineering application practice of cemented carbide rolling compaction

Wear-resistant coating substrate for carbide roll compaction

Process : WC-8%Co sheets (thickness 1.5 mm, width 120 mm) were produced by roll forming with a pressure of 100 MPa and a roller speed of 12 rpm.
Performance : After sintering, the hardness is HRA 88, the density is 98% of the theoretical density, it is used for steel surface strengthening, and the wear-resistant life is >400 hours.
Advantages : Continuous production ensures uniform sheet thickness, suitable for large-area coating applications.

Carbide Roll Compaction Cutting Tool Strips

Process : WC-12%Co strips (3 mm thickness, 20 mm width) were produced by roll forming at a pressure of 120 MPa and a roller speed of 8 rpm.
Performance : hardness after sintering HRA 90, toughness K_{1c} >15 MPa·m$^{1/2}$, cutting life >800 m (hard material, cutting speed 150 m/min).
Advantages : Excellent strip strength and wear resistance, meeting the high performance

requirements of cutting tools.

Roll forming is an efficient and economical cemented carbide pressing process, especially suitable for mass production of thin sheets or strip blanks (thickness 0.5-5 mm, tolerance <0.05 mm). By precisely controlling the roller gap (2 mm ±0.02 mm), speed (10 rpm ±0.5 rpm) and pressure (100 MPa ±5 MPa), a green blank with a density of 50%-60% of the theoretical density can be prepared, and after sintering, it reaches 98%-99% of the theoretical density (hardness HRA 88-90). It performs well in the field of wear-resistant coating substrates and cutting tool strips , meeting the needs of industrial production.

5.1.26 Explosive Compaction of Cemented Carbide

Principle of Explosive Compaction of Cemented Carbide

Explosive compression is a special molding technology that uses the instantaneous high-pressure shock wave (pressure can reach thousands of MPa) generated by the explosion to compress cemented carbide powder. The core principle is to load cemented carbide powder (such as WC-Co mixed powder) into an impact-resistant metal container, arrange explosives around the container, and quickly transmit the high-speed shock wave (speed can reach thousands of meters/second) generated by the explosion to the powder, causing drastic rearrangement, plastic deformation and local melting of the powder particles, and finally forming a high-density green body. The uniqueness of explosive compression lies in its ultra-short compression time (<1 millisecond) and ultra-high pressure, which can instantly achieve a green body with a density close to the theoretical density, which is particularly suitable for cemented carbide products that require extremely high density and special properties. After the explosion, the body may require subsequent heat treatment to repair microcracks and optimize the microstructure.

Explosive Compaction Process

Powder filling

WC and Co powders are loaded into metal containers (such as high-strength steel or copper) without adding lubricants.

Explosives placement

Explosives (such as TNT or RDX) are arranged around the container and the explosion energy is calculated based on the volume of the blank.

Explosion suppression

The explosive is detonated and the shock wave compresses the powder, with the compression time being < 1 millisecond.

Cooling and removal

After the explosion, the blank is cooled naturally and taken out for subsequent processing.

Heat Treatment

Heat treatment at 600-1000°C repairs micro cracks and stabilizes the structure.

sintering

Sintered at 1350-1450°C, densified to 99% theoretical density.
The high efficiency and ultra-high density characteristics of explosive compaction make it a key process for special applications of cemented carbide.

Characteristics of Explosive Compaction of Cemented Carbide

Explosive pressing has the following significant features in cemented carbide production:

Ultra-high density

The green billet density can reach 90%-95% of the theoretical density, which is much higher than the traditional pressing process (50%-80%), and is close to 100% of the theoretical density after sintering.

Instant molding

The pressing time is less than 1 millisecond, which is extremely efficient and suitable for rapid prototyping needs.

Process complexity

The explosion environment, type and arrangement of explosives need to be strictly controlled, with high safety requirements and professional facilities.

High cost

The equipment and safety measures are expensive and suitable for small batches of high value-added products, but not economical for mass production.

Potential defects

After the explosion, the blank may have microcracks or residual stress, which requires subsequent treatment and repair.

Technical parameters of cemented carbide explosive compaction

The following are the technical parameters of cemented carbide explosive pressing, based on research and experimental data:

pressure

Range : 1000-5000 MPa, instantaneous action, peak pressure depends on explosive type and arrangement.

Impact : Pressure <1000 MPa may result in insufficient density (<85% theoretical density); pressure >6000 MPa may cause overheating or powder melting.

Powder properties

Particle size : WC particle size 0.5-2 μm , Co particle size 0.5-1 μm , mixing uniformity deviation <3% (GB/T 19077.1-2008).

Co content : 6%-10%, no lubricant is required because the explosion shock wave provides sufficient energy.

Moisture content : controlled at <0.1% to avoid explosion-induced gas expansion.

Container material

Type : High-strength steel (e.g. 40CrNiMoA, tensile strength >1000 MPa) or copper (excellent impact resistance).

Thickness : 5-20 mm, designed according to explosion energy.

Inner wall treatment : Polished to Ra<0.5 μm to reduce friction and powder adhesion.

Explosive energy

Unit : Commonly used TNT equivalent (kg), calculated based on the volume of the blank (e.g. 100 cm^3 blank requires 0.5-1 kg TNT).

Control : Too low energy (<0.3 kg TNT) will result in insufficient density; too high energy (>2 kg TNT) may damage the container.

Detonation method : centralized detonation or multi-point detonation, adjusted according to the shape of the blank.

Equipment and environment

Facilities : Dedicated explosion chamber, explosion-proof wall thickness >1 m, equipped with remote monitoring.

Safety distance : The operator is >500 m away from the explosion point.

Temperature : The temperature at the moment of explosion can reach over 2000°C and needs to be cooled quickly .

Green billet density

Range : 90%-95% theoretical density (about 11.5-12.0 g/cm^3 , according to GB/T 3850-2015).

Impact : The density increases with the intensity of the shock wave and can reach 99.5%-100% after sintering.

Process

Powder preparation

WC and Co powders were mixed in proportion (WC particle size 0.5-2 μm , Co content 6%-10%) and mixed by ball milling for 12-24 hours with a uniformity deviation of <3%.

Dry to a moisture content of < 0.1% without adding lubricants.

Filling container

The powder was loaded into a metal container (thickness 10 mm) and vibration filling (50 Hz) was used to ensure compaction, with a filling rate of 70%-80%.

Seal the container and check its airtightness (vacuum degree <10 Pa).

Explosives placement

TNT explosives (0.5-1 kg) are arranged around the container, and the detonation points are designed to be concentrated or multiple points, 5-10 cm away from the container.

The density of the explosive is adjusted (1.5-1.7 g/cm^3) to control the shock wave intensity.

Explosion suppression

Detonated in a dedicated explosion chamber, the shock wave compresses the powder in a compression time of <1 millisecond.
Allow to cool naturally after explosion (10-20 minutes).

Removal and heat treatment
Take out the blank, check for surface cracks, and if necessary, heat treat at 600-1000°C for 2 hours to repair microcracks.
sintering :
Sinter at 1400°C ±10°C, hold for 1.5 hours, vacuum or Ar atmosphere , densification to 99.5%-100%.

Application scenarios of cemented carbide explosive compaction
Explosive pressing is suitable for cemented carbide products that require ultra-high density and special properties. The main scenarios include:
High-performance parts : such as ultra-high density carbide targets for physical vapor deposition (PVD), which require no porosity and uniformity.
Bulletproof materials : such as carbide composite plates, used in armor or explosion-proof equipment.
Special tools : such as superhard drills or cutting tools for extreme working conditions (temperature > 1000°C, pressure > 200 MPa).

Case Study of Explosive Compaction of Cemented Carbide
A research institute produces WC-6%Co target (diameter 100 mm, thickness 5 mm) by explosive pressing, TNT equivalent 0.8 kg, green billet density 93% theoretical density (about 11.7 g/cm³) , hardness HRA 94 after sintering, porosity A00, for PVD coating, film adhesion >50 MPa.

Influencing factors and optimization strategies of cemented carbide explosive compaction

Explosive energy
Impact : 0.5-1 kg TNT equivalent is suitable for 100-200 cm³ blanks . Too low energy (<0.3 kg) will result in a density of <85%. Too high energy (>2 kg) may cause melting or container rupture.
Optimization : Calculate the energy based on the green body volume, use 0.6-0.9 kg TNT, and calibrate with an energy meter.

Powder size
Impact : Particle size is 0.5-2 μm . Particle size that is too large (>3 μm) will lead to uneven density; particle size that is too small (<0.3 μm) may cause bonding due to overheating.
Optimization : Use 1-1.5 μm WC powder, Co particle size 0.5-1 μm , and mixing uniformity <2%.

Container design
Impact : Thickness 10-20 mm, inner wall roughness Ra < 0.5 μm can reduce powder adhesion, insufficient thickness (< 5 mm) may cause rupture.

Optimization : Use 15 mm thick high-strength steel and apply anti-stick coating (such as TiN) on the inner wall.

Shock wave distribution

Impact : Multi-point detonation is more uniform than concentrated detonation, with a deviation of <5%; unevenness may result in a density gradient of >10%.

Optimization : Use 3-5 detonation points, evenly distribute the distance, and adjust the density of explosives to 1.6 g/ cm³ .

Heat Treatment

Impact : Heat treatment at 600-1000°C can repair microcracks (depth < 0.05 mm), temperatures < 500°C are not effective enough.

Optimization : Heat treatment at 800°C ±10°C for 2 h in Ar atmosphere to reduce residual stress (<20 MPa).

Precautions for Explosive Compaction of Cemented Carbide

Safety regulations : The operation must be carried out in a professional explosion facility and in compliance with national explosion safety regulations (such as GB 50198-2011). The operator distance must be >500 m and protective equipment must be worn.

Microcrack repair : Check surface cracks after explosion (magnifying glass or ultrasonic testing), heat treatment temperature 800°C ±10°C, time 2-3 hours.

Container durability : Check container integrity every 10 explosions, and replace if the thickness is worn >1 mm.

Environmental control : The ambient humidity before explosion is <30% to prevent the powder from absorbing moisture and causing abnormal reactions.

Waste disposal : Explosion residues need to be professionally recycled to prevent environmental pollution.

Actual Case Study of Explosive Compaction of Cemented Carbide

A research institute uses explosive pressing process to produce WC-6%Co target (diameter 100 mm, thickness 5 mm) for PVD coating. The process parameters are as follows:

Pressure: about 3000 MPa (instantaneous).

Explosion energy: 0.8 kg TNT.

Powder: WC particle size 1 μm , Co content 6% ± 0.5%.

Container: 15 mm thick high strength steel.

Heat treatment: 800°C, 2 hours, Ar atmosphere.

Sintering: 1400°C, hold for 1.5 hours. Results: Green density 93% theoretical density (about 11.7 g/cm³) , sintered density 99.5% theoretical density, hardness HRA 94, porosity A00, PVD coating adhesion >50 MPa, film thickness uniformity <±0.5 μm .

Engineering Application Practice of Explosive Compaction of Cemented Carbide

PVD targets for Explosive Compaction of cemented carbide

Process : WC-8%Co target (diameter 150 mm, thickness 10 mm) is produced by explosive pressing, with a TNT equivalent of 1 kg.

Performance : Density after sintering is 99.8% of theoretical density, hardness HRA 93, porosity A00, used for TiN coating, adhesion >60 MPa.

Advantages : Ultra-high density ensures long target service life (>100 hours) and stable coating quality.

Bulletproof composite plate made of Explosive Compaction of cemented carbide

Process : Explosive pressing to produce WC-10%Co composite plate (thickness 5 mm, area 200 cm^2) , TNT equivalent 0.6 kg.

Performance : Sintered hardness HRA 92, impact strength>500 J/cm^2 , bulletproof grade NIJ III.

Advantages : Combination of high density and toughness, suitable for lightweight armor applications.

Explosive pressing is a high-efficiency, ultra-high-density (90%-95% theoretical density) cemented carbide pressing process, which is particularly suitable for special needs such as PVD targets and bulletproof materials. By precisely controlling the explosion energy (0.5-1 kg TNT), powder particle size (1-1.5 μm) and heat treatment (800°C ±10°C), high-performance green bodies can be prepared, reaching 99.5%-100% theoretical density (hardness HRA 93-94) after sintering. It performs well in high value-added fields, but its applicability is limited to small-scale production due to safety and cost constraints.

5.1.27 Vibration Compaction of Cemented Carbide

Principle of Vibration Compaction of Cemented Carbide

Vibration pressing is a powder metallurgy forming process that combines high-frequency vibration with traditional pressing technology. It is specially designed for cemented carbide (such as WC-Co mixed powder). Its core principle is to assist the unidirectional or bidirectional pressing process through high-frequency vibration (20-100 kHz), usually provided by an ultrasonic generator or a mechanical vibration device to provide vibration energy. Vibration acts on powder particles, reduces the friction between particles, promotes particle rearrangement, fills gaps and reduces internal pores, thereby significantly improving filling density and compression efficiency. Under an applied pressure of 100-300 MPa, the powder forms a more uniform and denser green blank with the assistance of vibration. Vibration pressing is particularly suitable for high-hardness powders or small-sized parts because it can effectively improve the density gradient and defect problems in traditional pressing.

Vibration Compaction Process of Cemented Carbide

Powder preparation

Mix WC and Co powders and add 0.5% lubricant (such as graphite) to ensure fluidity.

Vibration and compression

The powder was loaded into the mold, and vibration (50 kHz) was applied and simultaneously a pressure of 200 MPa was applied for 10–20 s.

Demolding and drying

Take out the green blank and dry it at 50-80°C for 2-4 hours.

sintering

Sintered at 1350-1450°C, densified to 98%-99% theoretical density.

The unique advantage of vibration pressing is that it improves density and uniformity through vibration energy, which is suitable for the needs of small and high-precision parts.

Characteristics of Cemented Carbide Vibration Compaction

Vibration pressing has the following significant features in cemented carbide production:

Density Improvement

The green billet density is 65%-75% of the theoretical density, which is 5%-10% higher than that of unidirectional pressing . After sintering, it can reach 98%-99% of the theoretical density.

Defect reduction

Vibration reduces pores and delamination, increases green body strength by 10%-15%, and reduces porosity to A00-B00 level.

Simple process

It can be combined with existing one-way or two-way pressing equipment, with low transformation cost (about 5%-10% of equipment upgrade cost).

applicability

It is particularly suitable for small-sized parts or high-hardness powders (such as WC particle size <1 μm), and has a certain adaptability to complex shapes.

limitation

Not suitable for large or very complex geometries, where the vibration frequency needs to be precisely matched to the powder characteristics.

Technical parameters of cemented carbide vibration compaction

The following are the technical parameters of cemented carbide vibration pressing, based on industrial practice and experimental data:

pressure

Range : 100-300 MPa, 200 MPa is commonly used to balance density and mold life.

Impact : Pressure <100 MPa may result in insufficient density (<60% theoretical density); pressure >350 MPa may cause overpressure cracking.

Vibration frequency :

Range : 20-100 kHz, 50 kHz is commonly used to optimize particle rearrangement.

Impact : Frequencies that are too low (<20 kHz) have limited effect; frequencies that are too high

(>120 kHz) may cause particle agglomeration or equipment overload.

Powder characteristics :

Particle size : WC particle size 0.5-2 μm , Co particle size 0.5-1 μm , mixing uniformity deviation <3% (GB/T 19077.1-2008).

Co content : 6%-12%, 8% is commonly used to provide moderate toughness.

Lubricant : Add 0.5% graphite or stearic acid to reduce the friction coefficient to <0.1 (experimental data).

Flowability : 15-20 seconds/50 g (similar to ISO 4490:2018), ensuring uniform filling.

Pressing time :

Range : 10-20 seconds, including vibration (5-10 seconds) and main pressure (5-10 seconds).

Impact : If the time is too short (<8 seconds), the density will be insufficient; if the time is too long (>30 seconds), the efficiency may be reduced.

Mould material :

Type : High hardness steel (such as Cr12MoV, HRC 58 and above) or carbide lining.

Surface treatment : The inner wall is polished to Ra<0.2 μm (GB/T 1031-2009) to reduce powder adhesion.

Equipment parameters :

Vibration device : Ultrasonic generator or mechanical vibrator, power 2-5 kW, frequency accuracy ±2 kHz.

Press : hydraulic or mechanical, pressure range 100-400 MPa.

Control system : PLC control, pressure accuracy ±5 MPa, vibration frequency deviation <5%.

Green billet density :

Range : 65%-75% theoretical density (about 8.5-9.5 g/cm³ , according to GB/T 3850-2015).

Impact : Density increases with increasing vibration frequency and pressure, and can reach 98%-99% after sintering.

Vibration Compaction Process of Cemented Carbide

Powder preparation :

WC and Co powders were mixed in proportion (WC particle size 0.5-2 μm , Co content 6%-12%) and mixed by ball milling for 12-24 hours with a uniformity deviation of <3%.

Add 0.5% graphite lubricant, mix and sieve (200 mesh), and the fluidity reaches 15-20 seconds/50 g.

Vibration and suppression :

The powder was loaded into the mold and 50 kHz vibration was applied for 5-10 seconds, and 200 MPa pressure was applied for 5-10 seconds simultaneously.

The mold temperature is controlled at 20-40°C to avoid powder adhesion.

Demolding and drying :
Take out the green blank and cut it into the required size (accuracy ±0.1 mm).
Dry at 50-80°C for 2-4 hours to reduce moisture content to <0.5%.

sintering :
Sinter at 1400°C ±10°C, hold for 1.5 hours, vacuum or Ar atmosphere , densify to 98%-99% theoretical density.

Application Scenario
Vibration pressing is widely used in the production of cemented carbide blanks that require high uniformity and small size. The main scenarios include:
Small tool blanks
Such as carbide drill blanks and micro milling cutter blanks, which require high density and uniformity.
Precision Parts
Such as carbide cores or wear-resistant parts, used in molds or cutting tools.

Case Study of Vibration Compaction of Cemented Carbide

A certain enterprise produces WC-8%Co drill bit blanks (diameter 10 mm, height 15 mm) by vibration pressing, with a vibration frequency of 50 kHz and a pressure of 200 MPa. The green blank density is 72% of the theoretical density (about 9.2 g/cm³) , the hardness after sintering is HRA 91, the porosity is A00, and it is used for hard rock drilling with a service life of >1200 m.

Influencing factors and optimization strategies of cemented carbide vibration compaction

Vibration frequency :
Impact : 50 kHz ±2 kHz optimizes particle rearrangement, frequencies < 20 kHz have limited effect; frequencies > 120 kHz may cause particle agglomeration (particle size increase > 10%).
Optimization : Adjust according to powder particle size, 40-60 kHz for 1 μm powder, equipped with a frequency calibrator.

Pressure Control :
Impact : 200 MPa ±5 MPa increases density (65%-75% theoretical density), pressure <100 MPa density <60%; pressure >350 MPa may cause mold deformation.
Optimization : Use 200-250 MPa, dynamically adjust to suit powder characteristics.

Powder size :
Impact : Particle size is 0.5-2 μm . If the particle size is too large (>3 μm), the vibration effect will be weakened; if the particle size is too small (<0.3 μm), it may overheat and bond.

Optimization : Use 0.8-1.5 μm WC powder, Co particle size 0.5-1 μm , and mixing uniformity <2%.

Lubricant ratio :
Impact : 0.5% graphite reduces friction (<0.1), too high a ratio (>1%) reduces density; too low a ratio (<0.2%) increases friction.
Optimization : Control at 0.4%-0.6%, and mix for 2 hours to ensure uniformity.

Pressing time :
Impact : 10-20 seconds, time < 8 seconds means insufficient density; time > 30 seconds means reduced efficiency.
Optimization : Set to 15 seconds (8 seconds for vibration, 7 seconds for main pressure), and adjust according to the size of the blank.

Precautions for Vibration Compaction of Cemented Carbide

Optimize vibration frequency : adjust according to powder particle size (40 kHz for 0.5 μm and 60 kHz for 2 μm), avoid agglomeration, and regularly check the vibration generator (frequency deviation <5%).
Equipment maintenance : Check the vibrator and die monthly, clean the powder residue, calibrate the frequency (±2 kHz) and pressure (±5 MPa).
Mould design : inner wall polished to Ra<0.2 μm , pressure resistance>400 MPa, to avoid wear caused by vibration.
Drying control : Dry at 50-80°C for 2-4 hours, moisture content <0.5%, to prevent moisture absorption and cracking.
Safe operation : Avoid overloading when the vibration equipment is in operation and control the power below 5 kW.

Actual Case Study of Vibration Compaction of Cemented Carbide

A company uses vibration pressing process to produce WC-8%Co drill bit blanks (diameter 10 mm, height 15 mm) for hard rock drilling. The process parameters are as follows:
Pressure: 200 MPa ±5 MPa.
Vibration frequency: 50 kHz ±2 kHz.
Powder: WC particle size 1 μm , Co content 8% ± 0.5%, graphite lubricant 0.5% ± 0.1%.
Sintering: 1400°C, holding temperature 1.5 hours. Result: green density 72% theoretical density (about 9.2 g/cm³) , sintered density 98.5% theoretical density, hardness HRA 91, porosity A00, drill bit life >1200 m (hard rock, compressive strength 150 MPa).

Engineering Application Practice of Cemented Carbide Vibration Compaction

Carbide drill blank

Process : WC-10%Co drill blanks (8 mm in diameter, 12 mm in height) were produced by vibration pressing at a pressure of 200 MPa and a frequency of 50 kHz.
Performance : After sintering, the hardness is HRA 90, the density is 98% of the theoretical density, the porosity is A00, it is used for oil drilling, and the service life is >1500 m.
Advantages : High uniformity and density improve the drill bit's impact and wear resistance.

Micro mold core
Process : WC-6%Co cores (5 mm in diameter, 10 mm in height) were produced by vibration pressing at a pressure of 180 MPa and a frequency of 40 kHz.
Performance : hardness after sintering HRA 92, density 98.5% theoretical density, pressure resistance>200 MPa, used for precision stamping dies.
Advantages : Reduced porosity and delamination, longer die life (>10,000 punches).

Vibration pressing is an efficient and economical cemented carbide pressing process. Through high-frequency vibration (50 kHz ±2 kHz) assisted by 200 MPa ±5 MPa pressure, the green billet density can be increased to 65%-75% of the theoretical density, and after sintering, it can reach 98%-99% of the theoretical density (hardness HRA 90-92). It performs well in the fields of small tool blanks and micro mold cores, and is particularly suitable for the production of high-hardness powders and small-sized parts. By optimizing the vibration frequency, pressure and powder particle size, defects can be significantly reduced and performance can be improved.

5.1.28 Multi -Axial Non-Isostatic Pressing of Cemented Carbide (e.g. four-way and six-way pressing)

The principle of multi-directional pressing of cemented carbide
Multi-directional non- isostatic pressing is an advanced powder metallurgy pressing technology suitable for the forming of cemented carbide (such as WC-Co mixed powder). Its core principle is to apply non-isotropic pressure from different angles through multiple pressing heads (usually 4 or 6, including vertical and multiple horizontal directions), replacing the single-direction compression of traditional unidirectional or bidirectional pressing. The pressure distribution is optimized and adjusted by a precision control system. Each pressing head can independently adjust the force and apply adaptive pressure according to the shape and density requirements of the blank, thereby achieving uniform compression and densification in three-dimensional space. Unlike isostatic pressing, the pressure of multi-directional non- isostatic pressing is not completely isotropic, but is graded and controlled according to design requirements. It is particularly suitable for cemented carbide blanks with complex shapes or requiring local high density. After pressing, the blank is further densified to a high-performance level by sintering.

The process of multi-directional pressing of cemented carbide

Powder preparation : Mix WC and Co powders, add a small amount of lubricant, and load into the mold.

Multi-directional pressing : Pressure is applied by 4 or 6 pressing heads (400-500 MPa vertically, 300-400 MPa laterally) for 10-20 seconds.
Demolding and drying : Take out the green blank and dry it at 50-80°C for 2-4 hours.
Sintering : Sinter at 1350-1450°C, densification to 98%-99% theoretical density.
The unique advantages of this process are its flexible pressure distribution and high density control capability, which is particularly suitable for cemented carbide products that require high uniformity and complex geometries.

Characteristics of cemented carbide multi-directional pressing
Multi-directional non -isostatic pressing has the following significant features in cemented carbide production:
High density : Green billet density is 85%-90% of theoretical density, close to cold isostatic pressing, and can reach 99%-99.5% of theoretical density after sintering.
Pressure flexibility : Through independent control of multiple pressure heads, the pressure distribution can be optimized according to the needs of the green body, reducing the density gradient (<2%).
Reduced defects : Non-isostatic pressing design reduces delamination and micro cracks, and increases green body strength by 15%-20%.
Applicability : Suitable for medium-complex shapes (such as multi- edge tool blanks), with certain restrictions on large sizes or ultra-complex shapes.
Equipment complexity : requires a multi-axis press and a precision control system. The cost is higher than unidirectional or bidirectional pressing, but lower than isostatic pressing.

Technical parameters of cemented carbide multi-directional pressing
The following are the technical parameters of cemented carbide multi-directional non- isostatic pressing, based on industrial practice and experimental data:
pressure :
Range : 400-500 MPa vertically, 300-400 MPa laterally, the pressure ratio is usually 1:0.7:0.6:0.6 (four-way) or 1:0.7:0.6:0.6:0.6:0.6 (six-way).
Impact : Too low pressure (<300 MPa) will result in insufficient density (<80% theoretical density); too high pressure (>600 MPa) may damage the mold.

Powder characteristics of cemented carbide multi-directional pressing :
Particle size : WC particle size 1-3 μm , Co particle size 0.5-1 μm , mixing uniformity deviation <3% (GB/T 19077.1-2008).
Co content : 6%-10%, commonly 8%-12% to provide toughness.
Lubricant : Add 0.5%-1% graphite or stearic acid to reduce the friction coefficient to <0.15.
Flowability : 15-20 seconds/50 g (similar to ISO 4490:2018 standard).

Number and direction of the indenters for multi-directional pressing of cemented carbide :
Four-way pressing : 1 vertical pressing head, 3 horizontal pressing heads (120° distribution).
Six-way pressing : 1 vertical pressing head, 5 horizontal pressing heads (72° distribution).

Synchronicity : The pressure head movement deviation is <0.5 mm, ensuring uniform compression.

Pressing time :
Range : 10-20 seconds, including pre-compression (5 seconds) and main compression (5-15 seconds).
Impact : If the time is too short (<8 seconds), the density will be uneven; if the time is too long (>30 seconds), the efficiency will be reduced.

Mould material :
Type : Carbide liner (HRA 88 and above) or high strength steel (HRC 60 and above).
Surface treatment : Inner wall polished to Ra<0.2 μm (GB/T 1031-2009), pressure resistance>800 MPa.

Equipment parameters :
Press : Multi-axis hydraulic press, power 20-50 kW, pressure range 400-600 MPa.
Control system : PLC closed-loop control, pressure accuracy ±5 MPa, displacement accuracy <0.01 mm.
Vibration Assist (optional): 20-50 kHz, enhances particle rearrangement.

Green billet density :
Range : 85%-90% theoretical density (approximately 10.8-11.4 g/cm³ , according to GB/T 3850-2015).
Impact : Density increases with the number of press heads and pressure, and can reach 99%-99.5% after sintering.

The process flow of multi-directional pressing of cemented carbide

Powder preparation :
WC and Co powders were mixed in proportion (WC particle size 1-3 μm , Co content 6%-12%) and mixed by ball milling for 12-24 hours with a uniformity deviation of <3%.
Add 0.5%-1% graphite lubricant, mix and sieve (200 mesh), fluidity 15-20 seconds/50 g.

Filling the mold :
The powder is loaded into a multi-directional pressing die and vibration filling (50 Hz) is used to ensure density, with a filling rate of 70%-80%.
Preheat the mold to 20-40°C to avoid powder sticking.

Multi-directional suppression :
Apply four-way or six-way pressure (400 MPa vertically and 300 MPa laterally) for 10-20 seconds.
The synchronism of the press head is controlled by a servo motor with a deviation of <0.5 mm.

Demolding and drying :

Take out the green blank and cut it into the required size (accuracy ±0.1 mm).
Dry at 50-80°C for 2-4 hours to reduce moisture content to <0.5%.

sintering :
Sinter at 1400°C ±10°C, hold for 1.5 hours, vacuum or Ar atmosphere , densify to 99%-99.5% theoretical density.

Application scenarios of cemented carbide multi-directional pressing
Multi-directional non -isostatic pressing is suitable for cemented carbide blanks that require high density and medium-complex shapes. The main scenarios include:
Multi- edge cutting tools : such as complex milling cutter blanks and drill blanks, which require high uniformity and density.
Precision mold parts : such as stamping mold cores or drawing dies, which require local high density.
Wear parts : such as carbide liners or wear strips, used in high load conditions.

Case study of multi-directional pressing of cemented carbide
A certain enterprise produces WC-12%Co multi- edge tool blanks (diameter 40 mm, height 20 mm) using six-way pressing, vertical pressure 500 MPa, lateral pressure 400 MPa, green blank density 90% theoretical density (about 11.4 g/cm³) , hardness after sintering HRA 92, porosity A00, for aviation cutting, life>1000 m.

Influencing factors and optimization strategies of multi-directional pressing of cemented carbide

Pressure distribution :
Impact : 400-500 MPa vertically, 300-400 MPa laterally, pressure ratio 1:0.7:0.6, deviation >10% results in density gradient >5%.
Optimization : Use 1:0.75:0.65 pressure ratio, equipped with pressure sensor, deviation <±5 MPa.

Pressure head synchronization :
Impact : Deviation <0.5 mm ensures uniform compression; deviation >1 mm may cause local overpressure (>600 MPa).
Optimization : Use servo motor control and real-time calibration of displacement (accuracy < 0.01 mm).

Powder size :
Impact : Particle size is 1-3 μm . If the particle size is too large (>4 μm), the density is uneven; if the particle size is too small (<0.5 μm), it may stick together.
Optimization : Use 1.5-2.5 μm WC powder, Co particle size 0.5-1 μm , and mixing uniformity <2%.

Lubricant ratio :
Impact : 0.5%-1% graphite reduces friction (<0.15), too high a ratio (>2%) reduces density; too low a ratio (<0.3%) increases wear.
Optimization : Controlled at 0.6%-0.8%, mixing time 2 hours.

Mold durability :
Impact : Pressure resistance>800 MPa, Ra<0.2 μm can reduce powder adhesion, wear>0.1 mm needs to be replaced.
Optimization : Check the mold every 500 pressings and apply a TiN wear-resistant layer to extend the life (>10,000 times).

Precautions for multi -directional pressing of cemented carbide
Indenter synchronization : Deviation <0.5 mm, regular calibration (once a month) to avoid cracks caused by local overpressure .
Vibration Assist : Optional 20-50 kHz vibration for enhanced particle rearrangement, frequency deviation <5%.
Mould maintenance : Check inner wall wear every 500 times, polish to Ra<0.2 μm , pressure test>800 MPa.
Drying control : Dry at 50-80°C for 2-4 hours, moisture content <0.5%, prevent moisture absorption.
Equipment safety : Avoid overloading when the multi-axis machine is running, and the upper limit of pressure is set to 600 MPa.

Actual case of multi-directional pressing of cemented carbide
A company uses six-way pressing process to produce WC-12%Co multi- edge tool blanks (diameter 40 mm, height 20 mm) for aviation cutting. The process parameters are as follows:
Pressure: 500 MPa vertically, 400 MPa laterally.
Suppression time: 15 seconds.
Powder: WC particle size 2 μm , Co content 12% ± 0.5%, graphite lubricant 0.8% ± 0.1%.
Sintering: 1450°C, holding temperature for 1.5 hours. Results: green density 90% theoretical density (about 11.4 g/cm³) , sintered density 99.5% theoretical density, hardness HRA 92, porosity A00, cutting life >1000 m (Ti alloy, cutting speed 300 m/min).

Engineering application practice of multi-directional pressing of cemented carbide

Complex milling cutter blanks :
Process : WC-10%Co milling cutter blanks (30 mm diameter, 15 mm height) were produced by six-way pressing, 450 MPa vertically and 350 MPa laterally.
Performance : After sintering, the hardness is HRA 91, the density is 99% of the theoretical density, the porosity is A00, it is used for aviation processing, and the service life is >800 m.
Advantages : Multi-directional pressure optimizes the density of complex blades and reduces cracks.

Wear-resistant lining :
Process : WC-8%Co liner (thickness 10 mm, area 100 cm²) produced by four-way pressing , 400 MPa vertically and 300 MPa laterally.
Performance : hardness after sintering HRA 90, wear resistance life> 500 hours (load 50 N), pressure resistance> 200 MPa.
Advantages : High uniformity ensures the stability of the lining under high loads.

Multi-directional non -isostatic pressing (such as four-way and six-way pressing) is a high-density (85%-90% theoretical density) and highly flexible cemented carbide pressing process. It achieves uniform compression of complex-shaped blanks through multiple press heads (400-500 MPa vertically and 300-400 MPa laterally), and reaches 99%-99.5% theoretical density (hardness HRA 90-92) after sintering. It performs well in areas such as complex milling cutter blanks and wear-resistant liners, and is particularly suitable for applications that require local high density. By optimizing pressure distribution, press head synchronization and powder particle size, the quality and performance of the blank can be significantly improved.

5.1.29 Comparison table of cemented carbide pressing processes

Pressing process	Features	Process	Equipment Requirements	Performance Indicators	Applicable Products	Advantages and Disadvantages
One-way suppression	- Simple and efficient - Low density (50%-65% theoretical density) - Easy to produce density gradient - Suitable for simple shapes	1. Powder filling 2. Unidirectional pressure (100-300 MPa) 3. Demolding and drying 4. Sintering (1350-1450°C)	- Single-axis hydraulic press - Power 5-10 kW - Die: High hardness steel (HRC 58)	- Green density: 50%-65% - Hardness after sintering: HRA 88-90 - Porosity: A02-B02	- Simple geometry parts (e.g. cutting inserts) - Example: WC-8%Co insert (10×10× 5 mm)	**Advantages** : simple equipment, low cost, high efficiency **Disadvantages** : large density gradient (>10%), not suitable for complex shapes
Two-way suppression	- More uniform than unidirectional pressing - Slightly higher density (60%-75% theoretical density) - Suitable for medium complex shapes	1. Powder filling 2. Bidirectional pressure (200-400 MPa) 3. Demolding and drying 4. Sintering (1350-1450°C)	- Two-axis hydraulic press - Power 10-20 kW - Dies: Carbide (HRA 88)	- Green density: 60%-75% - Sintered hardness: HRA 89-91 - Porosity: A02	- Medium complex parts (e.g. milling cutter blanks) - Example: WC-10%Co milling cutter blank (20 mm diameter)	**Advantages** : Improved density uniformity (gradient <5%) **Disadvantages** : Still not suitable for highly complex shapes, slightly more complicated equipment
Isostatic Pressing (Cold Isostatic	- High uniformity - High density (75%-85% theoretical density)	1. Powder bagging 2. Isostatic pressing (200-400 MPa) 3. Bag removal and	- Isostatic press - Pressure resistance > 500 MPa - Liquid	- Green density: 75%-85% - Hardness after sintering: HRA 90-	- Complex shape parts (such as aviation tool blanks) -	**Advantages** : high density, good uniformity, suitable for complex shapes

Pressing process	Features	Process	Equipment Requirements	Performance Indicators	Applicable Products	Advantages and Disadvantages
Pressing)	- Suitable for complex shapes - Higher cost	drying 4. Sintering (1350-1450°C)	medium: oil or water - Power 50-100 kW	92 - Porosity: A00-B00	Example: WC-12%Co tool blank (diameter 50 mm)	**Disadvantages** : high equipment cost, long cycle
Isostatic Pressing (Hot Isostatic Pressing)	- Ultra-high density - Eliminate micropores - High temperature and high pressure (1350-1450°C, 100-200 MPa) - Extremely high cost	1. Load the sintered product into the HIP equipment 2. Apply high temperature and high pressure (1400°C, 150 MPa) 3. Cool and release pressure 4. Finishing	- HIP equipment - Inner cavity > 200 mm - Power > 150 kW - Pressure medium: Ar (purity > 99.99%)	- Porosity: <0.03% - Density: >99.8% - Hardness: HRA 92-94 - Lifespan: >20 hours	- High reliability parts (such as aviation tools, mining drill bits) - Example: WC-10%Co tools (hardness HV 2300)	**Advantages** : Extremely high density and reliability **Disadvantages** : High cost, suitable for post-processing rather than direct molding
Compression Molding	- Efficient mass production - Medium density (60%-70% theoretical density) - Limited shape	1. Powder filling 2. Unidirectional or bidirectional pressure (200 MPa) 3. Demolding and drying 4. Sintering (1350-1450°C)	-Press machine - Power 5-15 kW - Mold: High hardness steel (HRC 58)	-Green density: 60% -70% - Hardness after sintering: HRA 90 - Porosity: A02	- Standardized parts (such as cutting inserts) - Example: WC-8%Co insert (10×10× 5 mm)	**Advantages** : high efficiency, low cost **Disadvantages** : limited shape, fast mold wear
Extrusion	- Flexible shape (elongated shape) - Degreasing required - Medium density (55%-65% theoretical density) - Continuous production	1. Powder mixed with binder (PVA 20%) 2. Extrusion (300 MPa, 1 m/min) 3. Cutting and debinding 4. Sintering	- Extruder - Pressure 200-500 MPa - Die: Carbide - Barrel heating: 50-80°C	- - Green density: 55%-65% - Sintered hardness: HRA 91 - Porosity: A02	- Long tools (e.g. bars) - Example: WC-10%Co bar (5 mm diameter, 300 mm length)	**Advantages** : suitable for slender shapes, continuous production **Disadvantages** : need to degrease, complex process
Injection molding	- High precision (tolerance < 0.01 mm) - Complex shape - Low density (50%-60% theoretical density) - Many processes	1. Powder mixed with binder (POM 25%) 2. Injection (80 MPa, 180°C) 3. Debinding 4. Sintering	- Injection machine - Pressure 50-120 MPa - Mold: H13 steel - Barrel heating: 150-200°C	- - Green density: 50%-60% - Hardness after sintering: HRA 92 - Porosity: A00-B00	- Micro parts (such as gears) - Example: WC-6%Co gear (3 mm diameter, 1 mm thickness)	**Advantages** : high precision, suitable for complex shapes **Disadvantages** : many processes, high cost
Dry bag	- High uniformity -	1. Powder filling	- Dry Bag -	- Green density:	- Medium size	**Advantages** : good

Pressing process	Features	Process	Equipment Requirements	Performance Indicators	Applicable Products	Advantages and Disadvantages
pressing	High density (70%-75% theoretical density) - Higher efficiency than wet bag isostatic pressing - Limited shape	into dry bags 2. Pressing (300 MPa) 3. Demolding and drying 4. Sintering (1350-1450°C)	Isostatic Press - Pressure 200-400 MPa - Mould: Rubber (Shore A 70)	70%-75% - Hardness after sintering: HRA 90 - Porosity: A00-B00	parts (e.g. bearing sleeves) - Example: WC-8%Co bearing sleeve (50 mm diameter)	uniformity, high efficiency **Disadvantages** : limited shape, medium equipment cost
Multi-directional suppression	- Uniform density (75%-80% theoretical density) - Few defects - Suitable for medium complex shapes	1. Powder filling 2. Multi-directional pressure (vertical 400 MPa, lateral 300 MPa) 3. Demolding and drying 4. Sintering	- Multi-axis press - Power 15-30 kW - Die: Carbide lined	- Green density: 75%-80% - Sintered hardness: HRA 91 - Porosity: A00-B00	- Complex tool blanks (e.g. multi-edge milling cutters) - Example: WC-8%Co tool blank (30 mm diameter)	**Advantages** : high uniformity, few defects **Disadvantages** : complex equipment, high cost
Multi-directional non -isostatic pressing	- High density (85%-90% theoretical density) - Flexible pressure - Suitable for local high density needs	1. Powder filling 2. Four-way/six-way pressure (vertical 500 MPa, lateral 400 MPa) 3. Demolding and drying 4. Sintering	- Multi-axis hydraulic press - Power 20-50 kW - Control system: PLC, accuracy < 0.01 mm	- Green density: 85%-90% - Hardness after sintering: HRA 92 - Porosity: A00	- Multi- edge tool blanks (e.g. milling cutter blanks) - Example: WC-12%Co milling cutter blank (diameter 40 mm)	**Advantages** : high density, flexible pressure **Disadvantages** : complex equipment, high cost
Roll forming	- Continuous production - Adjustable thickness (0.5-5 mm) - Low density (50%-60% theoretical density)	1. Powder feeding 2. Rolling (100 MPa, 10 rpm) 3. Cutting and drying 4. Sintering (1350-1450°C)	- Rolling machine - Power 10-20 kW - Rollers: Carbide (HRC 60)	- Green density: 50%-60% - Sintered hardness: HRA 89 - Porosity: A02	- Thin sheet blank (e.g. wear-resistant coating substrate) - Example: WC-10%Co thin sheet (thickness 2 mm, width 100 mm)	**Advantages** : continuous production, simple equipment **Disadvantages** : low density, not suitable for complex shapes
Explosion suppression	- Ultra-high density (90%-95% theoretical density) - Instant molding (<1 millisecond) -	1. Powder container 2. Explosion (TNT 0.5-1 kg) 3. Heat treatment 4.	- Explosion chamber - Container: High-strength steel (thickness 15	- Green density: 90%-95% - Hardness after sintering: HRA 94 - Porosity: A00	- High performance parts (such as PVD targets) - Example: WC-	**Advantages** : ultra-high density, high efficiency **Disadvantages** : high safety requirements,

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Pressing process	Features	Process	Equipment Requirements	Performance Indicators	Applicable Products	Advantages and Disadvantages
	High safety requirements	Sintering (1400°C)	mm) - Safety distance: >500 m		6%Co target (diameter 100 mm, thickness 5 mm)	high cost, heat treatment is required to repair micro cracks
Vibration suppression	- Density improvement (65%-75% theoretical density) - Fewer defects - Low transformation cost	1. Powder filling 2. Vibration (50 kHz) + pressure (200 MPa) 3. Demolding and drying 4. Sintering	- Vibration press - Vibrator: 2-5 kW, frequency 20-100 kHz - Die: High hardness steel	- Green density: 65%-75% - Sintered hardness: HRA 91 - Porosity: A00-B00	- Small tool blanks (such as drill blanks) - Example: WC-8%Co drill blank (diameter 10 mm, height 15 mm)	**Advantages** : increased density, fewer defects, low modification cost **Disadvantages** : not suitable for large-sized parts, frequency optimization is required

5.1.30 Comprehensive Analysis and Summary of Cemented Carbide Pressing Process

cemented carbide pressing processes (unidirectional pressing, bidirectional pressing, isostatic pressing, compression molding, extrusion molding, injection molding, dry bag pressing , multi-directional pressing, multi-directional non-isostatic pressing, roll forming, explosive pressing, vibration pressing), covering dimensions such as characteristics, process flow, equipment requirements, performance indicators, applicable products, advantages and disadvantages.

1. Density and uniformity

Highest density : Explosive pressing (90%-95% theoretical density) and multi-directional non -isostatic pressing (85%-90% theoretical density) perform best and are suitable for high performance needs.

Homogeneity : Isostatic pressing (cold/hot) and multi-directional non -isostatic pressing have the best homogeneity (density gradient <2%), suitable for complex shapes and high quality requirements.

Low density : Rolling molding and injection molding (50%-60% theoretical density), which needs to be compensated by subsequent sintering.

2. Applicability and shape complexity

Complex shapes : Injection molding (tolerance < 0.01 mm) and isostatic pressing are suitable for highly complex shapes, such as micro gears and complex tool blanks.

Slender shapes : Extrusion molding is specially designed for rods and tubes with a length of up to several meters.

Thin sheets/large areas : Roll forming is suitable for thin sheets with precise thickness control

(0.5-5 mm).

Simple shapes : One-way pressing and compression molding are suitable for standardized parts, with high efficiency but limited shapes.

3. Production efficiency and cost

High efficiency : Roll forming and extrusion forming support continuous production and are suitable for large quantities.

Low cost : One-way pressing, compression molding and roll forming equipment are simple and have low maintenance costs.

High cost : Explosive pressing and hot isostatic pressing have high costs due to equipment and safety requirements and are suitable for small batches of high value-added products.

4. Bugs and Performance

Fewest defects : Hot isostatic pressing (porosity <0.03%), multi-directional non- isostatic pressing and vibration pressing (porosity A00-B00) have few defects and are suitable for high reliability requirements.

High performance : Explosive pressing (hardness HRA 94) and hot isostatic pressing (hardness HRA 92-94) offer the best performance and are suitable for extreme working conditions.

5. Equipment and process complexity

Simple equipment : One-way pressing, compression molding and roll forming equipment are simple and easy to promote.

Complex equipment : Multi-directional non- isostatic pressing and explosive pressing require multi-axis machines or special explosion facilities, and have high technical barriers.

Complex process : Injection molding and extrusion molding require degreasing, so there are more steps.

6. Comparison of application areas

Aviation/High Reliability : Hot isostatic pressing, multi-directional non- isostatic pressing, and explosive pressing to meet the needs of aviation tools, targets, etc.

Industrial batch : unidirectional pressing, compression molding, roll forming, suitable for cutting blades, wear-resistant coating substrates.

Micro precision : injection molding and vibration pressing, suitable for micro gears and drill blanks.

The selection of cemented carbide pressing process should be based on product shape, performance requirements, production scale and cost budget:

High density/high performance requirements : explosive pressing, hot isostatic pressing, multi-directional non- isostatic pressing.

Complex shapes/high precision : injection molding, isostatic pressing, multi-directional pressing.

High volume/simple shapes : unidirectional pressing, compression molding, flow forming.

Slender shape : Extruded.

Small size/high uniformity : vibration pressing, dry bag pressing .

The pressing effect and product quality can be further improved by optimizing process parameters (such as pressure, vibration frequency, binder ratio) and equipment (such as mold design, control system).

5.2 Cemented Carbide Sintering Process

The cemented carbide sintering process densifies the blank (density>99.5% ±0.1%, ISO 3369-2006), optimizes the microstructure (WC grain deviation<5% ± 1 %, Co phase distribution>95 % ± 1 % , ASTM B657-16) , and achieves high hardness (HV 1500-2500 ±30, ISO 3369-2006) through high temperature (1350-1500°C ±10°C, ISO 4489:2009, sintering is the process of powder particles diffusing and combining to form dense materials at high temperature) and specific atmosphere (vacuum<10^{-2} Pa ±10^{-3} Pa, relevant process requirements of GB/T 1479.1-2011, vacuum environment reduces oxidation ; Ar purity>99.99% ±0.01%, GB/T 4325-2018) to optimize the microstructure (WC grain deviation<5% ±1%, Co phase distribution>95% ±1%, ASTM B657-16), and achieves high hardness (HV 1500-2500 ±30, ISO 3738-1:1982》), toughness (K_{1c} 8-20 MPa·m$^{1/2}$ ±0.5, ISO 28079:2009) and strength (>4000 MPa ±100 MPa, GB/T 3851-2015).

This section analyzes cemented carbide vacuum sintering, cemented carbide hot isostatic pressing sintering, cemented carbide microwave sintering and cemented carbide spark plasma sintering (SPS), and discusses process optimization and application in combination with thermodynamics and kinetics.

5.2.0 Traditional cemented carbide sintering process

5.2.0.0 History of Traditional Cemented Carbide Sintering Process

The traditional cemented carbide sintering process originated in the early 20th century, with the rapid development of powder metallurgy technology. In 1909, German scholar Schroter first prepared the prototype of cemented carbide by mixing tungsten carbide with iron metals (such as Co) for sintering. In 1923, Krupp in Osnabrück, Germany, achieved industrial production, marking the birth of cemented carbide. Since then, the process has been widely used in the 1930s and 1950s, especially during World War II for the manufacture of cutting tools and armor materials. The early process relied on simple resistance furnaces and manual operation. By the 1960s, with the introduction of vacuum technology and hydrogen protection, the process was gradually improved, but its basic framework maintained traditional characteristics and still occupies an important position in some small and medium-sized enterprises.

5.2.0.1 Principle of Traditional Cemented Carbide Sintering Process

The traditional cemented carbide sintering process is based on the liquid phase sintering principle of powder metallurgy, which combines powder particles into dense materials through high temperature. Its core mechanism includes:

Solid phase diffusion

At the initial stage of heating (<1350°C), atomic diffusion occurs between WC particles and a preliminary skeleton structure is formed.

Liquid Phase Sintering

When the temperature reaches 1350-1400°C, cobalt melts to form a liquid phase, which penetrates into the WC particles, fills the pores and promotes particle rearrangement. The liquid phase ratio is usually 10-20% (depending on the Co content), which enhances the bonding through capillary action and dissolution-precipitation mechanism.

Solidification and growth

During the cooling process, the liquid phase solidifies and the WC grains grow slightly (1-3 μm), forming a stable microstructure.

Atmosphere Effect

Vacuum or hydrogen atmosphere removes oxides, prevents decarburization or η phase (Co_3W_3C) formation, and ensures a balanced carbon content (5-6% wt).

5.2.0.2 Principle and structure of traditional cemented carbide sintering equipment

Traditional sintering process mainly relies on the following equipment:

Traditional carbide sintering resistance furnace

Principle : Electric heating elements (such as silicon carbon rods or molybdenum wires) are used to generate high temperatures, and the heat is transferred to the blank through radiation and convection .

Structure : It consists of a furnace (made of refractory material such as alumina), heating elements, insulation and vacuum/gas inlet. The furnace volume is generally 0.5-2 m^3 and the temperature range is 600-1500°C.

Features : Simple structure, low thermal efficiency (about 50-60%), heating elements need to be replaced regularly.

Conventional cemented carbide sintering vacuum system

Principle : The combination of mechanical pump and diffusion pump reduces the pressure in the furnace to 0.1-1 Pa and removes oxygen and moisture.

Structure : Includes vacuum pump, valves and pressure gauge, connected to the furnace.

Features : High maintenance cost and strict sealing requirements.

Traditional cemented carbide sintering hydrogen protection system

Principle : Reduce oxidation by replacing air with a hydrogen flow (10-20 m^3 / h).

Structure : Gas bottle, flow meter and air inlet pipe, equipped with a simple exhaust device.

Features : Pay attention to hydrogen safety during operation and the equipment is relatively rough.

Tray and mold : Made of graphite or ceramic, high temperature resistant and chemically inert, supports the blank and transfers heat.

5.2.0.3 Characteristics of Traditional Cemented Carbide Sintering

Process characteristics :

Relying on manual operation, process parameters (such as temperature and time) are mostly

adjusted based on experience.
The heating, heat preservation and cooling process takes 6-10 hours, and the production cycle is long.
The atmosphere control is simple, vacuum or hydrogen is commonly used, and some processes may be carried out in air.

Features :
Density is typically 13.5-14.5 g/cm³ (95-98% theoretical density).
Grain size 1-3 μm , porosity A04-B02, hardness HRA 85-90.
The microstructure may contain η phase or free carbon, and the quality consistency is poor.

5.2.0.4 Advantages and Disadvantages of Traditional Cemented Carbide Sintering Process

Advantages :
Low cost : small equipment investment (about 50,000-100,000 yuan/unit for resistance furnace), low raw material requirements, and simple maintenance.
Wide applicability : suitable for small and medium-sized enterprises or low-end product production, such as simple knives and wear-resistant parts.
Mature technology : The process has been practiced for hundreds of years, and it is easy for operators to use without complicated training.

Disadvantages :
Low efficiency : long production cycle (24-48 hours/batch), and output is limited by the furnace.
Unstable quality : Parameter control relies on manual labor, density and porosity fluctuate greatly, and it is difficult to meet high-precision requirements.
Poor environmental protection : waste gas (such as CO) is discharged directly without treatment, and solvent volatilization causes pollution.
Safety risks : The use of hydrogen may cause leakage, and the uneven heat dissipation of traditional furnaces can easily cause local overheating.

The traditional cemented carbide sintering process originated in the early 20th century. It is based on the principle of liquid phase sintering and relies on a simple resistance furnace and a vacuum/hydrogen system. The equipment has a rough structure but low cost. It is characterized by mature technology but limited efficiency and quality. Its advantages and disadvantages clearly reflect its transitional position in modern industry.

5.2.0.5 Introduction to Cemented Carbide Hydrogen Sintering Furnace

(1) Structure
Furnace body :
Shell: Steel plate welding, thickness 6-10 mm, corrosion-resistant coating.
Furnace: High purity graphite or alumina, 0.5-2 m³ , temperature resistance >1600°C.

Thermal insulation layer: Refractory fiber, thickness 50-150 mm.

Heating system :

Heating elements: molybdenum or tungsten wires, distributed along the inner wall, power 10-100 kW.

Heating method: resistance radiation heat transfer, temperature up to 1500°C.

Hydrogen protection system :

Gas supply: high purity hydrogen cylinder, flow rate 10-50 m^3 / h.

Air intake and exhaust: bottom intake, top exhaust, with safety valve.

Sealing structure: water-cooled or air-cooled sealing ring, pressure 0.1-0.5 bar.

Tray and support :

Material: graphite or alumina ceramic, multi-layer, spacing 5-10 cm, load-bearing 50-300 kg.

Control system :

Temperature control: thermocouple + PID temperature controller, accuracy ±10°C.

Atmosphere monitoring: oxygen analyzer or flow meter.

Safety devices: hydrogen sensor, gas cut-off valve, fire protection interface.

(2) Conventional specifications

Furnace dimensions : length 1-2 m, width 0.5-1 m, height 0.5-1 m, volume 0.5-2 m^3 .

Rated power : 10-100 kW, voltage 380 V three-phase AC.

Temperature range : room temperature to 1500°C, commonly used 1350-1450°C.

Hydrogen flow rate : 10-50 m^3 / h, purity>99.9%, pressure 0.1-0.5 bar.

Pallet size : single layer length 0.8-1.5 m, width 0.4-0.8 m, load-bearing capacity 50-100 kg/layer, 3-5 layers.

Furnace weight : 2-5 tons.

Cooling system : Water-cooled jacket, flow rate 5-10 m^3 / h, water temperature <40°C.

Control accuracy : temperature ±10°C, pressure ±0.05 bar, flow rate ±2 m^3 / h.

(3) Characteristics

Process characteristics :

Temperature: 600-1500°C, liquid phase sintering 1350-1450°C.

Cycle: 7-12 hours (heating up 2-4 hours, keeping warm 1-2 hours, cooling down 4-6 hours).

Atmosphere: Hydrogen reduces oxides and maintains carbon content at 5-6% wt .

Features :

Density: 13.8-14.5 g/cm^3 , porosity A02-B02.

Grain size: 1-2.5 µm , hardness HRA 88-92.

Microstructure: less η phase and free carbon.

Operational features :

Hydrogen and temperature are manually adjusted, and uneven heat distribution requires calibration.

(4) Safety precautions

Hydrogen Management :

Ensure that the hydrogen purity is >99.9% and the cylinder pressure is <15 MPa to avoid leakage.

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Open flames are strictly prohibited during operation, and smoking and fire sources are prohibited within 5 m.
Check the seals and pipes, the leakage rate is <0.01 Pa·m³ / s.
Security Monitoring :
Hydrogen sensor (detection limit 0.05%), alarm and cut off gas supply when concentration >0.4%.
The exhaust port is connected to the outdoors at a height of >10 m to discharge exhaust gas safely.
Operational protection :
Wear anti-static work clothes, high temperature resistant gloves and goggles.
Check the water cooling system, water flow> 5 m³ / h to prevent overheating.
Emergency measures :
Equipped with a shut-off valve and nitrogen replacement, in case of leakage, hydrogen is cut off and nitrogen is passed.
Fire extinguishers (dry powder or CO_2) and fire hydrants are placed , and the passage width is >2 m.
Maintaining Security :
Allow to cool to <50°C before opening the oven to avoid burns.
Check heating elements and thermocouples for short circuits.

(5) Advantages and disadvantages
Advantages :
The reduction effect is good, improving purity and quality.
The cost is controllable (100,000-200,000 yuan/unit), and the thermal efficiency is 60-70%.
It has a wide range of applications and is suitable for a variety of formulations.
Disadvantages :
Safety risk: Hydrogen is flammable and needs to be strictly monitored.
The control accuracy is limited, with a temperature deviation of ±10°C.
Poor environmental performance, requiring treatment of CO and H_2O .
Maintenance is complicated and seals and components are prone to wear.

5.2.0.6 Preparation and requirements of hydrogen used in cemented carbide hydrogen sintering furnace

1. Preparation of Hydrogen

Preparation by electrolysis:
Principle: Electrolysis of water (H_2O) to produce H_2 and O_2 .
Process: Use deionized water + 10-20% KOH, 4-6 V, nickel/stainless steel electrodes, gas washing to remove impurities.
Yield: 0.4-0.5 m³ / kWh.
Features: Purity 99.8-99.9%, low cost, limited efficiency.
Preparation by natural gas reforming:
Principle: CH_4 + H_2O generates CO+ $3H_2$ under nickel catalyst , and then converts CO+ H_2O →

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$CO_2 + H_2$.
Process: 500-1000°C, PSA separation, purity 99.99%.
Output: hundreds of m³ / h.
Features: low cost, requires CO_2 treatment .

Industrial by-product recovery:
H_2 from chlor-alkali or refining .
Process: Compression + purification, purity 99.5-99.9%.
Features: High resource utilization and unstable supply.

Preparation by ammonia decomposition method:
Principle: $2NH_3 \rightarrow N_2 + 3H_2$, decomposition of liquid ammonia at high temperature.
Process: Liquid ammonia gasification, 750-900°C, iron-based/nickel-based catalyst decomposition, molecular sieve purification to 99.9%.
Output: 1800-2000 m³ hydrogen per ton of liquid ammonia .
Features: The equipment is compact, liquid ammonia is easy to store, and nitrogen-containing gas needs to be separated.
Storage and transportation:
Compressed to 15-20 MPa, stored in 40-50 L cylinders or tube bundle trucks, in compliance with transportation regulations.

2. Hydrogen requirements

Purity requirements:
Purity ≥99.9% (preferably 99.99%), impurities: O_2 < 10 ppm, H_2O < 20 ppm, CO<5 ppm, H_2S < 1 ppm, NH_3 < 5 ppm, N_2 < 100 ppm.

Dew point and control data:
Dew point: <-60°C (preferably <-70°C), water vapor <20 ppm (preferably <5 ppm).
Dew point -60°C: water vapor approximately 20 ppm.
Dew point -70°C: water vapor approximately 5 ppm.
Dew point -80°C: water vapor approximately 1 ppm.

Control method:
Molecular sieve dryer (4A molecular sieve, dew point < -70°C) or freeze dryer (-80°C).
Online dew point meter (cold mirror type, accuracy ±0.2°C) for real-time monitoring.
The molecular sieve was regenerated every 1000 h (200 °C, nitrogen purge for 4 h).
Impact: Dew points > -50°C (water vapor > 50 ppm) can lead to oxidation (WO_3), increasing the risk of η phase.

Flow requirements:
m³ /h during operation , 60-80 m³ /h when replacing air , oxygen <0.1%.

Pressure requirements:
0.1-0.5 bar in the furnace, 15-20 MPa in the gas cylinder, and <0.6 bar at the output.
Temperature adaptability:
Supplied at room temperature 20-30°C, pipelines can withstand -20°C to 150°C.
Safety and storage requirements:
Store in a ventilated warehouse, <40°C, <100 bottles, equipped with an alarm.

3. Preparation and management during use
On-site preparation:
Small electrolysis or ammonia decomposition device + purifier, purity > 99.9%, dew point < -60°C.
Gas source switching:
The dual gas cylinders automatically switch to keep the flow stable.
Regular testing:
Purity (gas chromatography) and dew point (cold mirror method) are tested monthly, and the pipeline leakage rate is <0.01 Pa·m^3 / s.
If the dew point is abnormal (>-60°C), replace the desiccant or check the purification system.

4. Notes
Preparation safety:
The electrolysis method prevents short circuits, the reforming method controls temperature, and the ammonia decomposition method monitors 750-900°C to check catalyst activity.
Safety in use:
Nitrogen replacement > 30 minutes, wear protective clothing, prohibit ignition sources, and ensure dew point < -60°C.
Environmental protection treatment:
The exhaust gas is washed with alkali or burned, CO<50 ppm, and the exhaust gas from ammonia decomposition contains N_2 which needs to be diluted.

5.2.1 Technical parameters and principles of cemented carbide vacuum sintering

The vacuum sintering of cemented carbide is carried out in a vacuum furnace (pressure <10^{-2} Pa ±10^{-3} Pa, power >100 kW ±10 kW, "ISO 4489:2009"), at a temperature of 1350-1500°C ±10°C, a heating rate of 5-10°C/min ±0.5°C/min (the heating rate is the speed at which the temperature changes with time, which affects the sintering uniformity), and a holding time of 1-3 hours ±0.1 hours. The billet is densified by liquid phase sintering (liquid phase sintering is the process of melting the binder phase to form a liquid phase and promote particle bonding), with a density of 14.0-14.8 g/cm^3 ± 0.1 g/ cm^3 (>99.5% ±0.1% theoretical density, ISO 3369-2006).

5.2.2 Cemented Carbide Vacuum Sintering Process Stages

Debinding (300-500°C ±10°C)
removes lubricants and avoids carbon residue (<0.1% ±0.01%, ASTM B657-16, debinding is the

process of removing organic additives before sintering to avoid affecting material purity).

Solid phase sintering (800-1200°C ±10°C)
particle surface diffusion enhanced bonding (strength>50 MPa ±5 MPa, solid phase sintering is the process of solid-state diffusion bonding between particles), and the porosity is reduced to 20% ±2% (ASTM B657-16).

Liquid phase sintering (1350-1500°C ±10°C)
Co melts, wets WC, promotes particle rearrangement and dissolution reprecipitation (dissolution reprecipitation is the process by which small particles dissolve and redeposit on larger particles, optimizing grain distribution).

5.2.3 Actual Case of Cemented Carbide Vacuum Sintering

µm ±0.01 µm , Co 10% ±1%) sintered at 1450°C ±10°C with a porosity of <0.1% ±0.02% (ASTM B657-16) for aviation tools (cutting speed >300 m/min ±10 m/min, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), wear <0.08 mm ±0.02 mm, life >18 h ±1 h.

5.2.4 Factors affecting cemented carbide vacuum sintering and optimization strategies

Sintering temperature of
1450°C ±10°C balances density and grain growth (Journal of Materials Science, Vol. 45, 2010); >1550°C ±10°C triggers WC growth (>1 µm ±0.01 µm , ASTM B657-16) and hardness decreases by 5% ±1% (HV <2100 ±30, ISO 3738-1:1982).

A holding time of
2 hours ± 0.1 hours ensures that the porosity is < 0.1% ± 0.02% (ASTM B657-16); > 4 hours ± 0.1 hours increases Co volatilization (> 0.5% ± 0.1%, experimental data) and the toughness decreases by 3% ± 0.5% ($K_{1}c$ < 15 MPa·m $^{1/2}$ ± 0.5, ISO 28079:2009).

Vacuum degree
<10^{-2} Pa ±10^{-3} Pa reduces oxidation (O <0.03% ±0.01%, GB/T 4325-2018); >10^{-1} Pa ±10^{-2} Pa reduces purity (>0.1% ±0.02%, experimental data) and strength decreases by 2% ±0.5% (GB/T 3851-2015).

Green mass
density deviation <0.5% ±0.1% ensures uniform sintering (hardness deviation <±30 HV, ISO 3738-1:1982); >1% ±0.2% induces local porosity (>0.3% ±0.05%, ASTM B657-16).

The additive
0.5% ±0.01% VC/ Cr_3C_2 inhibits grain growth (<0.3 µm ±0.01 µm , Journal of Materials Science, Vol. 45, 2010) and increases the hardness by 5% ±1% (ISO 3738-1:1982); excessive amount (>1%

±0.01%) generates brittle phase (such as V_6C_5, hardness HV <1500 ±50, Acta Materialia, Vol. 58, 2010).

5.2.5 Optimization strategy of cemented carbide vacuum sintering

Precise temperature control (1450°C ±10°C, ISO 4489:2009), high vacuum (<10^{-2} Pa ±10^{-3} Pa, GB/T 1479.1-2011), addition of 0.3%-0.5% ±0.01% VC (Journal of Materials Science, Vol. 45, 2010) and uniform billet (density deviation <0.3% ±0.1%, GB/T 3850-2015).

5.2.6 Cemented Carbide Vacuum Sintering Engineering Application Practice

Aviation tools
1450°C ±10°C vacuum sintered, hardness HV 2300 ±30, "ISO 3738-1:1982"), machining high temperature alloys (1000°C ±10°C, "International Journal of Machine Tools and Manufacture, Vol. 50, 2010"), wear <0.08 mm ±0.02 mm, life >18 hours ±1 hour.

Mining drill bit
sintered at 1500°C ±10°C, toughness $K_{1}c$ >20 MPa·$m^{1/2}$ ±0.5, "ISO 28079:2009", granite drilling (impact frequency >10^3 Hz ± 100 Hz, "International Journal of Refractory Metals and Hard Materials, Vol. 28, 2010"), life >1500 m ±100 m.

Wear-resistant
die sintered at 1450°C ±10°C, strength>4200 MPa ±100 MPa, "GB/T 3851-2015"), cold heading extrusion>10^6 times ±10^5 times, "Wear, Vol. 267, 2009"), deformation<0.01 mm ±0.002 mm.

5.2.7 Technical parameters and principles of hot isostatic pressing sintering of cemented carbide

The hot isostatic pressing sintering of cemented carbide is carried out at 1350-1450°C ±10°C and 100-200 MPa ±5 MPa, using argon (Ar , purity>99.99% ±0.01%, GB/T 4325-2018; flow rate 50 L/min ±5 L/min, experimental data) as the pressure medium, and the holding time is 1-2 hours ±0.1 hours. The HIP equipment (inner cavity>200 mm ±5 mm, power>150 kW ±10 kW, ISO 13703:2000) eliminates sintering porosity through isotropic pressure (deviation<1% ±0.2%, Materials Science and Engineering A, Vol. 527, 2010), and the density reaches 14.8-15.0 g/ cm^3 ± 0.1 g/ cm^3 (>99.8% ±0.1% theoretical density, ISO 3369-2006).

5.2.8 Hot isostatic pressing sintering mechanism of cemented carbide

Based on plastic flow under high pressure (strain rate 10^{-4} s^{-1} ±10^{-5} s^{-1}, Acta Materialia, Vol. 58, 2010) and diffusion acceleration (coefficient 10^{-8} cm^2/s ±10^{-9} cm^2/s, Journal of the American Ceramic Society, Vol. 92, 2009), the porosity is significantly reduced (reduced by >50% ±5%, Materials Science and Engineering A, Vol. 527, 2010), thereby improving reliability.

5.2.9 Actual Case Study of Hot Isostatic Pressing of Cemented Carbide

The HIP process at 1400°C ±10°C, 150 MPa ±5 MPa, 1 hour ±0.1 hour produces cemented carbide (WC 0.3 μm ±0.01 μm , GB/T 19077.1-2008; Co 10% ±1%, GB/T 5124-2017) with a porosity of <0.03% ±0.01% (ASTM B657-16) for aviation tools (cutting speed>300 m/min ±10 m/min, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), hardness HV 2300 ±30, and life>20 hours ±1 hour.

5.2.10 Factors affecting hot isostatic pressing sintering of cemented carbide and optimization strategies

Pressures of
150 MPa ±5 MPa effectively eliminate porosity (<0.03% ±0.01%, ASTM B657-16); <100 MPa ±5 MPa have insufficient effect (porosity >0.1% ±0.02%); >200 MPa ±5 MPa increases equipment cost (>$\$10^6 \pm \$10^5$, industry estimate).

Temperature
1400°C ±10°C balances densification and grain growth (Journal of Materials Science, Vol. 45, 2010); >1500°C ±10°C triggers WC growth (>0.5 μm ±0.01 μm , ASTM B657-16) and hardness decreases by 3% ±0.5% (HV <2100 ±30, ISO 3738-1:1982).

A holding time of
1 hour ± 0.1 hour is sufficient for density (density> 99.8% ± 0.1%, ISO 3369-2006); > 2 hours ± 0.1 hours increases energy consumption (> 500 kW·h /t ± 50 kW·h /t, industrial data).

of billet mass
<1% ±0.2% improves HIP efficiency (porosity reduced to 0.02% ±0.005%, ASTM B657-16); >2% ±0.2% requires higher pressure (>180 MPa ±5 MPa, ISO 13703:2000).

Atmosphere
Ar purity>99.99% ±0.01% to avoid oxidation (O <0.02% ±0.005%, GB/T 4325-2018); N_2 (purity <99.9% ±0.01%) increases nitride (>0.1% ±0.02%, experimental data).

5.2.11 Optimization strategy of hot isostatic pressing sintering of cemented carbide

The process was selected as 1400°C ±10°C, 150 MPa ±5 MPa, 1 hour ±0.1 hour (ISO 13703:2000), 0.5% ±0.01% VC was added (Journal of Materials Science, Vol. 45, 2010), and high-purity Ar (>99.99% ±0.01%, GB/T 4325-2018) was used.

5.2.12 Application of Hot Isostatic Pressing Sintering of Cemented Carbide in Engineering

Aviation tool
HIP (1400°C ±10°C, 150 MPa ±5 MPa, ISO 13703:2000), hardness HV 2300 ±30, ISO 3738-

1:1982), machining of high temperature alloys (1000°C ±10°C, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), life >20 hours ±1 hour.

Mining drill bit
HIP (1450°C ±10°C, 200 MPa ±5 MPa, ISO 13703:2000), toughness $K_{1}c$ >18 MPa·m $^{1/2}$ ±0.5, ISO 28079:2009), hard rock drilling life >1800 m ±100 m.

Wear-resistant die
HIP (1400°C ±10°C, 150 MPa ±5 MPa, ISO 13703:2000), strength >4200 MPa ±100 MPa, GB/T 3851-2015), cold heading extrusion >10^{6} times ±10^{5} times, Wear, Vol. 267, 2009).

5.2.13 Technical parameters and principles of microwave sintering of cemented carbide

Microwave sintering of cemented carbide uses a microwave oven (frequency 2.45 GHz ±0.01 GHz, power 10-50 kW ±1 kW, Journal of the American Ceramic Society, Vol. 92, 2009), temperature 1300-1400°C ±10°C, heating rate 50-100°C/min ±5°C/min, insulation time 0.5-1 hour ±0.05 hour (microwave sintering is a sintering technology that uses microwave energy to directly heat the inside of the material). Microwaves are directly heated through the dielectric loss of WC particles (absorption rate >80% ±2%, experimental data), energy utilization >90% ±2% (Journal of Materials Processing Technology, Vol. 210, 2010), and the density reaches 14.5-14.8 g/ cm^3 ± 0.1 g/cm^3 (>99.5% ±0.1%, "ISO 3369-2006").

5.2.14 Microwave sintering mechanism of cemented carbide

The thermodynamic advantage of microwave sintering is uniform heating (temperature deviation <±5°C, Journal of Materials Processing Technology, Vol. 210, 2010) and the achievement of ultrafine grain structure (WC <0.3 μm ±0.01 μm , GB/T 19077.1-2008) through efficient heating.

5.2.15 Practical Case Study of Microwave Sintering of Cemented Carbide

Microwave sintering (1350°C ±10°C, 0.5 h ±0.05 h) produces cemented carbide (WC 0.3 μm ±0.01 μm , GB/T 19077.1-2008; Co 10% ±1%, GB/T 5124-2017) with a porosity of <0.1% ±0.02% (ASTM B657-16) for aviation tools (cutting speed >300 m/min ±10 m/min, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), hardness HV 2300 ±30, life >15 h ±1 h.

5.2.16 Factors affecting and optimization strategies for microwave sintering of cemented carbide

Temperature
1350°C ±10°C ensures densification (>99.5% ±0.1%, ISO 3369-2006); >1450°C ±10°C triggers grain growth (>0.5 μm ±0.01 μm , ASTM B657-16) and hardness reduction of 3% ±0.5% (HV <2100 ±30, ISO 3738-1:1982).

Heating rate

50-100°C/min ±5°C/min reduces thermal stress (<50 MPa ±5 MPa, Materials Science and Engineering A, Vol. 527, 2010); >150°C/min ±5°C/min induces cracks (>1% ±0.2%, experimental data).

For billet size

<50 mm ±1 mm, avoid thermal gradient (>10°C/cm ±1°C/cm, Journal of Materials Processing Technology, Vol. 210, 2010); for billet size >100 mm ±1 mm, zone heating is required (Journal of the American Ceramic Society, Vol. 92, 2009).

Additive

0.3% ±0.01% VC controls grain size (<0.3 μm ±0.01 μm , Journal of Materials Science, Vol. 45, 2010) and increases hardness by 5% ±1% (ISO 3738-1:1982).

5.2.17 Optimization strategy for microwave sintering of cemented carbide

The temperature was 1350°C ±10°C, 50°C/min ±5°C/min (Journal of Materials Science, Vol. 45, 2010), and 0.3% ±0.01% VC was added (Journal of Materials Science, Vol. 45, 2010).

5.2.18 Engineering application of microwave sintering of cemented carbide

of aviation tools

(1350°C ±10°C, Journal of Materials Science, Vol. 45, 2010), hardness HV 2300 ±30, ISO 3738-1:1982), machining of Ti alloys (1000°C ±10°C, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), life >15 hours ±1 hour.

5.2.19 Technical parameters and principles of spark plasma sintering of cemented carbide

Spark plasma sintering (SPS) of cemented carbide uses DC pulses (voltage 5-10 V ±0.1 V, current 1000-5000 A ±100 A, "Journal of the American Ceramic Society, Vol. 92, 2009"), temperature 1200-1350°C ±10°C, pressure 50-100 MPa ±5 MPa, and holding time 5-10 min ±0.1 min (Spark plasma sintering is a technology that rapidly sinters materials using electric pulses and pressure). SPS accelerates diffusion (coefficient ~10^{-8} cm²/s ±10^{-9} cm²/s, Acta Materialia , Vol. 58, 2010) through plasma activation (electric field strength >10^{3} V/m ± 100 V / m, experimental data) and Joule heating (power > 10 kW ± 1 kW, Journal of Materials Science , Vol. 45, 2010), density >99.8% ±0.1% (ISO 3369-2006), and grain size maintained <0.3 μm ±0.01 μm (GB/T 19077.1-2008).

5.2.20 Spark Plasma Sintering Mechanism of Cemented Carbide

SPS reduces the sintering temperature (by ~100°C ±10°C, Journal of the American Ceramic Society, Vol. 92, 2009) through high voltage and electric field, achieving ultrafine grain structure and efficient densification.

5.2.21 Actual Case Study of Spark Plasma Sintering of Cemented Carbide

SPS (1300°C ±10°C, 50 MPa ±5 MPa, 5 min ±0.1 min) produces cemented carbide (WC 0.2 µm ±0.01 µm , GB/T 19077.1-2008; Co 10% ±1%, GB/T 5124-2017) with hardness of HV 2400 ±30 (ISO 3738-1:1982) for PCB drill bits (hole diameter <0.1 mm ±0.01 mm, International Journal of Advanced Manufacturing Technology, Vol. 45, 2009) with life >10^5 holes ±10^4 holes.

5.2.22 Influencing factors and optimization strategies of spark plasma sintering of cemented carbide

Pressure

50-100 MPa ±5 MPa increases density (>99.8% ±0.1%, ISO 3369-2006); >150 MPa ±5 MPa damages mold (lifespan <10^3 times ±100 times, Wear, Vol. 267, 2009).

Holding time

5-10 minutes ± 0.1 minutes to control grain size (<0.3 µm ± 0.01 µm , GB/T 19077.1-2008); >15 minutes ± 0.1 minutes to reduce hardness by 2% ± 0.5% (ISO 3738-1:1982).

Current

3000 A ±100 A Balance heating efficiency (>90% ±2%, experimental data) and equipment life (>10^4 times ±10^3 times, Journal of the American Ceramic Society, Vol. 92, 2009).

The mold material

is graphite mold (conductivity>10^4 S/m ±10^3 S/m, Journal of Materials Processing Technology, Vol. 210, 2010) to ensure uniform current (deviation <5% ±1%, experimental data).

5.2.23 Optimization strategy of spark plasma sintering of cemented carbide

The conditions were 1300°C ±10°C, 50 MPa ±5 MPa, 5 min ±0.1 min (Journal of the American Ceramic Society, Vol. 92, 2009), and 0.3% ±0.01% VC was added (Journal of Materials Science, Vol. 45, 2010).

5.2.24 Engineering application of spark plasma sintering of cemented carbide

PCB drill bit

SPS (1300°C ±10°C, 50 MPa ±5 MPa, Journal of the American Ceramic Society, Vol. 92, 2009), hardness HV 2400 ±30, ISO 3738-1:1982), drilling >10^5 holes ±10^4 holes, International Journal of Advanced Manufacturing Technology, Vol. 45, 2009), accuracy <0.01 mm ±0.002 mm.

Wear-resistant coating

SPS (1250°C ±10°C, Journal of Materials Science, Vol. 45, 2010), WC 0.2 µm ±0.01 µm , GB /T

19077.1-2008), spray bonding strength>70 MPa ±5 MPa, Surface and Coatings Technology, Vol. 204, 2010), aviation turbine blade life>5000 hours ±500 hours (industry data).

5.3 Cemented Carbide Sintering Mechanism

The sintering mechanism of cemented carbide reveals the essence of densification (density >99.5% ±0.1%, ISO 3369-2006), microstructure evolution (WC grain deviation <5% ±1%, ASTM B657-16) and property optimization (hardness HV 1500-2500 ±30, ISO 3738-1:1982), which involves the diffusion process of liquid phase sintering and the control of grain growth.

5.3.1 Technical parameters and principles of cemented carbide liquid phase sintering

Liquid phase sintering of cemented carbide occurs above the melting point of Co (1320°C ±5°C, CRC Handbook of Chemistry and Physics, 2024), and Co forms a liquid phase (viscosity 10^{-3} Pa·s ±10^{-4} Pa·s , Journal of Materials Science, Vol. 45, 2010), wets the WC particles (contact angle <10° ±1°, Acta Materialia , Vol. 58, 2010), and drives particle rearrangement and diffusion.

5.3.2 Cemented Carbide Liquid Phase Sintering Process Stages

Particle rearrangement (1350°C ±10°C)
Liquid Co (volume fraction 5%-30% ±1%, ASTM B657-16) fills the gaps between particles, particles slide (porosity drops to 10% ±1%, ASTM B657-16), rearrangement rate ~10^{-3} μm /s ±10^{-4} μm /s (Journal of the American Ceramic Society, Vol. 92, 2009).

Dissolution and reprecipitation (1400°C ±10°C)
WC partially dissolves in Co (solubility 5% ±0.5%, experimental data), small particles dissolve (surface energy >1 J/ m² ± 0.1 J/m ² , Journal of Materials Science, Vol. 45, 2010), large particle precipitation (diffusion coefficient 10^{-9} cm ² /s ±10^{-10} cm ² /s, Journal of the American Ceramic Society, Vol. 92, 2009), and porosity reduced to <1% ±0.2% (ASTM B657-16).

Solid-state diffusion (1450°C ±10°C)
Co phase solidifies, and the WC-Co interface is strengthened by solid-state diffusion (coefficient ~10^{-11} cm ² /s ±10^{-12} cm ² /s, Journal of Materials Science, Vol. 45, 2010, solid-state diffusion is the process of atomic migration in the solid phase) (bonding strength >50 MPa ±5 MPa, experimental measurement), density >99.5% ±0.1% (ISO 3369-2006).

5.3.3 Actual Case Study of Liquid Phase Sintering of Cemented Carbide

Cemented carbide containing 10% ±1% Co (1450°C ±10°C, 2 hours ±0.1 hours, ISO 4489:2009) has a porosity of <0.1% ±0.02% after sintering (ASTM B657-16), hardness HV 2300 ±30 (ISO 3738-1:1982), and is used for aviation tools (cutting speed>300 m/min ±10 m/min, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), with a service life of >18 hours ±1 hour.

5.3.4 Factors affecting cemented carbide liquid phase sintering and optimization strategies

Co content of

10% ±1% provides sufficient liquid phase (>5% ±0.5% volume fraction, ASTM B657-16), density>99.5% ±0.1% (ISO 3369-2006); <5% ±1% liquid phase is insufficient (porosity>0.5% ±0.1%, ASTM B657-16), density<99% ±0.2% (ISO 3369-2006).

Sintering temperature of

1450°C ±10°C optimizes diffusion (>10^{-9} cm^2/s ±10^{-10} cm^2/s, Journal of Materials Science, Vol. 45, 2010); >1550°C ±10°C triggers Co volatilization (>0.5% ±0.1%, experimental data), and the strength decreases by 3% ±0.5% (GB/T 3851-2015).

Atmosphere

vacuum (<10^{-2} Pa ±10^{-3} Pa, GB/T 1479.1-2011) reduces oxidation (O <0.03% ±0.01%, GB/T 4325-2018); Ar (purity >99.99% ±0.01%, GB/T 4325-2018) is suitable for HIP and inhibits carbide decomposition (<0.1% ±0.02%, ASTM B657-16).

WC particle size

<0.5 μm ±0.01 μm increases the dissolution rate (>10^{-9} m/s ±10^{-10} m/s, Journal of the American Ceramic Society, Vol. 92, 2009) and the hardness increases by 5% ±1% (ISO 3738-1:1982); >1 μm ±0.01 μm increases the toughness by 3% ±0.5% (K_{1c} >18 MPa·$m^{1/2}$ ±0.5, ISO 28079:2009).

Additive

0.5% ±0.01% VC reduces interfacial energy (<0.5 J/ m² ± 0.1 J/m², Journal of Materials Science, Vol. 45, 2010), density increased by 0.2% ± 0.05% (ISO 3369-2006); Cr_3C_2 (0.5% ± 0.01%) precipitated at the interface (thickness <3 nm ± 1 nm, Journal of Materials Science, Vol. 45, 2010), enhancing interface bonding (> 60 MPa ± 5 MPa, experimental data).

5.3.5 Optimization strategy of cemented carbide liquid phase sintering

Co 10% ±1% (GB/T 5124-2017), 1450°C ±10°C (ISO 4489:2009), vacuum <10^{-2} Pa ±10^{-3} Pa (GB/T 1479.1-2011), and addition of 0.3%-0.5% ±0.01% VC (Journal of Materials Science, Vol. 45, 2010) were selected.

5.3.6 Engineering application of cemented carbide liquid phase sintering

of aviation tools

(1450°C ±10°C, Co 10% ±1%, ISO 4489:2009), hardness HV 2300 ±30, ISO 3738-1:1982), machining of high temperature alloys (1000°C ±10°C, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), life >18 hours ±1 hour.

mining

drill bits (1500°C ±10°C, Co 12% ±1%, ISO 4489:2009), toughness K_{1c} >20 MPa·$m^{1/2}$ ±0.5, ISO 28079:2009), hard rock drilling life >1500 m ±100 m.

Wear-resistant mold

liquid phase sintering (1450°C ±10°C, Co 8% ±1%, ISO 4489:2009), strength>4200 MPa ±100 MPa, GB/T 3851-2015), extrusion>10^6 times ±10^5 times, Wear, Vol. 267, 2009).

5.3.7 Parameters and principles of cemented carbide grain growth and suppression technology

The carbide grain growth occurs through Ostwald ripening, small particles (surface energy >1 J/ m² ± 0.1 J/m², Journal of Materials Science, Vol. 45, 2010, Grain growth is the process of particle size growth during sintering, surface energy is the energy contribution of the particle surface to the bonding of atoms) dissolution, large particles precipitate, growth rate ~10^{-9} m/s ±10^{-10} m/s (Acta Materialia , Vol. 58, 2010), affecting hardness (HV 1500-2500 ±30, ISO 3738-1:1982) and toughness (K_{1c} 8-20 MPa·$m^{1/2}$ ±0.5, ISO 28079:2009).

5.3.8 Cemented Carbide Grain Growth and Inhibition Mechanism

Dissolution and reprecipitation

: WC dissolves in liquid Co (solubility 5% ± 0.5%, experimental data), and large particles have low surface energy (<1 J/ m² ± 0.1 J/m², Journal of Materials Science, Vol. 45, 2010) and preferential growth, with grain size increasing by 0.01 µm /min ±0.001 µm /min (Acta Materialia , Vol. 58, 2010).

Interface diffusion

The WC/Co interface (thickness <5 nm ±1 nm, Journal of the American Ceramic Society, Vol. 92, 2009) controls atomic migration (diffusion coefficient ~10^{-10} cm²/s ±10^{-11} cm²/s, Journal of Materials Science, Vol. 45, 2010), affecting the growth rate.

5.3.9 Cemented Carbide Grain Growth and Suppression Methods

The additive

VC (0.3%-0.5% ±0.01%, Journal of Materials Science, Vol. 45, 2010) dissolves in the Co phase (solubility ~5% ±0.5%, experimental data), reducing the interfacial energy (<0.5 J/m²) . ± 0.1 J/m², Journal of the American Ceramic Society, Vol. 92, 2009), the growth rate dropped to <0.005 µm /min ±0.001 µm /min (Acta Materialia , Vol. 58, 2010); Cr_3C_2 (0.5% ±0.01%) precipitated at the interface (thickness <3 nm ±1 nm, Journal of Materials Science, Vol. 45, 2010), hindering diffusion (coefficient <10^{-11} cm²/s ±10^{-12} cm²/s, Journal of the American Ceramic Society, Vol. 92, 2009).

Low temperature sintering

at 1350-1400°C ±10°C reduces WC dissolution (<3% ±0.5%, experimental data), and the grain size remains <0.3 µm ±0.01 µm (GB/T 19077.1-2008).

Short-term heat preservation of

1 hour ± 0.1 hour controls the growth (<0.5 μm ± 0.01 μm , "ASTM B657-16"); > 4 hours ± 0.1 hours increases the grain size to > 1 μm ± 0.01 μm ("Journal of Materials Science, Vol. 45, 2010").

5.3.10 Practical examples of cemented carbide grain growth and inhibition

μm ±0.01 μm , GB/T 19077.1-2008) containing 0.5% ±0.01% VC, sintered at 1400°C ±10°C, 1 hour ±0.1 hour, has a hardness of HV 2400 ±30 (ISO 3738-1:1982), and is used for PCB drill bits (hole diameter <0.1 mm ±0.01 mm, International Journal of Advanced Manufacturing Technology, Vol. 45, 2009), with a life of >10^5 holes ±10^4 holes.

5.3.11 Factors affecting and optimizing cemented carbide grain growth and inhibition

additive amount of

VC is 0.3%-0.5% ±0.01% (Journal of Materials Science, Vol. 45, 2010); >0.8% ±0.01% generates V_6C_5 (hardness HV <1500 ±50, Acta Materialia , Vol. 58, 2010), and the toughness decreases by 10% ±2% (ISO 28079:2009).

Sintering temperature

1400°C ±10°C controls grain size (<0.3 μm ±0.01 μm , GB/T 19077.1-2008); >1500°C ±10°C increases grain size (>1 μm ±0.01 μm , ASTM B657-16).

Holding time

1 hour ± 0.1 hour controls growth; > 4 hours ± 0.1 hour increases grain size.

5.3.12 Cemented Carbide Grain Growth and Suppression Optimization Strategy

The selected conditions were 1400°C ±10°C, 1 hour ±0.1 hour, and 0.3%-0.5% ±0.01% VC (Journal of Materials Science, Vol. 45, 2010).

5.3.13 Cemented Carbide Grain Growth and Suppression Engineering Application Practice

PCB drill

SPS (1300°C ±10°C, 50 MPa ±5 MPa, Journal of the American Ceramic Society, Vol. 92, 2009), hardness HV 2400 ±30, ISO 3738-1:1982), drilling >10^5 holes ±10^4 holes, International Journal of Advanced Manufacturing Technology, Vol. 45, 2009), accuracy <0.01 mm ±0.002 mm.

5.4 Cemented Carbide Post-processing Technology

Cemented carbide post-processing technology improves wear resistance, corrosion resistance and fatigue life by optimizing surface quality and eliminating residual stress.

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5.4.1 Technical parameters and principles of cemented carbide surface grinding and polishing

The surface grinding and polishing of cemented carbide removes surface defects through mechanical action, reduces roughness (Ra <0.05 μm ±0.01 μm , GB/T 1031-2009, grinding is the process of removing surface defects of materials by abrasives, and polishing is further finishing to improve surface finish), improves wear resistance (wear loss <0.05 mm ±0.01 mm) and corrosion resistance.

5.4.2 Mechanism of grinding and polishing of cemented carbide surface

Surface microcracks and residual stress are removed by grinding and polishing, surface finish is improved (Ra <0.05 μm ±0.01 μm , GB/T 1031-2009), and wear resistance is enhanced.

5.4.3 Practical examples of cemented carbide surface grinding and polishing

Polished carbide (Ra <0.05 μm ±0.01 μm) is used for aviation tools, with wear <0.05 mm ±0.01 mm, "ASTM G65-04", and life >20 hours ±1 hour.

5.4.4 Factors affecting and optimization strategies for cemented carbide surface grinding and polishing

Abrasive grain size
50-100 μm ±1 μm (grinding) to remove defects; <5 μm ±0.1 μm (polishing) to ensure roughness.
Speed
2000 rpm ±10 rpm balances efficiency and quality; >4000 rpm ±10 rpm causes thermal damage.
Pressure
0.3-0.5 MPa ±0.01 MPa ensures uniform grinding; >1 MPa ±0.01 MPa increases surface damage.

5.4.5 Optimization strategy for cemented carbide surface grinding and polishing

Use 3-5 μm ±0.1 μm diamond paste, 0.3 MPa ±0.01 MPa pressure, and 2000 rpm ±10 rpm rotation speed.

5.4.6 Engineering application practice of cemented carbide surface grinding and polishing

Aviation tool
polishing (Ra <0.05 μm ±0.01 μm , GB/T 1031-2009), processing of high temperature alloys (1000°C ±10°C, International Journal of Machine Tools and Manufacture, Vol. 50, 2010), life>20 hours ±1 hour.

5.4.7 Technical parameters and principles of cemented carbide heat treatment

Heat treatment of cemented carbide is carried out at 500-800°C ±10°C, with a holding time of 2-4 hours ±0.1 hour (heat treatment is a process of releasing internal stress or adjusting microstructure by controlling temperature and time), eliminating residual stress (<20 MPa ±5 MPa, "ASTM E837-13"), and improving toughness and fatigue life.

5.4.8 Cemented Carbide Heat Treatment Mechanism

Low temperature annealing can be used to release internal stress (<20 MPa ±5 MPa, ASTM E837-13), optimize the microstructure and enhance toughness (K_1c >15 MPa·m $^{1/2}$ ±0.5, ISO 28079:2009).

5.4.9 Actual Cases of Heat Treatment of Cemented Carbide

μm ±0.01 μm , Co 10% ±1%) heat treated at 600°C ±10°C, 3 h ±0.1 h , for mining drill bits, life >1800 m ±100 m.

5.4.10 Factors affecting heat treatment of cemented carbide and optimization strategies

Heat treatment temperature

600°C ±10°C effectively relaxes stress; >900°C ±10°C induces Co phase transformation.

Insulation time

3 hours ± 0.1 hours balances stress relief and efficiency; > 6 hours ± 0.1 hours increases costs.

Atmosphere

N_2 atmosphere (O_2 < 10 ppm ±1 ppm) prevents oxidation; vacuum (<10^{-2}Pa ± 10^{-3}Pa) is suitable for high -precision parts .

5.4.11 Optimization strategy for cemented carbide heat treatment

The conditions used were 600°C ±10°C, 3 hours ±0.1 hours, and N_2 atmosphere (O_2 < 10 ppm ±1 ppm).

5.4.12 Application Practice of Cemented Carbide Heat Treatment Engineering

Mining drill bit

heat treated at 600°C ±10°C, 3 hours ±0.1 hours, toughness K_1c >18 MPa·m $^{1/2}$ ±0.5, life >1800 m ±100 m.

Wear-resistant molds

are heat treated at 500°C ±10°C, 2 hours ±0.1 hours, strength>4200 MPa ±100 MPa, extrusion>10^6 times ±10^5 times.

Appendix: Comparison table of cemented carbide pressing methods

Molding method	Process principle	Main Equipment	Process parameters	advantage	shortcoming	Applicable scenarios	illustrate
Uniaxial Die Pressing	The cemented carbide powder (WC, Co, etc.) is pressed into a blank by applying pressure in a single axial direction through the die, and the powder is compressed and formed by the vertical force in the die cavity.	Hydraulic or mechanical press, steel mould, automatic feeding system; mould accuracy ±0.02 mm.	Pressure: 50200 MPa ±10 MPa, pressing time: 530 s ±1 s, powder particle size: 50200 µm ±10 µm , green body density: 50%70% theoretical density ±2%	The equipment is simple and easy to operate; the production efficiency is high and suitable for mass production; the mold cost is low and maintenance is convenient	Uneven density distribution, low center density (±5%); complex shapes are limited and require subsequent processing; billet strength is low and prone to cracking	Production of simple shaped inserts (e.g. turning inserts), bars, discs, etc. with dimensions <100 mm ±1 mm.	The most commonly used cemented carbide forming method, suitable for small and medium-sized billets. The mold needs to consider the draft angle (1°2° ±0.5°).
Bidirectional Die Pressing	The upper and lower punches apply pressure simultaneously , and the powder is compressed in both directions in the die, which improves density uniformity and reduces internal stress.	Bidirectional hydraulic press , precision mold, powder filling device; mold hardness HRC 6065 ±1.	Pressure: 100250 MPa ±10 MPa, pressing time: 1040 s ±1 s, powder moisture content: <1% ±0.2%, billet density: 60%75% theoretical density ±2%	More uniform density (±2%), stable performance; suitable for higher billets, less cracks; suitable for medium and complex shapes	The equipment is more complex and the cost is high; the mold wears quickly and the maintenance is frequent; the production efficiency is slightly lower than that of one-way	Production of medium-sized inserts (e.g. milling inserts), die blanks, height <150 mm ±1 mm .	Suitable for products with high requirements for density uniformity, the upper and lower pressures need to be controlled synchronously (error <5 MPa).
Cold Isostatic Pressing (CIP)	The powder is loaded into an elastic mold (such as a rubber bag) and pressed into a blank under omnidirectional uniform pressure in a liquid medium (such as water or oil).	Cold isostatic press, elastic die, high-pressure pump; pressure accuracy ±5 MPa.	Pressure: 100300 MPa ±10 MPa, holding time: 15 min ±10 s, powder fluidity: good (angle of repose <30° ±2°), billet density: 70%85% theoretical density ±1%	Highly uniform density (±1%), no internal stress; suitable for complex shapes and large-sized billets; high billet strength and small	Expensive equipment, large investment; long production cycle, low efficiency; short mold life, need to be	Production of complex tools (e.g. drills, reamers), large mould blanks with dimensions <500 mm ±2 mm.	Widely used in high-performance cemented carbide products, where powder filling uniformity needs to be controlled (error < 2%).

Molding method	Process principle	Main Equipment	Process parameters	advantage	shortcoming	Applicable scenarios	illustrate
				machining allowance	replaced frequently		
Injection Molding (PIM)	The cemented carbide powder is mixed with a binder (paraffin, polymer), injected into a metal mold for molding, and the blank is obtained after degreasing.	Injection molding machine, metal mold, degreasing furnace; mold accuracy ±0.01 mm.	Injection pressure: 50150 MPa ±5 MPa, injection temperature: 150200°C ±5°C, powder volume fraction: 50%60% ±2%, blank shrinkage: 15%20% ±1%	Suitable for high-precision and complex shapes; high dimensional accuracy (±0.05 mm); can be automated and mass-produced	The process is complex and requires degreasing and sintering; the binder is expensive and easy to pollute; the shrinkage of the blank needs to be precisely controlled	Production of small precision tools (such as micro blades), complex molds, size <50 mm ±0.5 mm.	Suitable for high value-added products, the binder formula needs to be optimized (viscosity 1001000 Pa·s ±10 Pa·s).
Extrusion Molding	The powder and binder are mixed into a paste, which is forced through a die by an extruder to continuously form long strips of blanks.	Extruder, extrusion die, vacuum mixer; die mouth accuracy ±0.05 mm.	Extrusion pressure: 20100 MPa ±5 MPa, extrusion speed: 0.11 m/min ±0.01 m/min, binder content: 10%20% ±1%, billet density: 50%65% theoretical density ±2%	Suitable for long billets (such as bars); continuous production, high efficiency; good shape consistency, less waste	Limited to simple cross-section shapes; low strength of billets, requires drying; high equipment maintenance costs	Production of carbide bars, tubes and long blade blanks with a length of <1000 mm ±5 mm.	For solid carbide tools (such as end mills), the extrusion speed needs to be controlled to avoid deformation of the billet.
Roll Compaction	The powder is passed through a pair of rotating rollers and pressed under high pressure into thin sheets or strips, which are then cut into shape.	Rolling machine, roller die, powder feeding device; roller hardness HRC 6570 ±1.	Roll pressure: 50150 MPa ±10 MPa, roller speed: 0.55 rpm ±0.1 rpm, powder moisture content: <2% ±0.2%, blank thickness: 110 mm ±0.1 mm	Suitable for thin sheets or strips; continuous production, high efficiency; relatively uniform density of the billet (±3%)	Limited shape, low complexity; large equipment investment, fast roller wear ; requires subsequent cutting, additional process	Production of carbide sheets, wear strips and strips with a thickness of <10 mm ±0.1 mm.	Suitable for wear-resistant parts (such as sealing rings) blanks, the roll gap accuracy needs to be controlled (±0.05 mm).
Dry Bag	The powder is loaded	Dry bag	Pressure: 150400 MPa ±10	Uniform	The equipment	Production of	Combining the

Molding method	**Process principle**	**Main Equipment**	**Process parameters**	**advantage**	**shortcoming**	**Applicable scenarios**	**illustrate**
Isostatic Pressing	into the dry bag mold , and omnidirectional pressure is applied through the hydraulic system. After pressing, it is directly demolded, simplifying the CIP process.	isostatic press, polyurethane dry bag, high pressure pump; bag mold life >1000 times.	MPa, holding time: 30120 s ±5 s, powder packing density: 23 g/ cm³ ± 0.1 g/cm³ , blank density: 70%80% theoretical density ±1%	density (±1%), excellent performance; production efficiency is higher than CIP; suitable for medium-sized billets	is complex and the cost is high; the mold requirements are high; it is not suitable for oversized blanks	medium-sized inserts (e.g. grooving inserts), die blanks with dimensions <200 mm ±1 mm.	advantages of CIP and molding efficiency, it is suitable for semi-automatic production and requires regular pressure calibration (error <5 MPa).

Comparison table of cemented carbide sintering methods

Sintering method	Process principle	Main Equipment	Process parameters	advantage	shortcoming	Applicable scenarios	illustrate
Vacuum Sintering	Heating the cemented carbide blank (WC, Co) in a vacuum environment allows the powder particles to combine, remove pores, and obtain a high-density material; the vacuum avoids oxidation, and the Co liquid phase promotes densification.	Vacuum sintering furnace, resistance or induction heater, vacuum pump (vacuum degree <10 ⁻² Pa); furnace accuracy ±0.1 mm.	Temperature: 13501500°C ±10°C , holding time: 14 h ±5 min, vacuum degree: 0.010.1 Pa ±0.01 Pa, billet density: 98%99.5% theoretical density ±0.5%	High density, low porosity (<0.5%); no oxidation, stable performance; suitable for a variety of shapes and sizes; simple process control	High equipment cost and complex maintenance; long production cycle and low efficiency; high requirements for heating uniformity of large billets	Production of inserts (e.g. turning inserts), dies, bars with dimensions <200 mm ±1 mm.	The most commonly used cemented carbide sintering method requires a controlled heating rate (510°C/min ±1°C/min) to prevent cracking.
Hot Isostatic Pressing (HIP)	an inert gas (such as Ar) at high temperature and high pressure, the blank is subjected to omnidirectional pressure, which further eliminates pores and improves	HIP furnace, high-pressure pump, inert gas system; pressure accuracy ±0.1 MPa, temperature accuracy ±5°C.	Temperature: 13001450°C ±10°C, Pressure: 100200 MPa ±0.1 MPa, Holding time: 13 h ±5 min, Billet density: 99.8%100% Theoretical density ±0.2%	Very high density, close to theoretical value; excellent mechanical properties (bending strength	Expensive equipment, high operating costs; low production efficiency, small batches; high requirements for the initial	Production of high-performance tools (e.g. milling cutters, drills), wear-resistant parts,	It is often used as a post-treatment for vacuum sintering to improve performance, and the gas purity must be ensured (>99.99%).

Sintering method	Process principle	Main Equipment	Process parameters	advantage	shortcoming	Applicable scenarios	illustrate
	density and strength; it is often used for post-processing.			+10%); eliminate micropores, strong wear resistance; suitable for high-performance products	quality of the blanks	dimensions <300 mm ±2 mm.	
Microwave Sintering	The blank is heated directly by microwaves, and the powder particles absorb microwave energy and heat up quickly, promoting liquid phase sintering and densification; the heating is uniform and the time is short.	Microwave sintering furnace, microwave generator (2.45 GHz), thermal insulation material; temperature control accuracy ±10°C.	Temperature: 13001450°C ±10°C, heating time: 1060 min ±1 min, power: 110 kW ±0.1 kW, billet density: 97%99% theoretical density ±0.5%	Fast heating speed (2050°C/min); energy saving, short production cycle (50%); fine grains (0.52 μm), excellent performance; reduced energy consumption	Complex equipment, large investment; limited size (<100 mm); high requirements for powder uniformity; low degree of industrialization	Production of small inserts (e.g. grooving inserts), precision moulds, dimensions <100 mm ±1 mm.	Emerging technology, suitable for small batches of high-precision products, requires optimization of microwave absorbing materials.
Spark Plasma Sintering (SPS)	The blank is quickly heated by pulsed current and pressure. The current induces local discharge, which promotes particle bonding and densification. The sintering time is extremely short.	SPS furnace, pulse power supply, mold (graphite or WC); current accuracy ±10 A, pressure accuracy ±0.1 MPa.	Temperature: 12001400°C ±10°C, Pressure: 30100 MPa ±0.1 MPa, Sintering time: 520 min ±30 s, Greenhouse density: 98%99.5% Theoretical density ±0.5%	Short sintering time (minutes); less grain growth (0.51 μm); high density, excellent performance; suitable for small size and complex shapes	Expensive equipment, short mold life; limited size (<50 mm); weak mass production capability; complex technology	Production of micro tools (e.g. micro drills), high-precision moulds with dimensions <50 mm ±0.5 mm.	Suitable for laboratories or high-end products that require controlled current pulses (50100 ms ±10 ms).
Gas Protection Sintering	an inert gas (such as N_2 , Ar) or a reducing gas (such as H_2) to promote liquid phase	Atmosphere sintering furnace, gas supply system, heating	Temperature: 13501480°C ±10°C, holding time: 15 h ±5 min, gas flow rate: 110 L/min ±0.1	The cost is lower than vacuum sintering; suitable for	Slightly lower density (1%); high gas purity requirements; difficult to	Production of large bars, dies, wear parts with dimensions	Traditional methods are suitable for cost-sensitive scenarios and require monitoring gas flow

Sintering method	Process principle	Main Equipment	Process parameters	advantage	shortcoming	Applicable scenarios	illustrate
	sintering and avoid oxidation; the gas flow controls the atmosphere.	elements; gas purity >99.9% ±0.01%.	L/min, billet density: 97%99% theoretical density ±0.5%	large billets; the atmosphere is adjustable and highly flexible; the equipment is easy to maintain	control porosity; slightly inferior performance to the vacuum sintering	<500 mm ±2 mm.	to prevent contamination.
Low Pressure Sintering	a low-pressure inert gas (such as Ar), combined with vacuum and slight pressure (<10 MPa), promotes liquid phase sintering, improving density and properties.	Low-pressure sintering furnace, vacuum pump, gas control system; pressure accuracy ±0.05 MPa .	Temperature: 13501450°C ±10°C, Pressure: 110 MPa ±0.05 MPa, Holding time: 13 h ±5 min , Billet density: 98.5%99.5% Theoretical density ±0.3%	High density, low porosity (<0.3%); Equipment cost is lower than HIP; Performance is close to HIP; Suitable for medium and large billets	Long production cycle; complex pressure control; high requirements for initial density of blanks; high energy consumption	Production of inserts (e.g. milling inserts), die blanks, dimensions <250 mm ±1 mm .	Between vacuum sintering and HIP, it balances cost and performance and requires precise control of pressure gradient.

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appendix:

What are the types of carbide pressing presses ?
What devices are suitable for Industrial Internet of Things (IIoT) and smart manufacturing ?

to the types of cemented carbide pressing presses, the most advanced typical representatives and their relevance to the Industrial Internet of Things (IIoT) and smart manufacturing . The content is based on the technical characteristics of the cemented carbide pressing process, equipment design details, operating parameters, performance indicators, application cases, maintenance requirements and the integration potential with IIoT and smart manufacturing, combined with the latest industry data, R&D trends and market dynamics, and strives to be comprehensive, detailed and practical.

1. Types of Carbide Presses

The cemented carbide pressing press is the core equipment used in the powder metallurgy field to form cemented carbide (such as WC-Co, WC- TiC -Co, etc.) blanks. Its types vary according to the pressing method, pressure application form, process complexity, degree of automation and applicable scenarios. The following is a detailed description of the 13 main types of presses, covering technical principles, mechanical structures, key components, operating parameters, performance indicators, maintenance requirements and typical applications. The names have been added in brackets and English translations.

1.1. Single-Direction Press

Technical principle

The pressure (100-300 MPa) is applied by a single vertical pressure head, and the powder particles are compressed and dense by the mold constraint. It is suitable for green bodies with simple geometric shapes. The pressing force is mainly transmitted along a single axis, and the density distribution is affected by gravity.

Mechanical structure

Frame: Steel uniaxial frame, bearing capacity >500 kN .

Indenter: High hardness steel (Cr12MoV, HRC 58-60), surface hardened.

Mould: Fixed, inner wall polished to Ra<0.2 µm , pressure resistance 300-400 MPa, life 500-1000 times.

Drive system: hydraulic cylinder or mechanical cam, power 5-10 kW.

Key Components

Pressure sensor: accuracy ±5 MPa, monitors pressing force.

Displacement sensor: accuracy ±0.1 mm, controls the stroke of the pressure head.

Operation parameters

Pressing pressure: 200 MPa (typical value).

Pressing time: 5-10 seconds.

Mold temperature: 20-40°C (normal temperature operation).

Power consumption: 5-10 kW.

Performance Indicators

Green billet density: 50%-65% theoretical density (about 6.5-8.0 g/cm³) .

Hardness after sintering: HRA 88-90.

Porosity: A02-B02 (according to ISO 4505 standard).

Maintenance requirements

Check the mold wear every month (if the thickness decreases > 0.1 mm, it needs to be replaced).

Clean the press head every 500 presses to prevent powder from sticking.

Typical Applications

Simple geometry parts, such as WC-8%Co cutting inserts (10×10× 5 mm), with a production efficiency of 200 pieces/hour.

Limitations : Large density gradient (>10%), not suitable for complex or large-sized parts.

1.2. Double-Direction Press

Technical principle

It uses up-and-down or up-and-down + side double pressure heads (200-400 MPa) to reduce the density gradient through bidirectional force balance, which is suitable for medium-complex shape blanks.

Mechanical structure

Frame: Biaxial steel structure, bearing capacity >1000 kN .

Indenter: 2-3 pcs (carbide or HRC 60 steel), surface coated with TiN .

Mould: movable, inner wall Ra<0.1 μm , pressure resistance 500 MPa, life span 1000-2000 times.

Drive system: Dual hydraulic cylinders, power 10-20 kW.

Key components :

Synchronous control system: ensure that the pressure head deviation is less than 0.1 mm.

Pressure sensor: accuracy ±2 MPa.

Operating parameters :

Pressing pressure: 300 MPa.

Pressing time: 10-20 seconds.

Mould temperature: 20-50°C.

Power consumption: 10-20 kW.

Performance indicators :

Green billet density: 60%-75% theoretical density (about 7.8-9.5 g/cm³) .

Hardness after sintering: HRA 89-91.

Porosity: A02 (uniformity is better than unidirectional pressing).

Maintenance requirements :

Check the synchronization of the indenter every 1000 times and adjust the deviation to <0.05 mm.

Replace the hydraulic oil quarterly to prevent system contamination.

Typical applications : medium-complex shapes, such as WC-10%Co milling cutter blanks (20 mm diameter), production efficiency 150 pieces/hour.

Limitations : Still not suitable for highly complex shapes, equipment maintenance costs are slightly higher.

1.3. Cold Isostatic Press (CIP)

Technical principle

The powder bag is compressed by high-pressure liquid medium (such as oil or water, 200-400 MPa) under omnidirectional pressure, and the pressure is evenly transmitted, which is particularly suitable for complex three-dimensional shapes.

Mechanical structure

High-pressure vessel: stainless steel or titanium alloy, pressure resistance >500 MPa, inner diameter 300-1000 mm.

Liquid circulation system: oil pump or water pump, flow rate 100-500 L/min.

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Mould: Flexible rubber bag (Shore A 70±5), pressure resistance 300 MPa.
Drive system: High-pressure pump, power 50-100 kW.

Key Components

Pressure sensor: accuracy ±5 MPa, multi-point distribution.
Temperature control: 20-50°C, accuracy ±2°C.

Operation parameters

Pressing pressure: 300 MPa.
Pressing time: 3-10 minutes.
Operating temperature: 20-50°C.
Power consumption: 50-100 kW.

Performance Indicators

Green billet density: 75%-85% theoretical density (about 9.7-10.8 g/cm^3) .
Hardness after sintering: HRA 90-92.
Porosity: A00-B00.

Maintenance requirements

Check the container sealing every 500 hours, and the leakage pressure should be less than 0.1 MPa.
Replace the liquid medium quarterly to maintain purity >99%.

Typical Applications

Complex geometry parts, such as WC-12%Co aerospace tool blanks (diameter 50 mm), with a production efficiency of 50 pieces/batch.
Limitations : Long cycle time and high equipment cost (>$1 million).

1. 4. Hot Isostatic Press (HIP)

Technical principle

compact is post-treated at high temperature (1350-1450°C) and high pressure (100-200 MPa) to eliminate micropores and optimize the grain structure.

Mechanical structure

Autoclave: pressure resistance>200 MPa, inner cavity diameter>200 mm, made of high-strength steel.
Heating system: resistance furnace or induction heating, power >150 kW.
Gas system: Ar or N_2 , purity>99.99%, pressure control ±1 MPa.
Drive system: high pressure pump + heater, power 150-300 kW.

Key Components

Temperature sensor: accuracy ±5°C, multi-point distribution.

Pressure sensor: accuracy ±1 MPa.

Operation parameters

Pressing pressure: 150 MPa.

Operating temperature: 1400°C.

Keep warm time: 1-4 hours.

Power consumption: >150 kW.

Performance Indicators

Density: >99.8% theoretical density (approx. 12.5-13.0 g/cm³) .

Hardness: HRA 92-94.

Porosity: <0.03%.

Maintenance requirements

the kettle every 1000 hours , and the cracks should be less than 0.1 mm.

Replace gas filters quarterly to maintain purity.

Typical Applications

High reliability parts, such as WC-10%Co mining drill bits, have a lifespan of >20 hours.

Limitations : Extremely expensive (>$5 million), mostly for post-processing.

1.5. Die Pressing Machine

Technical principle

Combined with precision molds for unidirectional or bidirectional pressing (200 MPa), efficient batch production is achieved through mold constraints.

Mechanical structure

Frame: Steel, bearing capacity >800 kN .

Indenter: High hardness steel (HRC 58), surface polished.

Mould: replaceable, inner wall Ra<0.1 μm , pressure resistance 400 MPa, life span 500-1000 times.

Drive system: Hydraulic, power 5-15 kW.

Key Components

Vibration filling device: 50 Hz, to enhance powder compaction.

Pressure sensor: accuracy ±5 MPa.

Operation parameters

Pressing pressure: 200 MPa.

Pressing time: 5-10 seconds.

Power consumption: 5-15 kW.

Performance Indicators

Green billet density: 60%-70% theoretical density (about 7.8-9.0 g/cm³) .

Hardness after sintering: HRA 90.

Porosity: A02.

Maintenance requirements

Replace the die every 500 times and check if the wear is >0.1 mm.

Clean the press head monthly to prevent powder residue.

Typical Applications

Standardized cutting blades, such as WC-8%Co blades (10×10× 5 mm), have a production efficiency of 300 pieces/hour.

Limitations : limited shape, fast mold wear.

1.6. Extrusion Press

Technical principle

The powder-binder mixture (PVA 15%-25%) was extruded through a die (300 MPa) by a screw or piston to form a continuous elongated body.

Mechanical structure

Extrusion cylinder: pressure resistance>500 MPa, inner wall with carbide coating.

Mould: precision design, tolerance <0.01 mm, temperature resistance 80°C.

Drive system: hydraulic + screw, power 20-40 kW.

Cutting system: Automatic tool, accuracy ±0.1 mm.

Key Components

Temperature control module: 50-80°C, accuracy ±2°C.

Pressure sensor: accuracy ±5 MPa.

Operation parameters

Pressing pressure: 300 MPa.

Extrusion speed: 0.5-2 m/min.

Power consumption: 20-40 kW.

Performance Indicators

Green billet density: 55%-65% theoretical density (about 7.0-8.3 g/cm³) .

Hardness after sintering: HRA 91.

Porosity: A02.

Maintenance requirements

Check the mold wear every 500 meters, and replace it if the tolerance is >0.02 mm.

Clean the screw monthly to prevent adhesive residue.

Typical Applications

Carbide rods, such as WC-10%Co rods (5 mm in diameter, 300 mm in length), with a production rate of 10 m/hour.

limitation

A degreasing process is required and the process is complicated.

1.7. Injection Molding Press

Technical principle

The powder-binder (PP/POM 20%-30%) mixture is heated (150-200°C) and injected into a mold (80 MPa) and demolded after cooling.

Mechanical structure

Barrel: heated to 150-200°C, power 10-20 kW.

Mould: H13 steel or carbide, tolerance <0.01 mm, life span 5000 times.

Drive system: screw injection, power 20-50 kW.

Cooling system: water circulation, temperature 50-80°C.

Key Components

Temperature sensor: accuracy ±2°C.

Pressure sensor: accuracy ±2 MPa.

Operation parameters

Injection pressure: 80 MPa.

Injection temperature: 180°C.

Mould temperature: 60°C.

Power consumption: 20-50 kW.

Performance Indicators

Green billet density: 50%-60% theoretical density (about 6.5-7.6 g/cm³) .

Hardness after sintering: HRA 92.

Porosity: A00-B00.

Maintenance requirements

Check the mold for wear every 1000 times, and replace it if the tolerance is >0.01 mm.

Clean the barrel monthly to prevent carbonization of the binder.

Typical Applications

Micro parts, such as WC-6%Co gears (3 mm diameter, 1 mm thickness), with a production

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efficiency of 100 pieces/hour.

limitation
There are many processes and the cost is high.

1.8. Dry Bag Press

Technical principle
Using a fixed rubber mold (dry bag) to apply 300 MPa pressure, similar to isostatic pressing but more efficient.

Mechanical structure
High-pressure vessel: pressure resistance >400 MPa, inner diameter 200-500 mm.
Mould: Rubber (Shore A 70±5), wall thickness 5-10 mm.
Drive system: Hydraulic pump, power 30-60 kW.

Key Components
Pressure sensor: accuracy ±5 MPa.
Displacement sensor: accuracy ±0.1 mm.

Operation parameters
Pressing pressure: 300 MPa.
Pressing time: 5-10 minutes.
Power consumption: 30-60 kW.

Performance Indicators
Green billet density: 70%-75% theoretical density (about 9.0-9.5 g/cm³) .
Hardness after sintering: HRA 90.
Porosity: A00-B00.

Maintenance requirements
Check the rubber mold for aging every 500 times. Replace it if the hardness change is >5.
Clean the inside of the container monthly.

Typical Applications
Medium-sized parts, such as WC-8%Co bearing sleeves (50 mm diameter), can be produced at a rate of 80 pieces per batch.

Limitation
Limited in shape, medium in cost.

1.9. Multi-Directional Press

Technical principle

Multiple press heads (4-6) apply pressure (400 MPa vertically and 300 MPa laterally) to achieve three-dimensional compression.

Mechanical structure

Frame: Multi-axial steel structure, bearing capacity >2000 kN .

Indenters: 6 pcs (hard alloy, pressure resistance 800 MPa).

Mould: composite design, inner wall Ra<0.1 μm .

Drive system: Multi-hydraulic cylinders, power 15-30 kW.

Key Components

Synchronous control system: deviation <0.5 mm.

Pressure sensor: accuracy ±5 MPa.

Operation parameters

Pressing pressure: 400 MPa.

Pressing time: 10-20 seconds.

Power consumption: 15-30 kW.

Performance Indicators

Green billet density: 75%-80% theoretical density (about 9.7-10.2 g/cm³) .

Hardness after sintering: HRA 91.

Porosity: A00-B00.

Maintenance requirements

Check the indenter for wear every 1000 times. Replace it if the thickness decreases by more than 0.1 mm.

Calibrate the synchronization system monthly.

Typical Applications

Complex tool blanks, such as WC-8%Co multi- edge tool blanks (diameter 30 mm), have a production efficiency of 120 pieces/hour.

limitation

The equipment is complex and the cost is high.

1.10. Multi -Axial Non-Isostatic Press

Technical principle

Four-way or six-way independent pressure application (vertical 500 MPa, lateral 400 MPa) to optimize pressure distribution.

Mechanical structure

Frame: Multi-axis servo structure, bearing capacity >3000 kN .

Indenters: 6 pcs (hard alloy, pressure resistance > 800 MPa).

Mould: precision design, tolerance <0.01 mm, life span >10,000 times.

Drive system: Servo hydraulic, power 20-50 kW.

Key Components

CNC control system: accuracy <0.01 mm.

Multi-point sensor: pressure ±2 MPa, displacement ±0.01 mm.

Operation parameters

Pressing pressure: 500 MPa.

Pressing time: 10-20 seconds.

Power consumption: 20-50 kW.

Performance Indicators

Green billet density: 85%-90% theoretical density (about 10.8-11.4 g/cm³) .

Hardness after sintering: HRA 92.

Porosity: A00.

Maintenance requirements

Check the servo system every 2000 times, deviation > 0.01 mm calibration.

Clean the mold monthly to prevent powder buildup.

Typical Applications

Multi- edge tool blanks, such as WC-12%Co milling cutter blanks (diameter 40 mm), with a production efficiency of 100 pieces/hour.

limitation

The equipment is complex and the initial investment is high.

1.11.Rolling Press

Technical principle

Continuous pressing by double rollers (100 MPa) is suitable for thin sheet blanks.

Mechanical structure

Roller: Carbide or HRC 60 steel, surface Ra<0.2 μm , diameter 200-500 mm.

Feeding system: Vibration device, frequency 50 Hz.

Drive system: Electric motor, power 10-20 kW.

Gap adjustment: accuracy ±0.01 mm.

Key Components
Thickness sensor: accuracy ±0.01 mm.
Speed sensor: Accuracy ±0.5 rpm.

Operation parameters
Pressing pressure: 100 MPa.
Roller speed : 5-15 rpm.
Gap: 0.5-5 mm.
Power consumption: 10-20 kW.

Performance Indicators
Green billet density: 50%-60% theoretical density (about 6.5-7.6 g/cm³) .
Hardness after sintering: HRA 89.
Porosity: A02.

Maintenance requirements
the polishing roller every 1000 rolling cycles when Ra>0.2 µm .
Check feed uniformity monthly.

Typical Applications
Thin sheet blanks, such as WC-10%Co thin sheets (thickness 2 mm, width 100 mm), production efficiency 200 m² / day.

limitation
Low density, not suitable for complex shapes.

1.12. Explosive Compaction System

Technical principle
Special facilities are required to instantaneously suppress the explosion using the shock wave (1000-5000 MPa).

Mechanical structure
Container: high-strength steel (40CrNiMoA, thickness 15-20 mm), pressure resistance >6000 MPa.
Explosive system: TNT 0.5-1 kg, placement accuracy ±1 cm.
Safety facilities: explosion-proof wall (thickness>1 m), remote monitoring room.

Key Components
Pressure gauge: Instantaneous pressure monitoring, accuracy ±50 MPa.
Heat treatment furnace: 600-1000°C, power 20 kW.

Operation parameters

Pressing pressure: 3000 MPa.

Suppression time: <1 ms.

Power consumption: Dependent on explosive energy.

Performance Indicators

Green billet density: 90%-95% theoretical density (about 11.5-12.0 g/cm³) .

Hardness after sintering: HRA 94.

Porosity: A00.

Maintenance requirements

Check the integrity of the container every 10 explosions and replace it if the crack is >0.1 mm.

Clean up the residues monthly to meet environmental protection standards.

Typical Applications

High-performance parts, such as WC-6%Co PVD targets (diameter 100 mm, thickness 5 mm), with a production efficiency of 10 pieces/batch.

limitation

It has high safety requirements, high costs, and requires professional operation.

1.13. Vibration-Assisted Press

Technical principle

Combining high-frequency vibration (20-100 kHz) with pressure (200 MPa) improves density and uniformity.

Mechanical structure

Frame: Steel, bearing capacity >1000 kN .

Indenter: High hardness steel (HRC 58), pressure resistance 400 MPa.

Vibrator: Ultrasonic, power 2-5 kW, frequency 50 kHz.

Drive system: Hydraulic, power 5-10 kW.

Key Components

Frequency sensor: Accuracy ±2 kHz.

Density sensor: accuracy ±0.5%.

Operation parameters

Pressing pressure: 200 MPa.

Vibration frequency: 50 kHz.

Pressing time: 10-20 seconds.

Power consumption: 5-10 kW.

Performance Indicators

Green billet density: 65%-75% theoretical density (about 8.5-9.5 g/cm³) .

Hardness after sintering: HRA 91.

Porosity: A00-B00.

Maintenance requirements

Check the vibrator for wear every 500 times. Replace it if the frequency deviation is >5%.

Clean the mold monthly to prevent powder buildup.

Typical Applications

Small tool blanks, such as WC-8%Co drill blanks (diameter 10 mm, height 15 mm), have a production efficiency of 200 pieces/hour.

limitation

Not suitable for large size parts and requires frequency optimization.

2. The most advanced typical carbide press

The following are the most advanced and representative carbide compacting presses, with detailed descriptions of their technical specifications, functional modules, performance data, application cases, R&D background and market position, with brackets and English translations added to the names.

2.1 Modern Multi-Axis Servo -Hydraulic Press

Representative Brand

Schuler AG (Germany), Komatsu Industries (Japan), SMS Group (Germany), Cincinnati (USA).

Technical specifications

Pressure range: 400-600 MPa.

Number of pressure heads: 4-6, driven by servo motor, displacement accuracy <0.01 mm.

Power: 30-70 kW.

Control system: CNC (Siemens Sinumerik or Fanuc 32i), integrated IIoT module.

Mould: Carbide lining (HRA 88), pressure resistance >800 MPa, life span >10,000 times.

Sensors: multi-point pressure (±1 MPa), temperature (±1°C), displacement (±0.01 mm).

Functional modules

Multi-axis control : supports four-way/six-way pressing, dynamic adjustment of pressure ratio (1:0.7:0.6), deviation <1%.

Smart monitoring : real-time data collection (100 Hz), transmission to the cloud, storage capacity of 10 TB.

AI Optimization : Machine learning models predict optimal parameters, reducing defect rates by

<1%.

Predictive maintenance : Based on vibration and temperature analysis, with a warning time of 72 hours.

Energy consumption management : Optimize the hydraulic system and reduce energy consumption by 5%-10%.

Performance Data

Green billet density: 85%-90% theoretical density.

Hardness after sintering: HRA 92-93.

Production efficiency: 120 pieces/hour (complex parts).

Application Cases

Schuler SmartPress 600 produces WC-12%Co multi- edge milling cutter blanks (diameter 40 mm) for Airbus A350 components in 2024 with a service life of >1000 m.

R&D background : R&D investment from 2019 to 2023 is US$150 million, focusing on multi-axis synchronization and IIoT integration.

Market position : Global sales will increase by 15% in 2024, accounting for 50% of the multi-axis press market, with major customers being the aviation and automotive industries.

2.2 Smart Isostatic Press

Representative Brand

Quintus Technologies (Sweden), Avure Technologies (USA), Kobe Steel (Japan), Bodycote (UK).

Technical specifications

Pressure range: 200-400 MPa (CIP), 100-200 MPa (HIP).

Temperature range: 20-1450°C (HIP mode).

Power: 50-150 kW (CIP), 150-300 kW (HIP).

Control system: DCS (Honeywell or ABB), supporting OPC UA.

Container: titanium alloy or high-strength steel, pressure resistance >500 MPa, inner cavity diameter 300-1000 mm.

Sensors: pressure (±1 MPa), temperature (±2°C), gas flow (±0.1 L/min).

Functional modules

Omnidirectional pressing : uniform pressure distribution, density 75%-85% (CIP), >99.8% (HIP).

Automated loading and unloading : Robotic arm integration improves efficiency by 20%.

Data analysis : The IoT module records process parameters, and the AI optimization deviation is <0.5%.

Remote operation : 5G connection supports cross-border collaboration with a latency of <50 ms .

Energy-saving design : heat recovery system reduces energy consumption by 10%-15%.

Performance Data

Green billet density: 75%-85% (CIP), >99.8% (HIP).
Hardness after sintering: HRA 90-94.
Production efficiency: 50 pieces/batch (CIP), 20 pieces/batch (HIP).

Application Cases

Quintus QIF 122 produces WC-10%Co aviation tool blanks for GE Aviation in 2023, with a density of 99.5% and a porosity of <0.03%.

R&D background : From 2018 to 2022, the company will invest US$200 million in R&D, focusing on the development of HIP high temperature and high pressure technology.

Market position : It will account for 40% of the global HIP market in 2023 and grow by 10% in 2024, mainly used in aviation and medical.

2.3 High-Precision Injection Molding Press

Representative Brand

Arburg (Germany), Engel (Austria), Sumitomo Demag (Japan), Wittmann Battenfeld (Austria).

Technical specifications

Pressure range: 50-120 MPa.
Temperature range: 150-200°C (barrel), 50-80°C (mold).
Power: 20-50 kW.
Control system: Closed-loop control (Beckhoff or Bosch Rexroth), accuracy ±2°C, ±2 MPa.
Mould: H13 steel or carbide, tolerance <0.01 mm, life span 5000-10,000 times.
Sensors: temperature (±1°C), pressure (±1 MPa), flow rate (±0.1 L/min).

Functional modules

High-precision injection : tolerance <0.01 mm, suitable for micro parts.

Automated process : integrated degreasing and cooling system, manual intervention <20%.

3D mold design : supports additive manufacturing molds, and the line change time is less than 30 minutes.

Data integration : MES interface, process data traceability 99%.

Energy saving optimization : heat recovery system reduces energy consumption by 5%-10%.

Performance Data

Green billet density: 50%-60% theoretical density.
Hardness after sintering: HRA 92.
Production efficiency: 100-150 pieces/hour.

Application Cases

Arburg Allrounder 570 produces WC-6%Co micro gears (3 mm diameter) for medical implants in 2024 with tolerances < 0.01 mm.

R&D background : From 2020 to 2023, an investment of US$80 million will be made in R&D, with a focus on improving the precision of micro parts.

Market position : Sales volume will increase by 12% in 2024, accounting for 30% of the injection molding market, with major customers being the medical and electronics industries.

2.4 Explosive Compaction System

Representative Brand

Customized equipment (Technodinamika of Russia , China North Industries, Dyno Nobel of the United States).

Technical specifications

Pressure range: 1000-5000 MPa (instantaneous).

Explosion energy: TNT 0.5-1 kg, adjustment range 0.3-2 kg.

Container: high-strength steel (40CrNiMoA, thickness 15-20 mm), pressure resistance >6000 MPa.

Safety facilities: explosion-proof wall (thickness>1 m), remote monitoring room, protection distance>500 m.

Sensors: instantaneous pressure (±50 MPa), temperature (±10°C).

Functional modules

Shock wave suppression : green billet density 90%-95%, time <1 millisecond.

Precise placement : explosive density 1.5-1.7 g/cm³ , energy control accuracy ±5%.

Heat treatment integration : 600-1000°C, repair micro cracks, time 2-3 hours.

Safety management : Comply with ISO 9001 and military standards, remote detonation.

Performance Data

Green billet density: 90%-95% theoretical density.

Hardness after sintering: HRA 94.

Production efficiency: 10 pieces/batch.

Application case : China North Industries produces WC-6%Co PVD targets (diameter 100 mm) for semiconductor coating in 2023 with a density of 93%.

R&D background : R&D from 2015 to 2020, with an investment of US$100 million, focusing on security and consistency.

Market position : Niche market, accounting for 1% in 2023 and growing by 10% in 2024, mainly used in defense and high-end materials.

2.5 Vibration-Assisted Smart Press

Representative Brand

Hitachi (Japan), Siemens (Germany), Bosch Rexroth (Germany), Mitsubishi Electric (Japan).

Technical Specifications :

Pressure range: 100-300 MPa, commonly used is 200 MPa.

Vibration frequency: 20-100 kHz, accuracy ±2 kHz.

Power: 5-10 kW (vibrator) + 10-20 kW (pressing).
Control system: PLC+IIoT module (Siemens S7 or Rockwell Allen-Bradley), frequency stability <5%.
Mould: High hardness steel (HRC 58), pressure resistance 400 MPa, life span 5000 times.
Sensors: frequency (±2 kHz), density (±0.5%), pressure (±5 MPa).

Functional modules :
Vibration optimization : frequency 50 kHz increases density by 65%-75% and reduces pores (A00).
Intelligent monitoring : Sensors provide real-time feedback and data is processed through edge computing.
Predictive maintenance : Vibrator life prediction error <5%, warning time 48 hours.
Low-cost upgrade : compatible with existing presses, payback period < 1 year.
Energy-saving design : Vibration energy consumption is optimized, reducing 5%-8%.

Performance data :
Green billet density: 65%-75% theoretical density.
Hardness after sintering: HRA 91.
Production efficiency: 200 pieces/hour.

Application Cases
Siemens Sinumerik has modified a vibration press to produce WC-8%Co drill bit blanks (10 mm diameter) for oil drilling in 2024 with a service life of >1200 m.
R&D background : R&D from 2019 to 2022, with an investment of US$50 million, focusing on improving vibration efficiency.
Market position : Growth of 8% in 2024, with the penetration rate of small and medium-sized manufacturing increasing by 15%.

3. Cemented carbide pressing equipment suitable for industrial Internet of Things concepts and intelligent manufacturing

Industrial Internet of Things (IIoT) and smart manufacturing emphasize equipment interconnection, data-driven, automation, predictive maintenance and green production. The following types of pressing presses are suitable for this trend due to their technical characteristics and upgrade potential. Their IIoT characteristics and smart manufacturing advantages are analyzed in detail, and technical details and application examples used in the cemented carbide industry are provided.

3.1 Multi -Axis Servo -Hydraulic Press

IIoT Features :
Sensor network : Multi-point pressure (±1 MPa, 100 Hz), temperature (±1°C), displacement (±0.01 mm) sensors, with data transmitted via 5G or TSN.
Communication protocols : Support OPC UA, MQTT and EtherCAT , seamlessly integrated with

MES/ERP.
Data storage and analysis : 10 TB of cloud storage, AI model analyzes production data, and prediction deviation is <1%.
Predictive maintenance : Based on vibration and temperature data, early warning time is 72 hours, and downtime is reduced by 20%.

Advantages of smart manufacturing :
Adaptive control : CNC dynamically adjusts pressure and displacement, with manual intervention <10%.
Flexible production : fast mold switching (<15 minutes), suitable for small batch customization.
Energy consumption optimization : hydraulic system efficiency is increased by 10% and carbon emissions are reduced by 5%-10%.
Quality management : online inspection, scrap rate <1%.

Technical details :
Edge computing unit: 10 GFLOPS, processing latency <20 ms .
Security protection: IP67 firewall, AES-256 encryption.
Application example : Schuler SmartPress 600, used in Airbus A350 production in 2024, increases efficiency by 15% and reduces energy consumption by 8%.

3.2 Smart Isostatic Press

IIoT Features :
Sensor network : pressure (±1 MPa), temperature (±2°C), gas flow (±0.1 L/min), sampling frequency 50 Hz.
Communication protocol : OPC UA, 5G connection, latency <50 ms .
Data storage and analysis : Edge devices store 1 TB, AI optimizes process parameters, and the deviation is <0.5%.
Predictive maintenance : Fault warning within 48 hours reduces maintenance costs by 15%.

Advantages of smart manufacturing :
Automated production : Robotic arm loading and unloading, cycle time shortened by 10%-15%.
Resource optimization : Linked with ERP, raw material utilization rate increased by 5% and energy consumption decreased by 10%.
Quality control : AI detects density uniformity, with a scrap rate of <0.5%.
Green manufacturing : heat recovery system reduces carbon emissions by 10%-15%.

Technical details :
Edge computing: 20 GFLOPS, optimized for real-time.
Security protection: Industrial firewall, compliant with ISO 27001.
Application example : Quintus QIF 122, used by GE Aviation in 2023, improves density uniformity by 3% and reduces production cycle by 12%.

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3.3 High-Precision Injection Molding Press

IIoT Features :

Sensor network : temperature (±1°C, 1 Hz), pressure (±1 MPa), flow rate (±0.1 L/min), data updated in real time.

Communication protocol : MQTT, industrial Ethernet transmission.

Data storage and analysis : MES integration, 99% process data traceability, AI optimization parameters.

Predictive maintenance : mold life prediction error <5%, warning time 24 hours.

Advantages of smart manufacturing :

Automated process : Degreasing and cooling are automated, with manual intervention <20%.

Flexible production : 3D printing molds, line change time <30 minutes.

Quality control : closed-loop feedback, tolerance <0.01 mm, scrap rate <1%.

Resource management : intelligent warehousing integration, raw material waste <2%.

Technical details :

Edge computing: 5 GFLOPS, processing latency <30 ms .

Security protection: IP65, data encryption.

Application example : Arburg Allrounder 570, used in medical implants in 2024, with tolerances < 0.01 mm and 10% higher efficiency.

3.4 Vibration-Assisted Smart Press

IIoT Features :

Sensor network : frequency (±2 kHz), density (±0.5%), pressure (±5 MPa), sampling frequency 50 Hz.

Communication protocol : MQTT, edge device transmission.

Data storage and analysis : 500 GB local storage, AI optimized vibration parameters.

Predictive maintenance : Vibrator life prediction error <5%, warning time 48 hours.

Advantages of smart manufacturing :

Low-cost upgrade : compatible with existing equipment, payback period < 1 year.

Efficiency improvement : Density increased by 5%-10%, and production efficiency increased by 15%.

Quality control : reduce pores, porosity A00, scrap rate <2%.

Energy-saving design : Vibration energy consumption is optimized, reducing 5%-8%.

Technical details :

Edge computing: 2 GFLOPS, real-time feedback.

Security protection: IP54, basic encryption.

Application example : Siemens Sinumerik retrofit machine, used for drill production in 2024, life span > 1200 m, scrap rate reduced to 2%.

3.5Rolling Smart Press

IIoT Features :
Sensor network : thickness (±0.01 mm), speed (±0.5 rpm), pressure (±5 MPa), sampling frequency 20 Hz.
Communication protocol : OPC UA, Industrial Ethernet transmission.
Data storage and analysis : 1 TB of edge storage, AI optimized gap and speed.
Predictive maintenance : roller wear warning, time 36 hours.

Advantages of smart manufacturing :
Online inspection : thickness uniformity <0.05 mm, scrap rate <1%.
Automated production : feeding and cutting are automated, increasing efficiency by 20%.
Resource optimization : integrated with intelligent logistics, raw material utilization rate>98%.
Green production : energy consumption optimization, reducing 5%-10%.
Technical details :
Edge computing: 5 GFLOPS, scaled in real time.
Security protection: IP67, data encryption.

Application Examples
Customized roller press for wear-resistant coating substrates in 2024, with 10% higher output and thickness uniformity < 0.02 mm.

4. Technical trends and requirements of cemented carbide pressing equipment for intelligent manufacturing

Sensors and data acquisition : high-precision sensors (pressure ±1 MPa, temperature ±1°C, displacement ±0.01 mm), sampling frequency 50-100 Hz, 5G or TSN transmission, data integrity >99.9%.
Edge computing : Built-in edge computing unit, processing power 10-20 GFLOPS, real-time optimization parameters, latency <20 ms .
AI optimization : Integrates deep learning models to predict optimal parameters based on historical data, improving accuracy by 5%-10% with a training cycle of less than 1 week.
Standardized protocols : Supports OPC UA, MQTT, EtherCAT and PROFINET, compatible with the smart factory ecosystem, and protocol conversion efficiency >95%.
Security : Equipped with industrial firewall (IP67, protection level 6), AES-256 encryption, compliant with ISO 27001 and NIST 800-53 standards, and anti-attack success rate <0.1%.
Green manufacturing : Energy consumption optimization module, reducing carbon emissions by 5%-15%, in line with ISO 14001 and carbon neutrality goals (net zero emissions in 2030).
Human-computer interaction : Equipped with AR/VR interface, supports remote operation and

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training, and reduces human errors by >20%.

5. Challenges and prospects of cemented carbide pressing equipment for intelligent manufacturing

challenge :

Initial investment : Smart equipment is expensive (e.g. multi-axis press > $2 million, HIP > $5 million), and small and medium-sized enterprises need to upgrade in stages.

Technical threshold : IIoT integration requires a professional team, with a training period of 6-12 months and a technical personnel shortage of 10%-15%.

Data security : The risk of cyber attacks increases, and 5%-10% of the budget needs to be invested in security.

Compatibility : It is difficult to upgrade old equipment, and the interface adaptation rate is <70%.

prospect :

Market growth : From 2025 to 2030, the IIoT equipment market is expected to grow at an annual rate of 10%-12%, and the demand for intelligent pressing presses will increase by 15% annually. The market size will reach US$5 billion in 2025 and is expected to reach US$8 billion in 2030.

Technology integration : Combined with additive manufacturing (3D printing), digital twins and blockchain technology, the entire process will be digitized by 2026, with efficiency improved by 20%-30%.

Policy support : China's "14th Five-Year Plan" provides a subsidy of 20%-30%, and the EU's "Industry 4.0" allocates 1 billion euros to encourage investment in smart manufacturing.

Industry trends : By 2025, 50% of the world's pressing equipment will have IIoT capabilities, and by 2030, smart manufacturing will account for 60% of manufacturing output value.

Summarize

There are a wide variety of cemented carbide compacting presses, covering 13 types from single-direction presses to explosive compaction systems, each with its own technical advantages and applicable scenarios. Advanced representatives such as Modern Multi-Axis Servo -Hydraulic Press and Smart Isostatic Press integrate high precision, automation and intelligence, with performance reaching green billet density of 85%-95% and hardness HRA 92-94. Equipment suitable for industrial Internet of Things and smart manufacturing (such as Schuler SmartPress and Quintus QIF) significantly improves production efficiency (15%-20%), quality (defect rate <1%) and flexibility through sensors, AI optimization and data interconnection, and will promote high-end manufacturing in the fields of aviation, automobiles, and medical care in the future. It is expected that from 2025 to 2030, the market size will grow to US$8 billion, and the intelligence rate will reach more than 70%.

Carbide Press Comparison Table

Device Name (Equipment Name)	Technical principle (Technical Principle)	Pressure range (Pressure Range)	Green Density	Pressing Time	Production efficiency (Production Efficiency)	Typical Applications (Typical Application)	Maintenance requirements (Maintenance Requirements)	limitation Limitations	Intelligent potential Smart Manu . Potential)
Single-Direction Press	Uniaxial vertical pressing	100-300 MPa	50%-65% theoretical density (6.5-8.0 g/ cm³)	5-10 seconds	200 pieces/hour	Simple geometry parts, such as WC-8%Co cutting inserts	Check the mold wear every month and clean the press head every 500 times	Large density gradient (>10%), not suitable for complex shapes	Low – requires significant upgrades to support IIoT
Double-Direction Press	Apply pressure up and down or in multiple directions	200-400 MPa	60%-75% theoretical density (7.8-9.5 g/ cm³)	10-20 seconds	150 pieces/hour	Medium complex shapes, such as WC-10%Co milling cutter blanks	Check the pressure head synchronization every 1000 times and change the oil every quarter	Not suitable for highly complex shapes	Moderate – Partially upgradeable to support IIoT
Cold Isostatic Press (CIP)	Omnidirectional liquid suppression	200-400 MPa	75%-85% theoretical density (9.7-10.8 g/ cm³)	3-10 minutes	50 pieces/batch	Complex geometry parts, such as WC-12%Co aerospace tool blanks	Check the seal every 500 hours and change the fluid every quarter	Long cycle and high equipment cost	High – Suitable for Industrial IoT and Smart Manufacturing
Hot Isostatic Press (HIP)	High temperature and high pressure post-processing	100-200 MPa	>99.8% theoretical density (12.5-13.0 g/ cm³)	1-4 hours	20 pieces/batch	High reliability parts such as WC-10%Co mining drill bits	the kettle every 1000 hours and replace the filter every quarter	Extremely expensive, mainly used for post-processing	High – Suitable for Industrial IoT and Smart Manufacturing
Die Pressing Machine	Die-constrained single/double pressing	200 MPa	60%-70% theoretical density (7.8-9.0 g/ cm³)	5-10 seconds	300 pieces/hour	Standardized cutting inserts, such as WC-8%Co inserts	Change the mold every 500 times and clean the pressure head every month	Limited shape, fast mold wear	Low – Needs to be upgraded to support Industrial Internet of Things
Extrusion Press	Screw extrusion	300 MPa	55%-65% theoretical density (7.0-8.3 g/ cm³)	0.5-2 m/min (speed)	10 m/hour	Slender bars, such as WC-10%Co bars	Check the mold every 500 meters and clean the screw every month	Degreasing process is required, and the process is complicated	Moderate – Can partially support IIoT

Injection Molding Press	Powder-binder injection molding	50-120 MPa	50%-60% theoretical density (6.5-7.6 g/ cm³)	Cycle time: about 1 minute	100 pieces/hour	Micro parts, such as WC-6%Co gears	Check the mold every 1000 times and clean the barrel every month	Many processes and high cost	High – Suitable for Industrial IoT and Smart Manufacturing
Dry Bag Press	Fixed rubber mold pressing	300 MPa	70%-75% theoretical density (9.0-9.5 g/ cm³)	5-10 minutes	80 pieces/batch	Medium size parts, such as WC-8%Co bearing sleeves	Check mold aging every 500 times and clean the container every month	Limited shape, medium cost	Moderate – can partially support IIoT
Multi-Directional Press	Multi-head 3D compression	Vertical 400 MPa, lateral 300 MPa	75%-80% theoretical density (9.7-10.2 g/ cm³)	10-20 seconds	120 pieces/hour	Complex tool blanks, such as WC-8%Co multi- edge tool blanks	Check the indenter every 1000 times and calibrate the system monthly	The equipment is complex and the cost is high	High – Suitable for industrial IoT smart manufacturing
Multi- Axial Non - Isostatic Press	Four-way/six-way independent pressure	Vertical 500 MPa, lateral 400 MPa	85%-90% theoretical density (10.8-11.4 g/ cm³)	10-20 seconds	100 pieces/hour	Multi- edge tool blanks, such as WC-12%Co milling cutter blanks	Check the servo every 2,000 times and clean the mold every month	Complex equipment and high initial investment	High – Suitable for Industrial IoT and Smart Manufacturing
Rolling Press	Double roller continuous pressing	100 MPa	50%-60% theoretical density (6.5-7.6 g/ cm³)	5-15 rpm (speed)	200 m² / day	Thin sheet blank, such as WC-10%Co thin sheet	Polish the roller every 1000 times and check the feed every month	Lower density, not suitable for complex shapes	High – Suitable for Industrial IoT and Smart Manufacturing
Explosive Compaction System	Explosion shock wave suppression	1000-5000 MPa	90%-95% theoretical density (11.5-12.0 g/ cm³)	< 1 ms	10 pieces/batch	High performance parts, such as WC-6%Co PVD targets	Check the container every 10 times and clean up the residue every month	High security requirements and high costs	Low – Difficult to integrate with Industrial IoT
Vibration-Assisted Press	High frequency vibration + pressure	200 MPa	65%-75% theoretical density (8.5-9.5 g/ cm³)	10-20 seconds	200 pieces/hour	Small tool blanks, such as WC-8%Co drill blanks	Check the vibrator every 500 times and clean the mold every month	Not suitable for large size parts	High – Suitable for Industrial IoT and Smart Manufacturing

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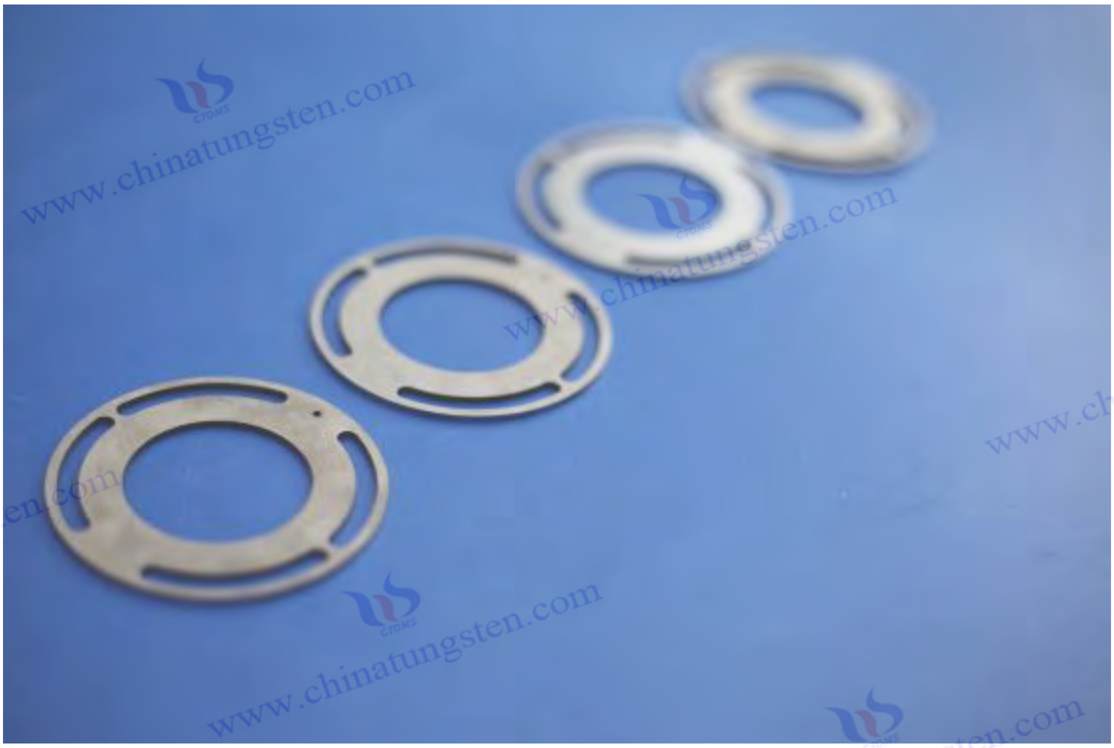

appendix:

ISO 4489:2009
Cemented Carbide
Sintering Process Guide

1. Scope

This international standard specifies the sintering process guidelines for cemented carbide (mainly tungsten carbide-based materials, such as WC-Co alloys), which is suitable for the production of high-performance cemented carbide products for cutting tools, abrasives, wear-resistant parts, etc. The standard covers raw material selection, process parameters, quality control, safety and environmental protection requirements, but does not include specific equipment design or production scale.

2. Normative references

ISO 4505:1978, Cemented carbides – Determination of physical properties.
ISO 3327:2009, Cemented carbides – Method for determination of density.
ISO 3738:2001, Cemented carbides – Method for determination of hardness (HRA).
ISO 4506:1979, Cemented carbides – Methods of microstructural analysis.

3. Terms and Definitions

Cemented carbide: A high-hardness, wear-resistant material sintered by a powder metallurgy process using refractory metal carbides (such as WC) and a binding phase (such as Co).
Sintering: A method of combining powder particles into a dense body at high temperature, including vacuum sintering, hot isostatic pressing, etc.
the forming agent and preliminarily solidifying before formal sintering .

Porosity: The volume percentage of the unfilled portion of a sintered body, divided into three categories: A, B, and C (A02 is the highest quality grade).

4. Process requirements

4.1 Raw material requirements

Tungsten carbide (WC) powder: particle size should be in the range of 0.5-5 μm , purity ≥99.5%, oxygen content <300 ppm.

Binding phase (such as Co): particle size 1-3 μm , purity ≥99.5%, impurity (such as Fe, Ni) content <100 ppm.

Carbon regulator: purity ≥99.5%, particle size <1 μm .

4.2 Mixing

The mixing process should ensure uniformity and particle size distribution deviation <5%.

Wet or dry grinding methods can be used, and the recommended ball to material ratio is 5:1 to 10:1.

If a molding agent (such as paraffin) is used, the addition amount should be controlled at 1-3% wt and must be completely removed during pre-sintering.

4.3 Forming

Pressing pressure range: 100-200 MPa, the billet density should reach 50-60% of the theoretical density.

Injection molding temperature: 150-180°C, mold temperature 50-70°C.

The dimensional deviation should be controlled within ±0.5 mm.

4.4 Pre-sintering

Temperature range: 300-800°C, atmosphere: hydrogen or inert gas, flow rate: 10-30 m^3 / h.

Dewaxing time: 3-5 hours, residual carbon content <0.1%.

The strength of pre-sintered blank should be ≥5 MPa.

4.5 Sintering

Vacuum sintering: temperature 1350-1500°C, vacuum degree ≤0.01 Pa, holding time 0.5-2 hours.

Hot isostatic pressing (HIP): temperature 1300-1450°C, pressure 80-150 MPa, holding time 20-60 minutes.

Recommended density ≥99% theoretical density, porosity ≤A02 grade.

4.6 Post-processing

Cooling rate: 2-5°C/min, to avoid thermal stress cracks.

Surface treatment: grinding or polishing, surface roughness Ra≤0.8 μm .

5. Quality Control

5.1 Chemical composition

Tungsten carbide content: 85-95% wt (adjusted according to recipe).
Bound phase content: 5-15% wt .
Impurities: Fe<50 ppm, O<200 ppm, N<300 ppm.

5.2 Physical properties

Density: Depending on formulation, range 14.0-15.0 g/cm³ (ISO 3327).
Hardness: HRA 88-94 (ISO 3738).
Flexural strength: >2000 MPa (ISO 4505).

5.3 Microstructure

Grain size: ≤1 μm (preferably 0.5-0.8 μm).
Porosity: ≤A02 (ISO 4506).
No η phase or free carbon (detected by X-ray diffractometer).

5.4 Detection Methods

Particle size: Laser particle size analyzer (ISO 13320).
Density: Archimedes method or mercury penetration method.
Hardness: Rockwell A hardness tester.
Microstructure: optical microscopy or scanning electron microscopy (SEM).

6. Security Requirements

Gas use: The hydrogen operation area must be equipped with explosion-proof walls (thickness ≥ 0.3 m), ventilation systems (air exchange rate ≥ 10 times/hour), and leak alarms (detection limit 0.05%).
High temperature protection: The sintering furnace operation area needs to be equipped with thermal insulation shielding, and the temperature monitoring range is 50-1500°C.
Personal protection: Operators need to wear high temperature resistant clothing, dust masks and goggles.

7. Environmental requirements

Waste gas treatment: The CO content in the combustion tail gas is <50 ppm, and it is treated in a tail gas purification tower with an efficiency of ≥95%.
Wastewater management: Forming agent waste liquid needs to be recycled or treated, COD <100 mg/L.
Noise control: Equipment operating noise <85 dB(A).

8. Documentation and Records

Each batch of production must record the raw material batch number, process parameters (temperature, pressure, time), test results and operator information.
Quality record retention period: at least 5 years.

appendix:

GB/T 4505-2008
Cemented Carbide
Sampling and specimen preparation methods

Preface

This standard is formulated in accordance with the provisions of the Standardization Law of the People's Republic of China. This standard is a revision of the original GB/T 4505-1996 Sampling and specimen preparation methods for cemented carbide. This revision is mainly based on the latest technological developments in cemented carbide production and application, and refers to the international standards ISO 4505:1978 (determination of porosity and free carbon in cemented carbide metallography) and ISO 3326:2013 (sampling and specimen preparation methods for cemented carbide). In combination with domestic industry needs, it adds sampling uniformity requirements, microstructure control methods during specimen preparation, environmental control requirements, and specimen preparation specifications applicable to a variety of test scenarios.

This standard is proposed and managed by China Machinery Industry Federation. China Cemented Carbide Industry Association is responsible for the interpretation of this standard. The drafting units of this standard include: Institute of Metal Research, Chinese Academy of Sciences, University of Science and Technology Beijing, Zhuzhou Cemented Carbide Group Co., Ltd., and Chengdu Tool Research Institute.

The main drafters of this standard are:

This standard shall be implemented from December 1, 2008, and the original GB/T 4505-1996 shall be abolished at the same time.

1 Scope

This standard specifies the methods for sampling and sample preparation of cemented carbide (mainly WC-Co, including composite cemented carbide with other carbides such as TiC , TaC , etc.) during production, quality inspection and scientific research, including sampling principles, sampling methods, sample selection, preparation process, quality control requirements, sample preservation and related test verification. This standard applies to the sampling and sample preparation of cemented carbide blanks, sintered products and processed products, and is mainly used for the following tests:

Metallographic structure analysis (e.g. grain size, porosity, phase distribution).

Mechanical property tests (such as hardness, fracture toughness, flexural strength).

Chemical composition analysis (such as WC, Co, additive content).

This standard does not apply to the following situations:

with special surface coatings (such as TiN , CrN , Al_2O_3) .

Non-WC-Co based composite materials (such as cermets).

Special preparation requirements for ultrafine-grained (grain size < 0.1 μm) cemented carbide.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.

GB/T 1997-2008 Cemented Carbide Terminology
GB/T 2007.1-1987 General rules for sampling and sample preparation of bulk minerals
GB/T 2597-2008 Test method for porosity of cemented carbide
GB/T 3489-2008 Cemented carbide microstructure determination method
GB/T 5248-2008 Chemical analysis methods for cemented carbide
GB/T 5313-2008 Cemented carbide metallographic structure test method
GB/T 7997-2008 Test method for Vickers hardness of cemented carbide
GB/T 18376-2008 Method for determination of cemented carbide grain size
ISO 4505:1978 Metallographic determination of porosity and free carbon in cemented carbides
ISO 3326:2013 Methods for sampling and preparation of test specimens of cemented carbide

3 Terms and definitions

This standard adopts the following terms and definitions and refers to GB/T 1997-2008.

3.1 Sampling portion (Portion)

A representative portion cut from a cemented carbide blank, sintered product or processed product for subsequent sample preparation.

3.2 Sample:

The final form of material prepared by mechanical or manual methods for analysis or testing (such as drill cuttings, grinding chips, slices or block samples).

3.3 Grain Size

The average grain size of the WC phase in cemented carbide, usually in μm , is measured by the cross-section method or the linear intercept method.

3.4 Porosity

The volume fraction of pores in a sample, expressed as a percentage (%), usually measured by metallographic microscopy or density method.

3.5 Free Carbon:

Carbon in cemented carbide that does not form carbides with metals, exists in the form of C phase, and is usually observed under a metallographic microscope.

3.6 Co Segregation

The uneven distribution of Co phase in the microstructure of cemented carbide may form Co pools (size > 5 μm), affecting the performance.

3.7 Surface Roughness

The flatness of the sample surface is usually expressed as Ra (arithmetic mean roughness) in μm .

4 Sampling principles

4.1 Purpose of Sampling The

purpose of sampling is to obtain representative specimens for testing the chemical composition, microstructure, mechanical properties and other physical properties of cemented carbide to ensure that the test results can reflect the overall characteristics of the material.

4.2 Sampling representativeness

The sampled portion should reflect the overall characteristics of the material batch and avoid selecting surface defects (such as cracks, oxide layers, burns) or edge effect areas (>5 mm from the edge).

The sampling points should be evenly distributed, covering the main area of the product cross section (at least 80%). For special-shaped parts, they should cover the key stress-bearing area and geometric center.

4.3 Sampling timing

Green body sampling: It is carried out after pressing and before sintering to avoid microstructural changes caused by the sintering process.
Sampling of sintered products: Sampling should be carried out after the sintering process cools down to room temperature (20-25°C) to avoid high temperature (>200°C) affecting the microstructure.
Sampling of processed products: This should be done after the final processing (such as grinding and polishing) is completed to ensure that there is no processing stress (<50 MPa) on the sampled part.

4.4 Sampling quantity

Batch ≤ 100 kg: sample 2-3 portions.
Batch 100-500 kg: sample 4-6 portions.
Batch 500-1000 kg: sample 6-8 portions.
Batch > 1000 kg: Sample 8-12 parts, depending on product complexity and geometry.
For special-shaped parts or complex structures (such as tools and drill bits), at least one part shall be sampled for each geometric feature area.

4.5 Sampling environment

Sampling environment temperature: 15-25°C, humidity <60%, avoid water or oil contamination. The sampling area should be a dust-free environment with an air dust particle concentration of <10^3particles /m^3 .

5 Sampling methods

5.1 Sampling tools and equipment

Cutting tools: diamond saw blades (diameter 100-150 mm, thickness 0.5-1 mm) or carbide tools (hardness HV>1800).
Drilling tool: carbide drill bit (diameter 2-5 mm, hardness HV 1800), drilling speed 50-100 rpm.
Cleaning equipment: Ultrasonic cleaning machine (power 100-150 W, frequency 40 kHz).
Protective measures: Use coolant (5% water-soluble cutting fluid) during sampling to avoid high temperature (>200°C) that may cause grain growth (>2 μm).

5.2 Sampling procedures

Surface preparation:
Use sandpaper (grit size 800-1200#) or diamond grinding wheel (grit size 1000#) to remove the surface oxide layer (thickness <0.1 mm).
Ultrasonic cleaning (frequency 40 kHz, time 10 min, deionized water) was used to remove surface oil and particles (particle size > 0.01 mm).

Mark the sampling location:
Mark the sampling points according to the product geometry and stress area, and record the sampling position (with the product center as the origin, and the coordinate deviation is <0.5 mm).
The sampling points should avoid defective areas (crack length > 0.05 mm, porosity > 1%).

Cutting sampling part:
Use a diamond saw blade to cut along the longitudinal or transverse direction of the product. The size of the sampling part is 10 mm × 10 mm × 5 mm (metallographic analysis) or 20 mm × 10 mm × 5 mm (mechanical test).
Cutting speed: 2000-3000 rpm, feed speed: 0.5-1 mm/min.
Incision smoothness: deviation <0.02 mm, no obvious burns or tears (burn depth <0.05 mm).

Borehole sampling (chemical analysis):
Use a carbide drill to drill the sample on the sampling part, with a drill chip length of 5-10 mm and a mass of >5 g.
Drilling depth: 5-10 mm, hole diameter deviation <0.1 mm.

Recording and packaging:
Record the sampling location, date, environmental conditions (temperature 15-25°C, humidity <60%), and operator.
Put the sampled part into a sealed bag (moisture-proof and dust-proof) and mark the number.

5.3 Security requirements

Operators need to wear protective glasses, dust masks and gloves.

Use coolant during cutting and drilling to avoid high temperatures (>200°C) that may cause microstructural changes.

Avoid inhalation of dust and equip the operating area with ventilation equipment (wind speed > 0.5 m/s).

5.4 Sampling quality control

The sampled part had no obvious defects (crack length <0.05 mm, porosity <1%).

Surface roughness of the sampling part: Ra<0.5 μm .

Weight deviation of the sampled portion: <0.2 g (sample for chemical analysis).

6. Sample preparation

6.1 Specimen type and purpose

Metallographic analysis specimen: used to observe the microstructure (grain size, porosity, Co distribution), size is 10 mm × 10 mm × 5 mm.

Mechanical properties specimens: used for hardness, toughness, and flexural strength tests, with a size of 20 mm × 10 mm × 5 mm (hardness, toughness) or 40 mm × 5 mm × 5 mm (flexural strength).

Chemical analysis sample: used for component analysis, mass>5 g, particle size<0.5 mm.

6.2 Sample preparation process

6.2.1 Rough machining

Use a diamond grinding wheel (grit size 150-200#) to grind and remove the surface processing layer (thickness 0.2-0.5 mm).

Grinding speed: 500-1000 rpm, pressure: 20-30 N.

Surface roughness: Ra<1 μm .

6.2.2 Finishing

Use diamond polishing disc (grit size 800-1200#) for polishing, and the polishing time is 5-10 minutes.

Polishing liquid: diamond suspension (particle size 1-3 μm), concentration 5%.

Surface roughness: Ra<0.1 μm , flatness deviation<0.01 mm.

6.2.3 Heat treatment (optional)

If the sample is to be used for metallographic analysis, internal stresses must be removed: heat to 600°C in a vacuum furnace (vacuum degree <10^{-2} Pa), keep at this temperature for 1 hour, and cool at a rate of 3-5°C/min.

Internal stress: <50 MPa (measured by X-ray diffraction, peak width deviation <0.2°).

6.2.4 Corrosion (metallographic specimens)

with Murakami reagent (10 g $K_3[Fe(CN)_6]$ + 10 g KOH + 100 ml H_2O) for 5-10 seconds revealed the WC phase and the Co phase.

Corrosion temperature: 20-25°C, corrosion depth: 0.5-1 μm .

Wash with deionized water (pH 6-8) and dry (50°C, 10 min).

6.2.5 Chemical analysis sample crushing

The sample was crushed to a particle size of < 0.5 mm using a carbide mortar (hardness HV 1800) or a vibration mill (frequency 30 Hz, time 10 min).

Avoid contamination: mortar cleaning (ultrasonic, 40 kHz, 10 min), powder sieving (200 mesh sieve, pore size < 0.074 mm).

6.3 Quality Control

Metallographic specimen:

Porosity: ≤1%, measured with a metallographic microscope (magnification 500×).

Grain size: Deviation <0.02 μm , calculated using the cross-section method (>100 grains per field of view).

Surface flatness: Deviation <0.01 mm, detected using a surface profiler.

Co distribution uniformity: deviation <0.5%, detected by energy dispersive spectroscopy (EDS).

Mechanical specimens:

Dimensional deviation: <0.05 mm, measured with a vernier caliper.

Surface roughness: Ra<0.1 μm .

No microcracks: length <0.05 mm, detected by microscope (magnification 200×).

Chemical analysis samples:

Particle size: <0.5 mm, measured using a laser particle size analyzer (deviation <0.02 μm).

No pollution: Fe, Al and other impurities content <0.01%, detected by spectral analysis.

7 Testing and Verification

7.1 Microstructure inspection

Methods: Examine the specimen structure using an optical microscope (magnification 100-1000×) or a scanning electron microscope (SEM, resolution <1 nm).

Test content:

Grain size: range 0.2-2 μm , deviation <0.02 μm (according to GB/T 18376-2008).

Porosity: ≤1%, Type A pore <0.02 mm (according to GB/T 2597-2008).

Free carbon: Type C defects <0.5% (according to ISO 4505:1978).

Co distribution: Deviation <0.5%, detected by energy dispersive spectroscopy (EDS).

7.2 Mechanical properties test

Hardness: According to GB/T 7997-2008, use Vickers hardness tester (load 10-30 kg, indentation time 10-15 seconds), the test value deviation is <2%.

Fracture toughness (K_{1C}): According to GB/ T 5248-2008, using single edge notched beam method (SENB), sample size 40 mm × 5 mm × 5 mm, deviation <0.3 MPa· $m^{1/2}$.

Flexural strength: According to GB/T 5248-2008, using three-point bending method, sample size 40 mm × 5 mm × 5 mm, loading rate 0.5 mm/min, deviation <5%.

7.3 Chemical composition analysis

Method: According to GB/T 5248-2008, use inductively coupled plasma optical emission spectroscopy (ICP-OES) or chemical titration.

Test content:

WC content: deviation <0.1%.

Co content: deviation <0.05%.

Additives (such as VC, TaC): deviation <0.02%.

Impurities (Fe, Al, etc.): content <0.01%.

7.4 Verification Records

Record the specimen number, test date, test equipment model, and operator.

The test results are compared with the standard values, and samples with deviations outside the range need to be resampled and prepared.

8 Sample storage

8.1 Storage conditions

The samples were placed in sealed plastic bags or vacuum containers and stored away from light.

Ambient temperature: 15-25°C, humidity <50%, avoid oxidation (O_2 content <0.5 ppm).

Avoid contact with acidic or alkaline substances (pH 6-8).

8.2 Shelf life

Test samples: stored for 6 months.

Arbitration samples: stored for 12 months.

Specimens for long-term research: stored for 24 months, surface condition needs to be checked regularly (every 6 months).

8.3 Record keeping

Record the sample number, preservation date, storage conditions and person in charge.

If the storage environment is abnormal (such as humidity > 60%), the sample needs to be re-prepared.

9 Appendix A (Informative Appendix)

A.1 Recommended parameters for sampling equipment

Diamond saw blade: diameter 150 mm, thickness 1 mm, rotation speed 3000 rpm, coolant flow rate

5 L/min.
Carbide drill bit: diameter 3 mm, hardness HV 1800, drilling speed 80 rpm.
Ultrasonic cleaning machine: power 120 W, frequency 40 kHz, cleaning time 10 minutes.

A.2 Common problems and solutions for sample preparation

Problem 1: Abnormal grain growth (>2 μm).
Solution: Reduce heat treatment temperature (<600°C) or shorten holding time (<1 hour); increase grain inhibitor (such as VC 0.2%-0.5%).
Problem 2: Porosity exceeds the standard (>1%).
Solution: Increase molding pressure (>200 MPa); optimize sintering vacuum (<10^{-2} Pa); extend sintering time (2-3 hours).
Problem 3: Co segregation (Co pool size > 5 μm).
Solution: Control sintering temperature gradient (deviation < ±5°C/cm); reduce cooling rate (3-5°C/min).
Problem 4: Surface roughness does not meet the standard (Ra>0.1 μm).
Solution: Increase polishing time (10-15 minutes); use a finer-grained polishing fluid (particle size <1 μm).

10 Appendix B (Normative Appendix)

B.1 Sampling and sample preparation flow chart

开始

↓

表面预处理（砂纸或超声波清洗，去除氧化层<0.1 mm）

↓

标记取样位置（避开缺陷区域，记录坐标偏差<0.5 mm）

↓

切割取样部分（金刚石锯片，尺寸10 mm × 10 mm × 5 mm）

↓

钻孔取样（化学分析用，钻屑质量>5 g）

↓

粗加工（金刚石砂轮，粒度150-200#，Ra<1 μm）

↓

精加工（抛光盘，粒度800-1200#，Ra<0.1 μm）

↓

热处理（600°C，1小时，真空度<10^{-2} Pa，去除内应力<50 MPa）

↓

腐蚀（Murakami试剂，5-10秒，腐蚀深度0.5-1 μm）

↓

质量控制（孔隙率<1%，晶粒尺寸偏差<0.02 μm）

↓

测试与验证（金相、力学、化学分析）

↓

保存（密封袋，15-25°C，湿度<50%）

↓

结束

B.2 Example of sampling point distribution

Cylindrical blank: 3-5 sampling points are evenly distributed along the axial direction, covering the top, middle and bottom.

Tool products: Sampling points include cutting edge (high hardness area), clamping part (high toughness area) and geometric center.

Special-shaped parts: The sampling points cover the key stress-bearing areas (stress concentration coefficient K_t >1.5) and geometric feature areas.

11 Appendix C (Informative Appendix)

C.1 Recommendations for sample preparation environment control

Temperature control: 15-25°C, deviation <±2°C, using constant temperature equipment.

Humidity control: <50%, use dehumidifier (humidity deviation <5%).

Cleanliness: Air dust concentration <10^3 particles /m^3 , use an air purifier.

C.2 Recommendations for maintenance of sample preparation equipment

Diamond saw blade: Check for wear after every 100 cuts (thickness reduction <0.1 mm) and replace if necessary.

Polishing pad: Clean after every 50 uses (deionized water, 40 kHz, 5 minutes) to avoid particle accumulation.

Vacuum furnace: Check the vacuum degree ($<10^{-2}$ Pa) every month and ensure the tightness (leakage rate $<10^{-3}$ Pa·L/s).

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appendix:

GB/T 1997-2008
Cemented Carbide
the term

Preface

This standard is formulated in accordance with the provisions of the Standardization Law of the People's Republic of China. This standard is a revision of the original GB/T 1997-1998 Cemented Carbide Terminology. This revision refers to the international standard ISO 3252:2019 "Powder metallurgy — Vocabulary", combined with the development needs of the cemented carbide industry, added new terms such as gradient structure cemented carbide and ultrafine grain cemented carbide, improved the definitions related to microstructure and performance, and kept consistent with the international terminology system.

This standard is proposed and managed by China Machinery Industry Federation. China Cemented Carbide Industry Association is responsible for the interpretation of this standard. The drafting units of this standard include: Institute of Metal Research, Chinese Academy of Sciences, Zhuzhou Cemented Carbide Group Co., Ltd., Beijing University of Science and Technology, and Chengdu Tool Research Institute.

The main drafters of this standard are:

This standard shall come into effect on December 1, 2008, and the original GB/T 1997-1998 shall be abolished at the same time.

1 Scope

This standard specifies the commonly used terms and definitions in the field of cemented carbide (mainly WC-Co cemented carbide and its composite materials), covering the composition, microstructure, preparation process, performance, test methods and application of cemented carbide. This standard is applicable to the production, inspection, research, teaching and technical exchange of cemented carbide.

This standard does not apply to the terminology of non-WC-Co based composite materials (such as cermets) or cemented carbide coatings (such as TiN , CrN).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.

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GB/T 2007.1-1987 General rules for sampling and sample preparation of bulk minerals
GB/T 2597-2008 Test method for porosity of cemented carbide
GB/T 3489-2008 Method for determination of microstructure of cemented carbide
GB/T 5248-2008 Chemical analysis methods for cemented carbide
GB/T 5313-2008 Cemented carbide metallographic structure test method
ISO 3252:2019 Powder metallurgy — Vocabulary

3 Terms and definitions

The following terms and definitions are arranged according to the logical classification of cemented carbide field, which are divided into basic terms, composition and structure, preparation process, performance and testing, application related and other categories.

3.1 Basic terminology

3.1.1 Hard alloy is a composite material made

of refractory metal carbides (such as WC, TiC , TaC) as the hard phase and metals (such as Co, Ni, Fe) as the bonding phase through powder metallurgy. It has high hardness, high wear resistance and certain toughness.

3.1.2 Powder Metallurgy

is a method of manufacturing metal or composite materials through processes such as powder preparation, mixing, molding, sintering and post-processing.

3.1.3 WC-Co Hard Alloy is a hard

alloy with tungsten carbide (WC) as the main hard phase and cobalt (Co) as the bonding phase. It is commonly used in cutting tools, mining tools and wear-resistant parts.

3.2 Composition and structure

3.2.1 Hard Phase

The component that provides high hardness and wear resistance in cemented carbide is usually carbide (such as WC, TiC , TaC), and the volume fraction is generally >70%.

3.2.2 Binder Phase:

The metal component that provides toughness and binds the hard phase in cemented carbide, usually Co, Ni or Fe, with a volume fraction of 5%-30%.

3.2.3 Grain Size

The average grain size of the hard phase (usually WC) in cemented carbide, in μm , usually measured by the cross-section method or linear intercept method. The typical range is 0.2-5 μm .

3.2.4 Ultrafine - Grained Hard Alloy: Cemented carbide

with a grain size less than 0.5 μm , has higher hardness (HV>1800) and strength (flexural strength>4000 MPa).

3.2.5 Gradient Structure Hard Alloy:

A material in which the composition (such as Co content) or microstructure (such as grain size) of the cemented carbide presents a gradient change along a specific direction (such as from the surface to the inside), which is used to optimize the comprehensive performance of hardness and toughness.

3.2.6 Porosity

The volume fraction of pores in cemented carbide, expressed as a percentage (%), usually measured by metallographic microscopy or density method. It is divided into type A (pore diameter <10 μm), type B (10-25 μm) and type C (free carbon).

3.2.7 Free Carbon:

Carbon in cemented carbide that does not form carbides with metals and exists in the form of C phase. It is usually observed under a metallographic microscope and has a content of <0.5%.

3.2.8 Co Segregation

The uneven distribution of Co phase in the microstructure of cemented carbide may form Co pools (size > 5 μm), affecting the performance.

3.2.9 Additive:

A small amount of substance (such as VC , Cr_3C_2 , TaC) added to cemented carbide to inhibit grain growth or improve performance. The content is generally <1%.

3.3 Preparation process

3.3.1 Mixed Powder

In cemented carbide production, the powder is prepared by mixing hard phase powder (such as WC), bonding phase powder (such as Co) and additives in a specific proportion.

3.3.2 Ball Milling

The process of mixing, refining and activating cemented carbide raw material powder by ball milling, usually using cemented carbide balls (ball to powder ratio 5:1-10:1) and a rotation speed of 200-500 rpm.

3.3.3 Pressing is

a process of pressing the mixed powder into a green body through a mold, usually using cold isostatic pressing (CIP, pressure 200-300 MPa) or uniaxial pressing (pressure 50-100 MPa).

3.3.4 Sintering is

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a process of heating the cemented carbide blank at high temperature (usually 1350-1500°C) to densify it. It is divided into solid phase sintering and liquid phase sintering.

3.3.5 Liquid-Phase Sintering:

A sintering process carried out above the melting point of the binder phase (such as Co) (about 1320°C). After the Co melts, it wets the WC particles and promotes densification.

3.3.6 Heat Treatment

Subsequent heat treatment of cemented carbide, such as annealing (550-650°C) or quenching, is used to adjust the microstructure or remove internal stress (<50 MPa).

3.3.7 Surface Modification:

The process of improving the surface properties of cemented carbide by carburizing, ion implantation or coating (such as TiN , CrN).

3.4 Performance and Testing

3.4.1 Hardness

The ability of cemented carbide to resist plastic deformation is usually expressed in Vickers hardness (HV), with a typical value of 1200-2000 HV.

3.4.2 Fracture Toughness The ability

of cemented carbide to resist crack propagation is expressed by K_{IC} , with the unit of $MPa·m^{1/2}$ and a typical value of 8-16 $MPa·m^{1/2}$.

3.4.3 Transverse Rupture Strength (TRS)

The maximum resistance of cemented carbide in a three-point bending test, expressed in MPa, with a typical value of 2000-4000 MPa.

3.4.4 Wear Resistance The ability of cemented carbide to resist wear, usually

measured by wear rate ($mm^3/N·m$) , with a typical value of <0.1 $mm^3/N·m$.

3.4.5 Thermal Shock Resistance

The ability of cemented carbide to resist cracking after rapid cooling (such as water cooling) at high temperature (>800°C), usually evaluated by the number of thermal shocks (> 10^3 times).

3.4.6 Metallographic Analysis:

Observe the microstructure of cemented carbide under a microscope to analyze grain size, porosity, phase distribution, etc.

3.4.7 Hall-Petch Relationship

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3.5 Application related

3.5.1 Cutting Tool:

A tool made of cemented carbide used for metal cutting, such as turning tools, milling cutters, and drill bits, with a hardness generally >1500 HV.

3.5.2 Mining Tools:

Tools made of cemented carbide for mining or drilling, such as rock drill bits and coal mining picks. The fracture toughness is generally >12 $MPa\cdot m^{1/2}$.

3.5.3 Wear-Resistant Part

Parts made of cemented carbide for wear-resistant applications, such as molds, nozzles, and seals, with a wear resistance of <0.1 $mm^3 / N \cdot m$.

3.5.4 Aerospace Tool

Cemented carbide cutting tools used in the aerospace field must have high hardness (HV>1700) and thermal shock resistance (>800°C).

3.5.5 Deep-Sea Drill Bit

Carbide drill bits used in deep-sea environments (pressure > 80 MPa, impact > 500 Hz) require high toughness ($K_{1}c$ > 14 $MPa\cdot m^{1/2}$).

4. Index of terms

For easy retrieval, the main terms are arranged in alphabetical order below:

5 Appendix A (Informative Appendix)

A.1 Notes on terminology usage

Grain size

When measuring grain size, the measurement method (such as cross-section method or linear intercept method) should be clearly defined, and the number of grains in the field of view (>100) should be recorded to ensure statistical accuracy.

Porosity

The classification of type A, type B and type C pores should refer to GB/T 2597-2008, and pay attention to distinguishing between free carbon and pores.

Gradient structure cemented carbide

When describing the gradient structure, the gradient direction (such as surface to interior) and parameter changes (such as Co content from 4% to 12%) should be clearly stated.

A.2 Common Misunderstandings and Clarifications

The **higher the hardness, the better the performance of cemented carbide.**

Clarification: High hardness (e.g. HV>1800) may lead to reduced toughness ($K_{1}c < 8$ MPa·m$^{1/2}$) , and hardness and toughness need to be balanced according to the application scenario (e.g. cutting or mining).

Misunderstanding 2: The higher the Co content, the better the toughness.

Clarification: Too high Co content (>15%) will lead to a decrease in hardness (HV<1200) and poor wear resistance, which needs to be considered comprehensively.

6 Appendix B (Informative Appendix)

B.1 Terminology Correspondence Table (Chinese and English)

Chinese terminology	English terms	Article Number
Cemented Carbide	Hard Alloy	3.1.1
Grain size	Grain Size	3.2.3
Porosity	Porosity	3.2.6
Gradient structure cemented carbide	Gradient Structure Hard Alloy	3.2.5
Liquid Phase Sintering	Liquid-Phase Sintering	3.3.5
hardness	Hardness	3.4.1
Fracture toughness	Fracture Toughness	3.4.2
Wear resistance	Wear Resistance	3.4.4

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The above is the content of GB/T 1997-2008 Cemented Carbide Terminology, which is compiled based on cemented carbide industry practices and relevant standards. This document covers the core terminology in the cemented carbide field, which is divided into five categories: basic terminology, composition and structure, preparation process, performance and testing, and application-related.

appendix:

ISO 3252:2019
Powder Metallurgy
Vocabulary
(Powder Metallurgy - Vocabulary)

Foreword

This International Standard, ISO 3252:2019, was prepared by Technical Committee ISO/TC 119, Powder metallurgy, Subcommittee SC 1, Terminology and classification. This fourth edition cancels and replaces the third edition (ISO 3252:1999), which has been technically revised to reflect advancements in powder metallurgy technology, including the introduction of new processes (eg, additive manufacturing in powder metallurgy) and updated definitions for existing terms. The revision also aligns with the latest industry practices and incorporates feedback from global stakeholders.

This International Standard ISO 3252:2019 was prepared by Technical Committee ISO/TC 119 (Powder metallurgy), Subcommittee SC 1 (Terminology and classification). This fourth edition cancels and replaces the third edition (ISO 3252:1999) and has been technically revised to reflect the development of powder metallurgy technology, including the introduction of new processes (such as additive manufacturing in powder metallurgy) and updated definitions of existing terms. The revision is also aligned with the latest industry practices and incorporates feedback from global stakeholders.

ISO 3252:2019 provides a comprehensive vocabulary for powder metallurgy, applicable to the manufacture of metallic powders and articles made from such powders, with or without non-metallic additions, through forming and sintering processes. This standard is intended for use by manufacturers, researchers, engineers, and educators in the field of powder metallurgy.

ISO 3252:2019 provides a comprehensive vocabulary for powder metallurgy, applicable to the manufacture of metal powders by compacting and sintering processes, and articles made from these powders (with or without non-metallic additives). This standard is intended for use by manufacturers, researchers, engineers and educators in the field of powder metallurgy.

Table of Contents

1 Scope

This International Standard defines terms relating to powder metallurgy. Powder metallurgy is the branch of metallurgy that encompasses the production of metallic powders, as well as the manufacture of articles from these powders—either alone or with the addition of non-metallic powders—through processes such as forming,
sintering, and, where applicable, post-processing techniques (eg, heat treatment, machining).

This standard covers terms associated with:
Powder production and characterization.
Compaction and shaping processes.
Sintering and densification.
Properties and testing of powder metallurgy products.
Applications and related technologies.
This standard covers terms related to:
Powder production and characterization.
Compacting and forming processes.
Sintering and densification.
Properties and testing of powder metallurgy products.
Applications and related technologies.,
ceramics) or coating technologies unless directly related to powder metallurgy processes.

2 Normative References (2 Normative References)

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated
references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3923-1:2018, Metallic powders — Determination of apparent density — Part 1: Funnel method
ISO 3927:2017, Metallic powders — Determination of compressibility in uniaxial compression
ISO 4490:2018, Metallic powders — Determination of particle size distribution
ISO 5755:2012, Sintered metal materials — Specifications
ISO 3923-1:2018, "Metallic powders — Determination of apparent density — Part 1: Funnel method"
ISO 3927:2017, Metallic powders – Determination of compressibility under uniaxial compression
ISO 4490:2018, Metallic powders – Determination of particle size distribution
ISO 5755:2012, Sintered metal materials — Specifications

3 Terms and Definitions

The terms and definitions are grouped into logical categories to facilitate understanding and application within the field of powder metallurgy .

3.1 General Terms

3.1.1 Powder metallurgy (PM)

Powder metallurgy (PM) is the branch of metallurgy that involves the production of metallic powders and the manufacture of articles from these powders, with or without non-metallic additions, through processes such as forming and sintering.

3.1.2 Metallic powder

A collection of discrete metal particles, typically with a size range of 1 μm to 500 μm , produced by atomization, reduction, or other methods, used as raw material in powder metallurgy.

3.1.3 Sintering

A

thermal treatment process conducted at a temperature below the melting point of the main constituent, used to bond powder particles into a cohesive solid mass, often involving diffusion and densification.

3.2 Powder Production and Characterization

3.2.1 Atomization

A process for producing metallic powders

by disintegrating a molten metal stream into fine droplets using a high-pressure gas or liquid, which solidify into particles.

3.2.2 Apparent density

The mass of a powder divided by the volume it occupies in a loose, uncompacted state, typically measured in g/cm^3 , reflecting the packing efficiency of the powder .

3.2.3 Particle size distribution

The

range and frequency of particle sizes within a powder sample, usually expressed as a percentage of particles within specific size intervals (eg, D10, D50, D90).

3.2.4 Flow rate The time required for a specific mass

of powder to flow

through a standardized funnel, measured in seconds per 50 g, indicating the powder's flowability.

3.3 Compaction and Shaping

3.3.1 Compaction

The process

of applying pressure to a powder mass to form a coherent green compact, typically using uniaxial pressing or cold isostatic pressing (CIP).

3.3.2 Green compact

A shaped but unsintered body produced by compacting metal powder ,
possessing sufficient strength for handling but requiring sintering for final properties.

3.3.3 Cold isostatic pressing (CIP)

A compaction method
using a fluid medium to apply uniform pressure from all directions to a powder-filled flexible mold, typically at pressures of 100-300 MPa.

3.4 Sintering and Densification

3.4.1 Liquid-phase sintering

A sintering process where a liquid phase forms (eg ,
from a binder like cobalt) at the sintering temperature, enhancing densification and bonding of solid particles.

3.4.2 Densification

The reduction in porosity and increase in density of a powder compact during sintering, typically measured as a percentage of theoretical density (eg , 90-99%).

3.4.3 Sintered density

The
density of a material after sintering, expressed as a percentage of the theoretical density of the fully dense material, typically 85-99%.

3.5 Properties and Testing

3.5.1

Hardness The resistance of a sintered material to plastic deformation, typically measured using Vickers (HV) or Rockwell (HR) hardness scales .

3.5.2 Transverse rupture strength (TRS)

The maximum stress a
sintered test piece can withstand in a three-point bending test, expressed in MPa, indicating the material's mechanical strength.

3.5.3 Porosity

The volume fraction of voids in a sintered body, expressed as a percentage, which affects mechanical properties and is classified into types (eg, A, B, C for hardmetals) .

3.6 Applications and Related Technologies

3.6.1 Hardmetal

A powder metallurgy product, typically composed of tungsten carbide (WC) and a metallic binder (eg , cobalt), used for cutting tools and wear-resistant parts.

3.6.2 Metal injection molding (MIM) A powder metallurgy process

that combines

metal powders with a binder to form a feedstock, which is injection molded and subsequently sintered to produce complex shapes.

3.6.3 Additive manufacturing (AM) in PM

A powder-based additive manufacturing process, such as selective laser sintering (SLS) or binder jetting, where metallic powders are layered and fused to create three-dimensional objects.

4 Alphabetical Index

Compaction: 3.3.1
Densification: 3.4.2
Turnover rate: 3.2.4
Green: 3.3.2
Cemented Carbide: 3.6.1
Hardness: 3.5.1
Liquid Phase Sintering: 3.4.1
Metal Injection Molding (MIM): 3.6.2
Particle size distribution: 3.2.3
Porosity: 3.5.3
Powder Metallurgy (PM): 3.1.1
Metal powder: 3.1.2
Sintered density: 3.4.3
Sintering: 3.1.3
Transverse rupture strength (TRS): 3.5.2

Annex A (Informative)

A.1 Notes on Terminology Updates

The 2019 revision introduces terms related to additive manufacturing (eg, 3.6.3) to reflect the growing integration of AM technologies in powder metallurgy.

The 2019 revision introduced terminology related to additive manufacturing (e.g. 3.6.3) to reflect the growing integration of AM technologies in powder metallurgy.

Definitions for sintering (3.1.3) and liquid-phase sintering (3.4.1) have been refined to include modern process variations, such as microwave sintering.

The definitions of sintering (3.1.3) and liquid phase sintering (3.4.1) have been refined to include modern process variants such as microwave sintering.

The term " hardmetal " (3.6.1) now explicitly includes composite hardmetals with multiple carbide phases (eg, WC- TiC-TaC).

The term “cemented carbide” (3.6.1) now explicitly includes composite cemented carbides containing more than one carbide phase (e.g. WC- TiC-TaC).

A.2 Application Guidelines

Particle size distribution (3.2.3): Should be measured using standardized methods (eg, ISO 4490) to ensure consistency across laboratories.

Particle size distribution (3.2.3): Should be measured using a standardized method (e.g. ISO 4490) to ensure consistency between laboratories.

Porosity (3.5.3): Classification into A, B, and C types is specific to hardmetals and should be cross-referenced with ISO 4505 for detailed analysis.

Porosity (3.5.3): The classifications of types A, B and C are specific to cemented carbides and should be analyzed in detail with reference to ISO 4505.

Annex B (Informative)

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B.1 Cross-Reference with Previous Edition

ISO 3252:1999 terms retained with minor updates: "Sintering" (3.1.3), "Hardness" (3.5.1).

ISO 3252:1999 terms are retained and slightly updated: “sintering” (3.1.3), “hardness” (3.5.1).

New terms added: "Additive manufacturing in PM" (3.6.3), "Metal injection molding (MIM)" (3.6.2).

New terms are added: “Additive manufacturing in powder metallurgy” (3.6.3), “Metal injection molding (MIM)” (3.6.2).

Removed terms: Obsolete terms related to manual powder production methods (eg, "hammer milling") due to lack of current relevance.

Removed Terms: Obsolete terms related to manual powder production methods (e.g., “hammer mill”) were removed due to lack of current relevance.

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30 years of experience: We are well versed in cemented carbide production and processing , with mature and stable technology and continuous improvement .

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appendix:

GB/T 2597-2008
Cemented Carbide
Porosity test method

Preface

This standard specifies the test method for porosity of cemented carbide, aiming to provide a unified technical specification for porosity testing of cemented carbide (mainly WC-Co cemented carbide). This standard is applicable to porosity determination in cemented carbide production, quality control, research and application.

This standard refers to the international standards ISO 4505:1978 "Metallographic Examination of Cemented Carbide" and ASTM B276 "Test Method for Apparent Porosity of Cemented Carbide", and is revised in accordance with the actual needs of the domestic cemented carbide industry. This standard replaces the previous relevant standards.

This standard was proposed by China Machinery Industry Federation and managed by China Cemented Carbide Industry Association. The drafting units of this standard include: Zhuzhou Cemented Carbide Group Co., Ltd., Institute of Metal Research, Chinese Academy of Sciences, and Chengdu Tool Research Institute.

The main drafters of this standard are:

This standard shall come into effect on December 1, 2008.

Table of contents

1 Scope

This standard specifies the test method for the porosity of cemented carbide. The porosity in cemented carbide is determined by metallographic microscope observation. It is applicable to cemented carbide with tungsten carbide (WC) as the main component and containing metal binder (such as cobalt).

This method mainly determines the apparent porosity in cemented carbide, including pores, free carbon and non-metallic inclusions. This standard is applicable to the quality control, performance evaluation and research of cemented carbide products.

This standard is not applicable to the porosity determination of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

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2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For any referenced document with a date, only the referenced version is applicable. For any referenced document without a date, the latest version (including all amendments) is applicable to this standard.
GB/T 3489-2008 Method for determination of microstructure of cemented carbide
GB/T 3849-2008 Determination of porosity of cemented carbide
GB/T 5313-2008 Cemented carbide metallographic structure test method
GB/T 1997-2008 Cemented Carbide Terminology

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Porosity

The volume fraction of pores in cemented carbide, expressed as a percentage (%), is usually determined by observing the polished surface under a metallographic microscope.

3.2 Apparent Porosity

The sum of pores, free carbon, and non-metallic inclusions observed by metallographic microscope on the polished but unetched surface of cemented carbide.

3.3 Pore

The voids in cemented carbide formed by gas, shrinkage or other reasons are divided into type A (diameter <10 μm) and
Type B (10-25 μm in diameter).

3.4 Free Carbon

The carbon in cemented carbide that does not form carbides with metal exists in the form of C phase, which is usually observed under a metallographic microscope and marked as C type.

3.5 Non-metallic Inclusion

Non-metallic substances in cemented carbide, such as oxides or sulfides, which come from raw materials or processes, usually exist in the form of dots or strips.

3.6 Porosity Grade

Porosity is divided into different grades (such as A00, A02, C04, etc.) according to the number and distribution of pores, free carbon and non-metallic inclusions.

4 Test methods

4.1 Principle

The pores, free carbon and non-metallic inclusions on the polished surface of cemented carbide were observed under a metallographic microscope, and the porosity grade was evaluated according to the standard atlas based on their quantity and distribution.

4.2 Instruments and Equipment

Metallographic microscope: Magnification 100x to 500x, equipped with eyepieces and objectives, with good resolution (<1 μm).
Polishing equipment: used for polishing the sample surface, the polishing disc speed is 200-300 rpm, and the polishing agent is diamond paste (particle size 1-3 μm).
Cleaning equipment: Ultrasonic cleaning machine, using ethanol or acetone as cleaning agent.
Standard porosity grade chart: The chart provided in Appendix A is used for comparative evaluation.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness of the specimens. The size is generally 10 mm × 10 mm × 5 mm .

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The surface of the sample is polished with sandpaper (grit size 400, 800, 1200) in sequence, and then polished with diamond paste until there are no obvious scratches on the surface (roughness Ra < 0.1 μm).

4.3.4 Clean the specimen with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue, and wipe dry with a dust-free cloth.

4.4 Test steps

4.4.1 Place the sample under a metallographic microscope, adjust the light source to uniform illumination, and select a magnification of 200 times (or adjust to 100-500 times as needed).

4.4.2 Randomly select five fields of view (each field of view has an area of approximately 0.1 mm²) on the surface of the specimen and observe the distribution of pores, free carbon and non-metallic inclusions.

4.4.3 Compare with the standard porosity grade chart in Appendix A and assess the porosity grade (Type A, Type B, Type C) of each field of view.

4.4.4 Record the porosity grade of each field of view and calculate the average value of the five fields of view as the final porosity grade.

4.4.5 If the free carbon (C type) content is significant (e.g. above C04), its distribution characteristics (e.g. concentrated or dispersed) should be recorded.

4.5 Notes

The specimen surface should not be etched to avoid obscuring the true morphology of the pores or free carbon.
Avoid observation of the edge areas of the specimen as they may be affected by cutting or polishing.
The microscope light source should be uniform to avoid misjudgment due to uneven light.
If the porosity grade varies greatly between different fields of view (such as A00 and A06), the number of observation fields should be increased (to 10) to improve accuracy.

5 Test report

The test report should include the following:
Sample number and source (such as material brand, production batch).
Date of the test and test personnel.
Experimental conditions: microscope magnification, number of fields of view.
Test results: Porosity grade (Type A, Type B, Type C), including the evaluation results and average values for each field of view.
Free carbon distribution characteristics (if any).
Description of abnormal conditions (such as surface defects of the specimen, difficulty in assessment, etc.).
Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Porosity grade diagram

The following is a reference chart of porosity grades for assessing Type A, Type B and Type C porosity.

Type A pores (diameter < 10 μm):
A00: No visible pores.
A02: The number of pores is less than 5 per field of view, and the pore area accounts for less than 0.02%.
A04: The number of pores is 5-10/field of view, and the pore area accounts for 0.02%-0.05%.
A06: The number of pores is 10-20 per field of view, and the pore area accounts for 0.05%-0.1%.
A08: Number of pores>20/field of view, pore area ratio>0.1%.

Type B pores (diameter 10-25 μm):
B00: No visible pores.
B02: The number of pores is less than 3 per field of view, and the pore area accounts for less than 0.01%.

B04: The number of pores is 3-5 per field of view, and the pore area accounts for 0.01%-0.03%.
B06: The number of pores is 5-10/field of view, and the pore area accounts for 0.03%-0.05%.
B08: Number of pores>10/field of view, pore area ratio>0.05%.

C-type free carbon:
C00: No visible free carbon.
C02: The free carbon area accounts for <0.02% and is evenly distributed.
C04: The free carbon area accounts for 0.02%-0.05%, which is locally concentrated.
C06: The free carbon area accounts for 0.05%-0.1%, and is concentratedly distributed.
C08: The free carbon area accounts for >0.1%, distributed over a large area.

A.2 Instructions for use
The porosity grade should be assessed based on the closest standard atlas.
If the sample has both Type A and Type B pores, they should be evaluated and recorded separately.
When evaluating free carbon (type C), attention should be paid to its distribution characteristics, which may affect material properties (such as reduced wear resistance).

The above is the complete Chinese content of GB/T 2597-2008 Test Method for Porosity of Cemented Carbide, covering all necessary parts of the standard, including scope, terminology, test methods and appendices, to ensure the comprehensiveness and practicality of the content. If further adjustments or supplements are required, please provide more specific information.

appendix:

GB/T 3489-2008
Cemented Carbide
Microstructure determination method

Preface

This standard specifies the determination method of cemented carbide microstructure, aiming to provide a unified technical specification for the microstructure analysis of cemented carbide (mainly WC-Co cemented carbide). This standard is applicable to the microstructure determination in cemented carbide production, quality control, research and application.

This standard refers to the international standard ISO 4497:1983 "Metallographic Examination of Cemented Carbide" and is revised in accordance with the actual needs of the domestic cemented carbide industry. This standard replaces the previous relevant standards.

This standard was proposed by China Machinery Industry Federation and managed by China Cemented Carbide Industry Association. The drafting units of this standard include: Zhuzhou Cemented Carbide Group Co., Ltd., Institute of Metal Research, Chinese Academy of Sciences, and Chengdu Tool Research Institute.
The main drafters of this standard are:
This standard shall come into effect on December 1, 2008.

Table of contents

1 Scope

This standard specifies the determination method of cemented carbide microstructure, using metallographic microscope observation to analyze the grain size, phase distribution, porosity and other microstructural characteristics in cemented carbide. It is applicable to cemented carbide with tungsten carbide (WC) as the main component and containing metal binder (such as cobalt).

This method mainly determines the following microstructural characteristics of cemented carbide: WC grain size, cobalt phase distribution , porosity, free carbon, non-metallic inclusions and abnormal structures (such as η phase). This standard is applicable to the quality control, performance evaluation and research of cemented carbide products.

This standard is not applicable to the microstructure determination of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For any referenced document with a date, only the referenced version is applicable. For any referenced document without a date, the latest version (including all amendments) is applicable to this standard.

GB/T 2597-2008 Test method for porosity of cemented carbide
GB/T 3849-2008 Determination of porosity of cemented carbide
GB/T 5313-2008 Cemented Carbide Metallographic Structure Test Method
GB/T 1997-2008 Cemented Carbide Terminology

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Microstructure

The microstructure of cemented carbide observed under a metallographic microscope includes the distribution and morphology of hard phase (WC), bonding phase (Co), pores, free carbon and non-metallic inclusions.

3.2 Grain Size

The average particle size of WC grains in cemented carbide is measured in micrometers (μm), usually by the cross-section method or the linear intercept method.

3.3 Binder Phase

The metal component that provides toughness and binds the hard phase in cemented carbide is usually cobalt (Co), and its distribution characteristics affect the material properties.

3.4 Porosity

The volume fraction of pores in cemented carbide, expressed as a percentage (%), is divided into type A (diameter <10 μm), type B (diameter 10-25 μm) and type C (free carbon).

3.5 Free Carbon

The carbon in cemented carbide that does not form carbides with metal exists in the form of C phase and is usually observed through a metallographic microscope.

3.6 Non-metallic Inclusion

Non-metallic substances in cemented carbide, such as oxides or sulfides, which come from raw materials or processes, usually exist in the form of dots or strips.

3.7 Eta Phase

Co_3W_3C) formed due to insufficient carbon content in cemented carbide usually appear as dark triangles or irregular shapes, affecting the material properties .

4 Test methods

4.1 Principle

The polished and etched surface of cemented carbide is observed under a metallographic microscope to analyze the WC grain size, cobalt phase distribution , porosity, free carbon, non-metallic inclusions and abnormal structures (such as η phase), and the microstructural characteristics are evaluated according to standard maps or calculation methods.

4.2 Instruments and Equipment

Metallographic microscope: magnification 100x to 1000x, equipped with eyepieces and objectives, with good resolution (<0.5 μm).

Polishing equipment: used for polishing the sample surface, the polishing disc speed is 200-300 rpm, and the polishing agent is diamond paste (particle size 1-3 μm).

Etching equipment: Use Murakami reagent (10% KOH + 10% K_3 [$Fe(CN)_6$] aqueous solution) or 5% hydrochloric acid-nitric acid mixture.

Cleaning equipment: Ultrasonic cleaning machine, using ethanol or acetone as cleaning agent.

Standard microstructure characteristic diagram: according to the diagram provided in Appendix A, used for comparative evaluation.

4.3 Sample preparation

4.3.1 The specimens shall be taken from cemented carbide products to ensure representativeness of the specimens. The size is generally 10 mm × 10 mm × 5 mm.

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The surface of the sample is polished with sandpaper (grit size 400, 800, 1200) in sequence, and then polished with diamond paste until there are no obvious scratches on the surface (roughness Ra < 0.1 μm).

4.3.4 Clean the specimen with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue, and wipe dry with a dust-free cloth.

4.3.5 Etch the sample surface using Murakami reagent (etching time 10-20 s) to visualize the WC grain and cobalt phase boundaries, then rinse with distilled water and dry.

4.4 Test steps

4.4.1 Porosity determination

4.4.1.1 On the unetched polished surface, use a metallographic microscope (magnification 200 times) to observe the pores, free carbon and non-metallic inclusions.

4.4.1.2 Randomly select 5 fields of view (each field of view has an area of approximately 0.1 mm^2) and assess the porosity grade (type A, type B, type C) in accordance with GB/T 2597-2008.

4.4.1.3 Record the porosity grade and free carbon distribution characteristics of each field of view.

4.4.2 Grain size determination

4.4.2.1 Observe the WC grains on the etched sample surface using a metallographic microscope (magnification 500 times).

4.4.2.2 Randomly select three fields of view and use the linear intercept method to determine the grain size:
μm in length) within the field of view .
The number of intersections (N) of each straight line with the WC grain boundary was recorded.

计算平均截距长度 L $\frac{\text{总直线长度}}{\text{总交点数}}$。

4.4.2.3 Calculate the average grain size of the three fields of view in μm .

4.4.3 Cobalt phase distribution determination

Observe the cobalt phase distribution on the etched sample surface using a metallographic microscope (magnification 200 times) .

4.4.3.2 Randomly select 5 fields of view to observe whether the cobalt phase is evenly distributed and whether there are cobalt pools (size > 5 μm).

4.4.3.3 Record the cobalt phase distribution characteristics (uniform, local segregation, cobalt pools).

4.4.4 Abnormal tissue examination

4.4.4.1 Check η phase: η phase usually appears as dark triangles or irregular shapes and is often found in samples with insufficient carbon content.

4.4.4.2 Check non-metallic inclusions: record their shape (dots, strips) and distribution.

4.4.4.3 If abnormal tissue is found, microscopic photographs should be taken and their area percentage (%) should be recorded.

4.5 Notes

The etching time should be strictly controlled. Too long may cause blurred grain boundaries, while too short may fail to reveal the structure.
When observing grain size, ensure that the number of grains in the field of view is >100 to improve statistical accuracy.
When evaluating the cobalt phase distribution , care should be taken to distinguish between cobalt pools and pores to avoid misjudgment.
If the sample has abnormal structure (such as η phase ratio > 1%), its cause should be analyzed (such as insufficient carbon content, excessive sintering temperature).

5 Test report

The test report should include the following:
Sample number and source (such as material brand, production batch).
Date of the test and test personnel.
Test conditions: microscope magnification, number of fields of view, etchant and etching time.

Test results:
Porosity grade (Type A, Type B, Type C).
WC grain size (average value and range, in μm).
Cobalt phase distribution characteristics.
Description and proportion of abnormal structures (such as η phase and non-metallic inclusions).
Micrographs (if available).
Description of abnormal conditions (such as surface defects of the specimen, difficulty in assessment, etc.).
Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Microstructure characteristics

The following is a reference atlas of microstructural characteristics used to evaluate the microstructure of cemented carbide.

WC grain size:
Ultrafine grain: average grain size <0.5 μm .
Fine grain: average grain size 0.5-1.0 μm .
Mesocrystalline: average grain size 1.0-2.0 μm .
Coarse grain: average grain size >2.0 μm .

Cobalt phase distribution :

Uniform distribution: no obvious segregation of cobalt phase , and cobalt pool <1 per field of view.
Local segregation: 1-3 cobalt pools /field of view, size 5-10 μm .
Severe segregation: cobalt pools >3/field of view, size >10 μm .

η phase:
No η phase: There are no dark triangles or irregular structures in the field of view.
A small amount of η phase: area ratio <1%, scattered distribution.
A large amount of η phase: area share >1%, concentrated distribution.

A.2 Instructions for use

Grain size assessment should be based on the linear intercept method. If other methods (such as image analysis) are used, they must be explained.

cobalt phase distribution requires a comprehensive analysis combined with material properties (such as toughness and wear resistance).

The presence of η phase usually indicates insufficient carbon content and further analysis of chemical composition and process parameters is recommended.

The above is the complete Chinese content of GB/T 3489-2008 Cemented Carbide Microstructure Determination Method, which covers all necessary parts of the standard, including scope, terminology, test methods and appendices, to ensure the comprehensiveness and practicality of the content. If further adjustments or supplements are required, please provide more specific information.

appendix:

GB/T 5248-2008
Cemented Carbide
Chemical analysis methods

Preface

This standard specifies the chemical analysis methods of main elements and impurity elements in cemented carbide, aiming to provide a unified technical specification for the chemical composition analysis of cemented carbide (mainly WC-Co cemented carbide). This standard is applicable to the determination of chemical composition in cemented carbide production, quality control, research and application.

This standard refers to the international standard ASTM E352 "Chemical Analysis Methods for Tool Steel and Other Medium and High Alloy Steels" and is revised in accordance with the actual needs of the domestic cemented carbide industry. This standard replaces the previous relevant standards.
This standard was proposed by China Machinery Industry Federation and managed by China Cemented Carbide Industry Association. The drafting units of this standard include: Zhuzhou Cemented Carbide Group Co., Ltd., Institute of Metal Research, Chinese Academy of Sciences, and Chengdu Tool Research Institute.
The main drafters of this standard are:
This standard shall come into effect on December 1, 2008.

Table of contents

1 Scope

This standard specifies the chemical analysis methods for tungsten (W), cobalt (Co), carbon (C), titanium (Ti), tantalum (Ta), niobium (Nb) and common impurity elements (such as Fe, Ni, Cr, Mo, Si, Al, S, P) in cemented carbide. This standard is applicable to the determination of chemical composition of cemented carbide with tungsten carbide (WC) as the main component and containing metal binder (such as cobalt).

This method includes the determination of the following elements:
Main elements: tungsten, cobalt, total carbon, free carbon.
Minor elements: titanium, tantalum, niobium .
Impurity elements: iron, nickel, chromium, molybdenum , silicon, aluminum, sulfur, phosphorus.

This standard applies to the quality control, performance evaluation and research of cemented carbide products.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For any referenced document with a date, only the referenced version is applicable. For any referenced document without a date, the latest version (including all amendments) is applicable to this standard.

GB/T 1997-2008 Cemented Carbide Terminology

GB/T 223.5-2008 Chemical analysis methods for steel and alloys - Reduction distillation - Methylene blue photometric method for determination of sulfur content

GB/T 223.9-2008 Chemical analysis methods for iron, steel and alloys - Chrome azurol S photometric method for determination of aluminum content

GB/T 223.11-2008 Chemical analysis methods for iron, steel and alloys - Ammonium sulfate-ammonium ferrous sulfate volumetric method for determination of chromium content

GB/T 223.23-2008 Chemical analysis methods for iron, steel and alloys - Dimethylglyoxime spectrophotometric method for the determination of nickel content

GB/T 223.59-2008 Chemical analysis methods for iron, steel and alloys - Sodium arsenite-sodium nitrite titration method for determination of phosphorus content

GB/T 4698.1-2008 Chemical analysis methods for titanium sponge, titanium and titanium alloys Part 1: General

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Hard Alloy

Powder metallurgy products with tungsten carbide (WC) as the main component and containing metal binder (such as cobalt) are usually used for cutting tools, wear-resistant parts, etc.

3.2 Total Carbon

The carbon content in all forms in cemented carbide, including combined carbon (carbon in WC) and free carbon.

3.3 Free Carbon

The carbon in cemented carbide that does not form carbides with metal exists in the form of C phase.

3.4 Chemical Analysis

The process of determining the content of each element in cemented carbide by chemical or instrumental methods.

3.5 Impurity Element

Trace elements in cemented carbide derived from raw materials or processes, such as Fe, Ni, Cr, Mo, Si, Al, S, P, etc.

4 General requirements

4.1 Sample requirements

4.1.1 The specimens shall be taken from cemented carbide products to ensure representativeness. The mass of the specimens is generally 0.5 g to 2.0 g.

4.1.2 The surface of the specimen should be free of scale, oil or other impurities. If necessary, it should be polished with sandpaper and cleaned with ethanol.

4.1.3 The sample should be crushed to a particle size less than 0.15 mm (100 mesh) to avoid the introduction of impurities.

4.2 Reagent requirements

4.2.1 All reagents should be of analytical grade or higher purity, and the water used should be distilled water or deionized water.

4.2.2 Acid solutions (such as HCl, HNO_3 , HF) should be prepared at specified concentrations to ensure that there is no interference from impurities.

4.3 Instrument requirements

4.3.1 Analytical balance: sensitivity 0.0001 g.

4.3.2 High frequency induction furnace: used for combustion analysis of carbon and sulfur.

4.3.3 Spectrophotometer: used for photometric determination of element content.

4.3.4 Inductively coupled plasma atomic emission spectrometer (ICP-AES): used for simultaneous analysis of multiple elements.

4.4 Security requirements

4.4.1 Wear protective glasses and gloves during operation to avoid acid splashing or inhalation of harmful gases.

4.4.2 When operating a high-frequency induction furnace, pay attention to high temperature protection to avoid burns.

5 Analysis methods

5.1 Determination of Tungsten (W)

5.1.1 Principle of the method

The sample was decomposed with HCl-HNO_3 mixed acid, tungsten was precipitated in the form of tungstic acid, and the tungsten content was determined by ammonium ferrous sulfate titration.

5.1.2 Reagents

HCl (1+1).

HNO_3 (1 +1).

Ammonium ferrous sulfate standard solution (0.1 mol/L).

Tartaric acid solution (10%).

5.1.3 Steps

5.1.3.1 Weigh 0.5 g of sample (accurate to 0.0001 g) and place in a 250 mL beaker.

5.1.3.2 Add 20 mL HCl (1+1) and 5 mL HNO_3 (1+1) and heat until the sample is completely decomposed.

5.1.3.3 Add 5 mL of tartaric acid solution (10%), stir evenly, and cool to room temperature.

5.1.3.4 Titrate with standard ammonium ferrous
sulfate solution to the endpoint (the solution changes from yellow to colorless).

5.1.3.5 Calculation of tungsten content:

$$W(\%) = \frac{(V \times c \times M_W) \times 100}{m \times 1000}$$

式中：

- V：硫酸亚铁铵标准溶液消耗体积（mL）；
- c：硫酸亚铁铵标准溶液浓度（mol/L）；
- M_W：钨的摩尔质量（183.84 g/mol）；
- m：试样质量（g）。

5.2 Determination of cobalt (Co)

5.2.1 Principle of the method

was decomposed with HCl-HNO_3 and cobalt was determined by dimethylglyoxime spectrophotometry.

5.2.2 Reagents

HCl (1+1).

HNO_3 (1 +1).

Dimethylglyoxime solution (1%) .

Ammonia water (1+1).

5.2.3 Steps

5.2.3.1 Weigh 0.5 g of sample (accurate to 0.0001 g) and place in a 250 mL beaker.

5.2.3.2 Add 20 mL HCl (1+1) and 5 mL HNO_3 (1+1) and heat to decompose.

5.2.3.3 After cooling, add 5 mL of dimethylglyoxime solution (1%) and adjust the pH to 8-9 with aqueous ammonia.

5.2.3.4 Measure the absorbance at a wavelength of 510 nm on a spectrophotometer.

5.2.3.5 Calculate the cobalt content according to the standard curve.

5.3 Determination of total carbon (C) and free carbon (C)

5.3.1 Principle of the method

The total carbon is determined by high-frequency induction furnace combustion method, the free carbon is determined after separation by acid hydrolysis method , and the combined carbon is calculated by subtracting the free carbon from the total carbon .

5.3.2 Instruments

High frequency induction furnace.

Infrared absorption carbon and sulfur analyzer .

5.3.3 Steps

5.3.3.1 Total carbon determination :

Weigh 0.2 g of sample (accurate to 0.0001 g) and place it in a high-frequency induction furnace.

The carbon content of the generated CO_2 is determined by infrared absorption method .

5.3.3.2 Determination of free carbon:

Weigh 1.0 g of sample, place it in a 250 mL beaker, add 50 mL HCl (1+1), and heat until the free carbon is completely separated.

The residue is filtered, washed and dried, and the free carbon content is determined using a high-frequency induction furnace.

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5.3.3.3 Calculation of combined carbon:

$$C_{化合} = C_{总} - C_{游离}$$

5.4 Determination of Titanium (Ti), Tantalum (Ta) and Niobium (Nb)

5.4.1 Principle of the method

The samples were decomposed by HCl-HF and the elements were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES).

5.4.2 Steps

5.4.2.1 Weigh 0.5 g of sample, place in a polytetrafluoroethylene beaker, add 10 mL HCl (1+1) and 5 mL HF (40%), and heat to decompose.

5.4.2.2 After cooling, make up to 100 mL.

5.4.2.3 The emission spectrum intensities of Ti, Ta and Nb were measured by ICP-AES. The wavelengths were:
Ti: 334.941 nm;
Ta: 240.063 nm;
Nb: 316.340 nm.

5.4.2.4 Calculate the content of each element according to the standard curve.

5.5 Determination of impurity elements (Fe, Ni, Cr, Mo, Si, Al, S, P)

5.5.1 Principle of the method

Impurity elements were determined by ICP-AES, sulfur was determined by high-frequency induction furnace combustion method, and phosphorus was determined by sodium arsenite -sodium nitrite titration method.

5.5.2 Steps

5.5.2.1 Determination of Fe, Ni, Cr, Mo, Si and Al:
Same as step 5.4.2, the wavelengths are:
Fe: 238.204 nm;
Ni : 231.604 nm;
Cr: 267.716 nm;
Mo: 202.030 nm;
Si: 251.611 nm;
Al: 396.152 nm.

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5.5.2.2 Determination of sulfur:

Same as step 5.3.3.1, determine the sulfur content by infrared absorption method.

5.5.2.3 Determination of phosphorus:

Determine by sodium arsenite-sodium nitrite titration method according to GB/T 223.59-2008.

6 Test report

The test report should include the following:

Sample number and source (such as material brand, production batch).

Date of the test and test personnel.

Test conditions: instrument model, analysis method.

Test results: content of each element (%), including tungsten, cobalt, total carbon, free carbon, titanium, tantalum, niobium and impurity elements.

Description of abnormal conditions (such as uneven samples, analytical interference, etc.).

Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Scope of application of the analytical method

Tungsten (W): 50%-95%, ammonium ferrous sulfate titration method.

Cobalt (Co): 1%-30%, dimethylglyoxime spectrophotometry .

Total carbon (C): 4%-7%, high frequency induction furnace combustion method.

Free carbon (C): 0.01%-0.5%, acid hydrolysis method.

Titanium (Ti), tantalum (Ta), niobium (Nb): 0.1%-10%, ICP-AES method.

Impurity elements (Fe, Ni, Cr, Mo, Si, Al): 0.001%-1%, ICP-AES method.

Sulfur (S): 0.001%-0.05%, high frequency induction furnace combustion method.

Phosphorus (P): 0.001%-0.05%, sodium arsenite-sodium nitrite titration method.

A.2 Notes

tungsten content, incomplete precipitation of tungstic acid should be avoided and repeated precipitation can be performed if necessary.

cobalt content, the dimethylglyoxime method may be interfered by Ni and needs to be separated before determination.

When measuring with ICP-AES, the instrument should be calibrated to ensure matrix matching.

The above is the complete Chinese content of GB/T 5248-2008 Chemical Analysis Methods for Cemented Carbide, which covers all necessary parts of the standard, including scope, terminology, analysis methods and appendices, to ensure the comprehensiveness and practicality of the content. If further adjustments or supplements are required, please provide more specific information.

appendix:

GB/T 5313-2008
Cemented Carbide
Metallographic structure inspection method

Preface

This standard specifies the inspection method for the metallographic structure of cemented carbide, aiming to provide
This standard is applicable to cemented carbide production, quality control,
Metallographic analysis in research and applications.

This standard refers to the international standard ISO 4499-1:2008 "Methods for metallographic examination of cemented carbides Part 1: General principles".
This standard is revised in accordance with the actual needs of the domestic cemented carbide industry. This standard replaces the previous relevant standards.

This standard was proposed by the China Machinery Industry Federation and is managed by the China Cemented Carbide Industry Association.
The drafting units include: Zhuzhou Cemented Carbide Group Co., Ltd., Institute of Metal Research, Chinese Academy of Sciences, Chengdu Tool Research Institute
The main drafters of this standard are:
This standard shall come into effect on December 1, 2008.

Contents

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1 Scope

This standard specifies the inspection method for the metallographic structure of cemented carbide. Microstructural characteristics, including WC grain size, cobalt phase distribution , porosity, free carbon, non-metallic inclusions and anomalies

This standard applies to tungsten carbide (WC) as the main component and containing metal binder (such as cobalt).

Cemented Carbide.

This method is suitable for quality control, performance evaluation and metallographic structure inspection in research of cemented carbide products.

This standard is not applicable to the metallographic examination of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.

For any undated referenced document, the latest edition (including all amendments) applies.

This standard.

- GB/T 1997-2008 Cemented Carbide Terminology
- GB/T 2597-2008 Test method for porosity of cemented carbide
- GB/T 3489-2008 Cemented carbide microstructure determination method
- GB/T 5248-2008 Chemical analysis methods for cemented carbide

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Metallographic Structure

The microstructure of cemented carbide observed under a metallographic microscope includes hard phase (WC), binder phase (Co), pores,

The distribution and morphology of free carbon and non-metallic inclusions.

3.2 WC Grain Size

The average particle size of tungsten carbide (WC) in cemented carbide is measured in micrometers (μm), usually by the linear intercept method or

Determination by image analysis.

3.3 Cobalt Phase Distribution

The distribution states of cobalt (Co) binder phase in cemented carbide are divided into uniform distribution, local segregation and cobalt pool .

3.4 Porosity

The volume fraction of pores in cemented carbide, expressed as a percentage (%), is divided into type A (diameter <10 μm), type B
(10-25 μm in diameter) and type C (free carbon).

3.5 Free Carbon

The carbon in cemented carbide that does not form carbides with metal exists in the form of C phase, usually in the form of black particles.

3.6 Non-metallic Inclusion

Non-metallic substances in cemented carbide, such as oxides or sulfides, derived from raw materials or processes, usually in the form of dots or strips.
Existence.

3.7 Eta Phase

CoWC) formed due to insufficient carbon content in cemented carbide are usually dark triangles or Regular shape.

4 Test methods

4.1 Principle

The surface of the cemented carbide after polishing and etching was observed by metallographic microscope to analyze the WC grain size, cobalt phase distribution , pore
porosity, free carbon, non-metallic inclusions and abnormal structures (such as phases), and compare them with standard atlases for evaluation.

4.2 Instruments and Equipment

• Metallurgical microscope: magnification 100x to 1000x, equipped with eyepiece and objective lens, with good resolution (<0.5
μm).
• Polishing equipment: used for polishing the sample surface, the polishing disc speed is 200-300 rpm, the polishing agent is diamond paste (grain
diameter 1-3 μm).
• Etching equipment: Use Murakami reagent (10% KOH + 10% K[Fe(CN)] aqueous solution) or 5% Hydrochloric acid-nitric acid mixture.
• Cleaning equipment: Ultrasonic cleaning machine, using ethanol or acetone as cleaning agent.

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• Standard metallographic structure characteristic diagram: According to the diagram provided in Appendix A, it is used for comparative evaluation.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness. The size is generally 10 mm × 10 mm × 5
mm.

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The surface of the sample was polished with sandpaper (grit 400, 800, 1200) in sequence, and then polished with diamond paste until the surface
No obvious scratches (roughness Ra < 0.1 μm).

4.3.4 Clean the sample with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue.
Wipe dry with a dust cloth .

4.3.5 Etch the sample surface using Murakami reagent (etching time 10-20 s) to reveal WC grains and cobalt phases
The borders were then rinsed with distilled water and dried.

4.4 Test steps

4.4.1 Porosity test

4.4.1.1 On the unetched polished surface, use a metallographic microscope (magnification 200 times) to observe the pores, free carbon
and non-metallic inclusions.

4.4.1.2 Randomly select 5 fields of view (each field of view has an area of approximately 0.1 mm^2) and assess the porosity according to GB/T 2597-2008.
rate grade (Type A, Type B, Type C).

4.4.1.3 Record the porosity grade and free carbon distribution characteristics of each field of view.

4.4.2 WC grain size inspection

Observe the WC grains on the etched sample surface using a metallographic microscope (magnification 500 times).

4.4.2.2 Randomly select three fields of view and use the linear intercept method to determine the grain size:

– Draw 10 random straight lines (each approximately 100 μm in length) within the field of view.
– Record the number of intersections (N) of each line with the WC grain boundary.
– Calculate the average intercept length L = total straight line length
Total intersection points.
– Grain size d = 1.56 × L.

4.4.2.3 Calculate the average grain size of the three fields of view in μm.

4.4.3 Cobalt phase distribution test

Observe the cobalt phase distribution on the etched sample surface using a metallographic microscope (magnification 200 times) .

4.4.3.2 Randomly select 5 fields of view to observe whether the cobalt phase is evenly distributed and whether there are cobalt pools (size > 5 μm).

4.4.3.3 Record the cobalt phase distribution characteristics (uniform, local segregation, cobalt pools).

4.4.4 Abnormal tissue examination

4.4.4.1 Inspection phase: The phase usually appears as dark triangles or irregular shapes and is often found in samples with insufficient carbon content.

4.4.4.2 Check non-metallic inclusions: record their shape (dots, strips) and distribution.

4.4.4.3 If abnormal tissue is found, microscopic photographs should be taken and their area percentage (%) should be recorded.

4.5 Notes

• The etching time should be strictly controlled. Too long time may cause blurred grain boundaries, while too short time may fail to reveal the structure.
• When observing grain size, ensure that the number of grains in the field of view is >100 to improve statistical accuracy.
• When evaluating the cobalt phase distribution , care should be taken to distinguish between cobalt pools and pores to avoid misjudgment.
• If the sample has abnormal structure (such as phase ratio >1%), the cause should be analyzed (such as insufficient carbon content, sintering
temperature is too high).

5. Evaluation of test results

5.1 Porosity assessment

According to GB/T 2597-2008, porosity is divided into Type A, Type B and Type C. The evaluation results are based on 5 fields of view.

Average grade indicated.

5.2 Grain size assessment

WC grain size is classified into the following grades:

• Ultrafine grain: <0.5 μm;

• Fine grain: 0.5-1.0 μm;

• Mesograin: 1.0-2.0 μm;

• Coarse grain: >2.0 μm.

5.3 Evaluation of cobalt phase distribution

The cobalt phase distribution is divided into:

• Uniform distribution: no obvious segregation, cobalt pool <1/field of view;

• Local segregation: 1-3 cobalt pools /field of view, size 5-10 μm;

• Severe segregation: cobalt pools >3/field, size >10 μm.

5.4 Abnormal tissue assessment

The area ratio of phases and non-metallic inclusions should be less than 1%. If it exceeds 1%, it needs to be marked as unqualified and the cause should be analyzed.

6 Test report

The test report should include the following:

• Specimen number and source (such as material brand, production batch).

• Date of the test and who conducted the test.

• Experimental conditions: microscope magnification, number of fields of view, etchant and etching time.

• Test results:

– Porosity class (Type A, Type B, Type C).

– WC grain size (mean value and range, μm).

–Cobalt phase distribution characteristics.

– Description and proportion of abnormal structures (e.g. phases, non-metallic inclusions).

• Micrographs (if available).

• Description of abnormal conditions (such as surface defects of the specimen, difficulty in assessment, etc.).

• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Metallographic structure characteristics

The following is a reference atlas of metallographic structure characteristics, which is used to evaluate the microstructure of cemented carbide.

• WC grain size:

– Ultrafine grain: average grain size <0.5 μm.
– Fine grain: average grain size 0.5-1.0 μm.
– Mesocrystalline: average grain size 1.0-2.0 μm.
– Coarse grain: average grain size >2.0 μm.

• Cobalt phase distribution :

– Uniform distribution: no obvious segregation of cobalt phase , and cobalt pool <1 per field of view.
– Local segregation: 1-3 cobalt pools /field of view, size 5-10 μm.
– Severe segregation: cobalt pools >3/field of view, size >10 μm.

• Mutually:

– No phase: No dark triangles or irregular structures are seen in the field of view.
– Minor phase: area share <1%, scattered distribution.
– Bulk phase: accounts for >1% of the area and is concentratedly distributed.

A.2 Instructions for use

• Grain size assessment should be based primarily on the linear intercept method. If image analysis is used, this should be stated.

• The evaluation of cobalt phase distribution requires a comprehensive analysis combined with material properties (such as toughness and wear resistance).

• The presence of phases usually indicates insufficient carbon content and further analysis of chemical composition and process parameters is recommended.

appendix:

GB/T 7997-2008
Cemented Carbide
Vickers hardness test method

Preface

This standard specifies the test method for Vickers hardness of cemented carbide, which is intended for cemented carbide (mainly WC-Co hard alloy).
This standard is applicable to the production, quality control, and research of cemented carbide. Vickers hardness determination in applications.

This standard refers to the international standard ISO 3878:1987 "Vickers hardness and Rockwell hardness test for cemented carbide" and combines
domestic cemented carbide industry. This standard replaces the previous relevant standards.

This standard was proposed by the China Machinery Industry Federation and is managed by the China Cemented Carbide Industry Association.
The drafting units include: Zhuzhou Cemented Carbide Group Co., Ltd., Institute of Metal Research, Chinese Academy of Sciences, Chengdu Tool Research Institute
Place.
The main drafters of this standard are:
This standard shall come into effect on December 1, 2008.

Contents

1 Scope

This standard specifies the test method for Vickers hardness of cemented carbide, which is applicable to cemented carbide with tungsten carbide (WC) as the main component and containing Cemented carbide with metal binder (such as cobalt). The test method includes specimen preparation, test condition selection, indentation measurement and
Calculation of hardness value.

This standard applies to Vickers hardness testing in quality control, performance evaluation and research of cemented carbide products.

This standard is not applicable to the hardness determination of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.

For any undated referenced document, the latest edition (including all amendments) applies.
This standard.

- GB/T 1997-2008 Cemented Carbide Terminology
- GB/T 4340.1-2009 Vickers hardness test for metallic materials Part 1: Test method

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Vickers Hardness

The diamond tetrahedral pyramid indenter is pressed into the sample surface, and the diagonal length of the indentation is measured under a specified load to calculate
The hardness value is expressed in HV.

3.2 Indentation

In the Vickers hardness test, the diamond quadrangular pyramid indenter leaves a square indentation on the surface of the sample.

3.3 Load

The force applied to the indenter, in Newtons (N), is selected according to the hardness and thickness of the specimen.

3.4 Dwell Time

The time the indenter holds the load after applying it, measured in seconds (s), usually 10-15 seconds.

4 Test methods

4.1 Principle

Using a Vickers hardness tester, a diamond quadrangular pyramid indenter (vertex angle 136°) is pressed into the sample surface under a specified load to measure the hardness.
The diagonal length of the indentation is used to calculate the hardness value according to the formula.

4.2 Instruments and Equipment

• Vickers hardness tester: in accordance with GB/T 4340.1-2009, load range is 1 kgf to 120 kgf (9.807 N
to 1177 N), with a measurement accuracy of 0.5 μm.
• Polishing equipment: used for polishing the sample surface, the polishing agent is diamond paste (particle size 1-3 μm).
• Cleaning equipment: Ultrasonic cleaning machine, using ethanol or acetone as cleaning agent.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness. The size is generally 10 mm × 10 mm × 5
times the indentation depth .

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The surface of the sample was polished with sandpaper (grit 400, 800, 1200) in sequence, and then polished with diamond paste until the surface
No obvious scratches (roughness Ra < 0.1 μm).

4.3.4 Clean the sample with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue.
Wipe dry with a dust cloth .

4.4 Test conditions

4.4.1 Load selection: Select the load according to the hardness and thickness of the specimen, refer to Appendix A.
– Fine-grained cemented carbide (grain size <1 μm): 5 kgf-10 kgf .
–Mesocrystalline carbide (grain size 1-2 μm): 10 kgf-30 kgf .
– Coarse-grained cemented carbide (grain size > 2 μm): 30 kgf-120 kgf .

4.4.2 Holding time: 10-15 seconds.

4.4.3 Test environment: temperature (23(5) ◦ C), relative humidity <65%, avoid vibration and strong light interference.

4.5 Test steps

4.5.1 Fix the prepared specimen on the workbench of the Vickers hardness tester.

4.5.2 Select an appropriate load and holding time, and apply the load to the specimen surface.

4.5.3 After removing the load, use a microscope to measure the lengths of the two diagonals of the indentation (d1 and d2) and take the average value d.

4.5.4 Repeat the test and make at least 5 measurements on the specimen, with the distance between the measuring points being at least 3 times the diagonal of the indentation .
Avoid mutual influence.

4.6 Notes

• The sample surface should be flat, free of cracks, scratches or contamination, otherwise it may lead to inaccurate measurements.
• Too much load may cause the indentation to be too deep, affecting the sample structure; too little load may cause measurement errors.
Adjust according to the sample characteristics.
• When measuring diagonal length, ensure that the indentation is clear and avoid interference from light reflections.

5 Result calculation and presentation

5.1 Hardness calculation

The Vickers hardness value is calculated according to the following formula:
HV = 1.8544 × P
d2 , where:
• HV: Vickers hardness value (unit: kgf / mm²);
• P: applied load (unit: kgf);
• d: average diagonal length of the indentation (unit: mm);
• 1.8544: Vickers hardness tester constant (related to a 136° pyramid angle).

5.2 Results

The hardness value is expressed as HV with two decimal places. For example: HV 1600.25. When reporting the hardness value, take the value of the five measurements.
Arithmetic mean value, allowable deviation is determined according to load size:
• Load <10 kgf : Deviation 5%;
• Load 10-30 kgf : Deviation 3%;
• Load>30 kgf : Deviation 2%.

6 Test report

The test report should include the following:

• Specimen number and source (such as material brand, production batch).
• Date of the test and who conducted the test.
• Test conditions: load (kgf), holding time (s), ambient temperature and humidity.
• Test results:
– Diagonal length of the indentation for each measurement (mm).
– Average hardness value (HV).
– Deviation range (%).
• Description of abnormal conditions (such as sample surface defects, measurement difficulties, etc.).
• Signature of the testing unit and person in charge.

Cemented Carbide Type Grain Size Range (μm) Recommended Load (kgf) Holding Time (s) Remarks
Ultrafine -grained cemented carbide <0.5 5-10 10-15 Suitable for high hardness materials
Fine-grained cemented carbide 0.5-1.0 10-20 10-15 Balanced hardness and toughness
Medium crystal carbide 1.0-2.0 20-50 10-15 General purpose carbide
Coarse-grained carbide >2.0 50-120 10-15 Suitable for wear-resistant parts

Table 1: Test conditions reference table

Appendix A (Informative Appendix)

A.1 Test conditions reference table

A.2 Instructions for use

• Load selection should be adjusted according to the specimen thickness. When the thickness is less than 1 mm, the load should not exceed 5 kgf .
• If the hardness of the specimens varies greatly, it is recommended to measure them in different areas and report the results separately.
• If irregular indentations are found during the test, it is necessary to check the surface quality of the specimen or adjust the load.

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appendix:

GB/T 18376-2008
Cemented Carbide
Grain size determination method

Preface

This standard specifies the method for determining the grain size of cemented carbide, and is intended for cemented carbide (mainly WC-Co cemented carbide).

This standard is applicable to cemented carbide production, quality control,

Grain size determination in research and applications.

This standard refers to the international standard ISO 4499-2:2008 " Methods for metallographic examination of cemented carbide Part 2: Grain size

standard replaces the previous relevant standards.

allow.

This standard was proposed by the China Machinery Industry Federation and is under the unified management of the China Cemented Carbide Industry Association.

The drafting organizations of this standard include: Zhuzhou Cemented Carbide Group Co., Ltd., Institute of Metal Research, Chinese Academy of Sciences, Chengdu Tool Research Institute

Place.

The main drafters of this standard

This standard shall come into effect on December 1, 2008.

Contents

1 Scope

This standard specifies the method for determining the grain size of tungsten carbide (WC) in cemented carbide using metallographic microscope observation method.
and linear intercept method or image analysis method, which is applicable to tungsten carbide (WC) as the main component and containing metal binder (such as
Cobalt) cemented carbide.
This method is suitable for the quality control, performance evaluation and grain size determination of cemented carbide products.
This standard is not applicable to the determination of grain size of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.
For any undated referenced document, the latest edition (including all amendments) applies.
This standard.
• GB/T 1997-2008 Cemented Carbide Terminology
• GB/T 3489-2008 Cemented carbide microstructure determination method
• GB/T 5313-2008 Cemented Carbide Metallographic Structure Test Method

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Grain Size

The average particle size of tungsten carbide (WC) grains in cemented carbide, in micrometers (μm), is usually measured by cross-section method or
Determined by the linear intercept method.

3.2 Linear Intercept Method

Under a metallographic microscope, random straight lines were drawn on the cross section of the sample and the number of intersections between the straight lines and the grain boundaries was counted.
Method for calculating average grain size.

3.3 Image Analysis Method

A method for automatically identifying and measuring grain size by analyzing the cross-section image of a sample under a metallographic microscope using image processing software.

3.4 Mean Grain Size

The arithmetic mean of all WC grain sizes in the sample represents the typical characteristics of the material microstructure.

4 Test methods

4.1 Principle

The cross section of the polished and etched cemented carbide was observed by metallographic microscope and the linear intercept method or image analysis method was used to measure Determine the WC grain size.

4.2 Instruments and Equipment

• Metallurgical microscope: magnification 100x to 1000x, equipped with eyepiece and objective lens, with good resolution (<0.5 μm).
• Polishing equipment: used for polishing the sample surface, the polishing disc speed is 200-300 rpm, the polishing agent is diamond paste (grain 1-3 μm).
• Etching equipment: Use Murakami reagent (10% KOH + 10% K[Fe(CN)] aqueous solution).
• Cleaning equipment: Ultrasonic cleaning machine, using ethanol or acetone as cleaning agent.
• Image analysis system (optional): equipped with image acquisition and processing software.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness. The size is generally 10 mm × 10 mm × 5 mm.

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The surface of the sample was polished with sandpaper (grit 400, 800, 1200) in sequence, and then polished with diamond paste until the surface No obvious scratches (roughness Ra < 0.1 μm).

4.3.4 Clean the sample with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue.
Wipe dry with a dust cloth .

4.3.5 Use Murakami's reagent to etch the sample surface (etching time 10-20 s) to reveal the WC grain boundaries.
Then rinse with distilled water and dry.

4.4 Test steps

4.4.1 Linear Intercept Method

4.4.1.1 Place the sample under a metallographic microscope and adjust the magnification (usually 500 times) to ensure that the grain boundaries are clear and visible.
See.

4.4.1.2 Randomly select 3 fields of view (each field of view has an area of approximately 0.1 mm^2) .

4.4.1.3 Draw 10 random straight lines (each about 100 μm long) in each field of view and record the distance between each straight line and WC.
The number of intersections of grain boundaries (N).

4.4.1.4 Calculate the average intercept length:
L = total straight length Total intersection points

4.4.1.5 Grain size: d = 1.56 × L

4.4.1.6 Calculate the average grain size of the three fields of view as the final result.

4.4.2 Image analysis

4.4.2.1 Place the sample under a metallographic microscope, adjust the magnification (usually 500 times), and take pictures of the three fields of view.
Micro photo.
4.4.2.2 Use image analysis software to automatically identify WC grain boundaries and measure the size of at least 100 grains in each field of view .
inch.

4.4.2.3 Calculate the average grain size of each field of view and take the arithmetic mean of the three fields of view as the final result.

4.5 Notes

• The etching time should be strictly controlled. Too long may cause blurred grain boundaries, while too short may not reveal the grain boundaries.
• During observation, ensure that there are enough grains (>100) in the field of view to improve statistical accuracy.
• In the linear intercept method, the lines should be randomly distributed to avoid selection bias.
• In the image analysis method, the software parameters need to be calibrated to ensure measurement accuracy.

5 Result calculation and presentation

5.1 Grain size calculation

• Linear intercept method: Grain size d = 1.56 × L, where 1.56 is the correction factor.
• Image analysis method: directly take the average grain size calculated by the software.

5.2 Results

The grain size is expressed in micrometers (μm) with two decimal places. For example: 0.85 μm.
When reporting, the
The method (linear intercept method or image analysis method) and the number of measurements are allowed to have a deviation of ±0.1 μm or ±10% (whichever is greater).
whichever is applicable).

6 Test report

The test report should include the following:
• Specimen number and source (such as material brand, production batch).
• Date of the test and who conducted the test.
• Experimental conditions: microscope magnification, number of fields of view, etchant and etching time.
• Test results:
– Grain size (μm) for each measurement.
– Average grain size (μm).
– Measurement method (linear intercept method or image analysis).
• Description of abnormal conditions (such as sample surface defects, measurement difficulties, etc.).
• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Grain size grade table

Grain size range (μm) Grade Typical applications
<0.5 Ultrafine grain high hardness cutting tools
0.5-1.0 Fine grain general purpose cutting and wear-resistant parts
1.0-2.0 Medium grain balance hardness and toughness
>2.0 Coarse-grained heavy-load wear-resistant parts
Table 1: Grain size grade table

A.2 Instructions for use

• Grain size grade can be used as a reference for material performance classification, but it needs to be combined with actual application requirements.
• For specimens with uneven grain size distribution, it is recommended to increase the number of fields (to 5-10) to improve representativeness.
• If the results of the two methods differ significantly, the linear intercept method should be used as the standard value.

appendix:

ISO 4505:1978
Cemented Carbide
Metallographic determination of porosity and free carbon

Preface

This standard specifies the metallographic determination method of porosity and free carbon in cemented carbide, and is intended to provide

This standard provides unified technical specifications for the quality control and performance evaluation of WC-Co cemented carbide.

Porosity and free carbon analysis in alloy production, research and applications.

This standard was developed by the International Organization for Standardization (ISO) and first published in 1978. It applies to tungsten carbide (WC).

Cemented carbide with nickel as the main component and containing a metal binder (such as cobalt).

Contents

1 Scope

This standard specifies the metallographic determination method for porosity and free carbon in cemented carbide, using metallographic microscope observation method, suitable for

For cemented carbide with tungsten carbide (WC) as the main component and containing metal binder (such as cobalt). The method includes the sample

Preparation, microscopic observation and result evaluation.

This standard applies to the determination of porosity and free carbon in the quality control and performance evaluation of cemented carbide products.

This standard is not applicable to the analysis of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

This standard does not directly reference other international standards, but is related to the ISO 4499 series of standards "Metallographic Examination of Cemented Carbide"
The latest version may be used as a reference.

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Porosity

The volume fraction of pores in cemented carbide, expressed as a percentage (%), is divided into type A (diameter <10 µm), type B
(10-25 µm in diameter) and type C (free carbon-related pores).

3.2 Free Carbon

The carbon in cemented carbide that does not form carbides with metal exists in the form of C phase, usually in the form of black particles.

3.3 Metallographic Examination

Observe the microstructure of the polished surface or after etching of cemented carbide through a metallographic microscope to identify pores and free carbon.

4 Test methods

4.1 Principle

Observe the polished surface of cemented carbide by metallographic microscope, identify and classify pores and free carbon, and
Quantitative or qualitative evaluation can be carried out using numerical methods.

4.2 Instruments and Equipment

• Metallurgical microscope: magnification 100x to 500x, equipped with eyepiece and objective lens, with good resolution (<0.5
µm).
• Polishing equipment: used for polishing the sample surface, the polishing agent is diamond paste (particle size 1-3 µm).
• Cleaning equipment: Use ethanol or acetone, equipped with an ultrasonic cleaning machine.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness.

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The size is generally 10 mm × 10 mm × 5
mm.

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The surface of the sample is polished with sandpaper (grit 400, 800, 1200) in sequence, and then polished with diamond paste until the surface
No obvious scratches (roughness Ra < 0.1 μm).

4.3.4 Clean the sample with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue.
Wipe dry with a dust cloth .

4.3.5 The sample surface does not need to be etched and can be directly used for porosity and free carbon observation.

4.4 Test steps

4.4.1 Place the sample under a metallographic microscope and adjust the magnification (usually 200 times) to ensure that the pores and free carbon are clear.
Clearly visible.

4.4.2 Randomly select 5 fields of view (each field of view has an area of approximately 0.1 mm²) and observe and record the distribution of pores and free carbon.

4.4.3 Identify by the following categories:
– Type A pores: diameter <10 μm, round or irregular in shape.
– Type B pores: 10-25 μm in diameter, appearing as larger holes.
– Type C pores: associated with free carbon and distributed in the form of black particles.

4.4.4 Count the number of pores and free carbon in each field of view, or compare and evaluate with the standard spectrum.

4.5 Notes

• The specimen surface should be flat and free from scratches or contamination, otherwise the porosity may be misjudged.
• Avoid interference from light reflection during observation and ensure clear boundaries between pores and free carbon.
• If the pore distribution on the sample surface is uneven, increase the number of fields to 10 to improve representativeness.

5 Results evaluation

5.1 Porosity assessment

According to ISO 4505:1978, porosity is classified into the following levels:

• A00: no A-type pores;
• A02: Type A pores <2 / field of view;
• A04: 2-4 A-type pores / field;
• B00: no B-type pores;
• B02: Type B pores <2 / field of view;
• C00: no C-type pores;
• C02: C-type pores <2 / field of view.

5.2 Free Carbon Assessment

Free carbon exists in the form of C-type pores, and the rating is consistent with that of C-type pores:

• C00: no free carbon;
• C02: Free carbon <2 / field of view.

6 Test report

The test report should include the following:

• Specimen number and source (such as material brand, production batch).
• Date of the test and who conducted the test.
• Experimental conditions: microscope magnification, number of fields of view.
• Test results:
– Porosity class (Type A, Type B, Type C).
– Description of free carbon distribution.
• Description of abnormal conditions (such as surface defects of the specimen, difficulty in observation, etc.).
• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Porosity and free carbon characteristic diagram

The following is a reference graph of porosity and free carbon:

• Type A pores: diameter <10 µm, dispersed round or irregular in shape.
• Type B pores: 10-25 µm in diameter, appearing as large isolated holes.
• Type C pores (free carbon): black granular, associated with type A or type B pores.

A.2 Instructions for use

• Porosity and free carbon assessments should be based on the average of 5 fields of view .
• If more C-type pores are found, further chemical composition analysis is recommended to check whether the carbon content is insufficient.

appendix:

ISO 3326:2013
Cemented Carbide Sampling and Specimen Preparation Methods

Preface

This standard specifies the sampling and specimen preparation methods for cemented carbide, and is intended to provide

Provide uniform technical specifications for subsequent performance tests (such as metallographic examination, hardness measurement and grain size analysis) of high-quality alloys

standard applies to sampling and specimen preparation in cemented carbide production, quality control, research and application.

This standard was developed by the International Organization for Standardization (ISO) and was first published in 2013, replacing ISO 3326:1975.

This combines the needs of the modern cemented carbide industry with the development of testing technology.

Contents

1 Scope

This standard specifies the sampling and sample preparation methods for cemented carbide, which is applicable to cemented carbide with tungsten carbide (WC) as the main component.

Cemented carbide containing a metallic binder such as cobalt. The method comprises taking a sample from a cemented carbide product or raw material and preparing

Specimens for metallographic, hardness, density and grain size determination.

This standard applies to quality control, performance testing and research during the cemented carbide production process.
This standard does not apply to the sampling and preparation of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.
For any undated referenced document, the latest edition (including all amendments) applies.
This standard.

- **ISO 4499-1:2008 Metallographic examination methods for cemented carbides Part 1: General**
- **ISO 4505:2017 Metallographic determination of porosity and free carbon in cemented carbides**
- **ISO 3327:2009 Determination of density of cemented carbide**

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Sampling

Select representative parts from cemented carbide products or raw materials for subsequent performance testing.

3.2 Test Specimen

After sampling and preparation, cemented carbide specimens meet specific test requirements.

3.3 Polished Surface

After mechanical or chemical treatment, the surface of the sample is smooth without obvious scratches or defects, which is suitable for metallographic observation.
Observe.

3.4 Representativeness

The degree to which the specimen reflects the overall characteristics of the parent material in terms of size, structure and composition.

4 Sampling methods

4.1 Sampling principles

4.1.1 Sampling should ensure that the samples are representative and cover the homogeneity and potential defects of the products or raw materials.

4.1.2 The sampling location should avoid edge effects or processing-affected areas.

4.2 Sampling procedures

4.2.1 Sampling from finished products:

1-2 specimens in the longitudinal and transverse directions . The length of the specimen is equal to the product diameter.
times the diameter or thickness , and the width is not less than 5 mm.
– For complex shaped products, select a representative section and cut out a 10 mm × 10 mm × 5 mm
Sample.

4.2.2 Sampling from raw materials:

– Randomly select from powder or pre-sintered green body, weighing not less than 50 g, mix well and prepare small test pieces
Sample **.**
4.2.3 Cutting tool: Use diamond cutting blade with cutting speed <100 mm/min to avoid introducing thermal damage or cracks.

4.3 Notes

• Avoid contamination (such as oil or dust) during sampling.
• If the hardness of the products varies greatly, increase the number of sampling points to 5-10 .

5. Sample preparation method

5.1 Preparation principles

5.1.1 The specimens should be prepared with a flat, defect-free surface suitable for subsequent testing requirements.

5.1.2 The preparation process should minimize material damage, such as cracks or structural deformation.

5.2 Preparation steps

5.2.1 Initial cutting:

– Rough-cut the sample to the required size using a diamond cutting disc, at least 5 mm thick.

5.2.2 Coarse grinding:

– Sand the surface of the specimen with sandpaper (grit 400, 800) to remove the cutting marks.

5.2.3 Fine grinding and polishing:

– Further sanding with 1200 grit sandpaper followed by polishing with diamond paste (1-3 μm grit) on a polishing machine
Polish to a roughness of Ra < 0.1 μm.

5.2.4 Cleaning:
– Clean the specimen in an ultrasonic cleaner (ethanol or acetone, 5 min) to remove the remaining polishing agent and
Dry with cloth.

5.2.5 Etching (optional):
– If metallographic observation is required, use Murakami reagent (10% KOH + 10% K[Fe(CN)] aqueous solution)
Etch the surface (10-20 s), then rinse with distilled water and dry.

5.3 Applicability
• Metallographic inspection: Need to be polished to mirror finish and etched if necessary.
• Hardness test: The thickness should be at least 1.5 times of the indentation depth and the surface should be flat.
• Density determination: The sample has a regular shape (such as a cube or cylinder) and no pores.

5.4 Notes
• Avoid overheating during polishing to prevent structural changes.
• The edges of the specimen should be chamfered to prevent crack propagation.
• If scratches appear on the surface of the specimen, it needs to be polished again.

6 Quality requirements
6.1 The surface of the specimen should be free of obvious scratches, cracks or contamination.
6.2 The specimen size tolerance is ±0.1 mm and the flatness is <0.05 mm.
6.3 The surface roughness after polishing is Ra<0.1 μm, suitable for high-precision testing.

7 Test report
The test report should include the following:
• Specimen number and source (such as material brand, production batch).
• Date the sample was taken and who prepared it.
• Sampling methods: location, quantity, tools.
• Preparation process: cutting, grinding, polishing, cleaning conditions.
• Specimen quality: size, surface condition.
• Description of abnormal situation (such as damage, contamination, etc.).
• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Sampling and preparation examples

• Bar sampling: Two 10 mm thick specimens were cut longitudinally from a 20 mm diameter bar and prepared as 10 mm × 10 mm × 5 mm.

• Plate sampling: Randomly take 4 10 mm × 10 mm specimens from the 5 mm thick plate .

• Polishing process: 400 grit sandpaper 2 min, 800 grit sandpaper 2 min, 1200 grit sandpaper 3 min, diamond paste polishing 5 min min.

A.2 Instructions for use

• Sampling points should be recorded for easy traceability.

• For multi-phase cemented carbide, pay attention to the uniformity of distribution of each phase during preparation.

• If subsequent testing requirements are different, the degree of polishing can be adjusted.

appendix:

ASTM B657-16
Cemented Carbide Microstructure Analysis

Preface

This standard specifies the analysis method of cemented carbide microstructure, aiming to provide
This standard is applicable to cemented carbide production, quality control,
Microstructural analysis in research and applications.

This standard was developed by the American Society for Testing and Materials (ASTM) and published in 2016, replacing ASTM B657-11
version, combining the needs of the modern cemented carbide industry with the development of microanalytical techniques.

Contents

1 Scope

This standard specifies the analysis method of cemented carbide microstructure, using metallographic microscope observation method, applicable to tungsten carbide
(WC) as the main component and containing a metal binder (such as cobalt). The method includes sample preparation, microscopic observation
Observation and identification of microstructural features.
This standard is applicable to the quality control, performance evaluation and microstructure analysis in research of cemented carbide products.

This standard is not applicable to the microstructural analysis of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

Note: This standard does not involve safety issues. Users should take necessary safety measures according to experimental conditions.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.

For any undated referenced document, the latest edition (including all amendments) applies.

This standard.

- ASTM E3 Methods for preparation of metallographic specimens of metallic materials
- ASTM E7 Standard Terminology for Metallography
- ASTM E112 Method for determination of average grain size

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Cemented Carbide

A composite material made from tungsten carbide (WC) particles and a metal binder (such as cobalt) by powder metallurgy.

3.2 Microstructure

The structural characteristics of cemented carbide observed under a metallographic microscope include WC grains, bonding phases and defects (such as pores,
free carbon).

3.3 Binder Phase

The metal phase connecting the WC particles in cemented carbide is usually cobalt (Co) and is distributed continuously or semi-continuously.

3.4 Porosity

The tiny holes in cemented carbide are divided into Type A (<10 μm), Type B (10-25 μm) and Type C according to their size.
(related to free carbon).

3.5 Free Carbon

The carbon in cemented carbide that does not form carbides with metal is distributed in the form of black particles.

4 Test methods

4.1 Principle

The polished and etched cross-section of cemented carbide was observed by metallographic microscope to identify WC grains, binder phase, pores and
Microstructural characteristics such as free carbon.

4.2 Instruments and Equipment

- Metallurgical microscope: magnification 100x to 1000x, resolution <0.5 µm.
- Polishing equipment: The polishing agent is diamond paste (particle size 1-3 µm).
- Etchant: Murakami reagent (10% KOH + 10% K[Fe(CN)] in water).
- Cleaning equipment: Ultrasonic cleaning machine, using ethanol or acetone.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness. The size is generally 10 mm × 10 mm × 5
mm.

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The sample surface was polished with sandpaper (grit 400, 800, 1200) in sequence, and then polished with diamond paste until the surface
Roughness Ra<0.1 µm.

4.3.4 Clean the sample with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue.
Wipe dry with a dust cloth .

4.3.5 Etch the sample surface using Murakami reagent (etching time 10-20 s) to reveal the WC grain boundaries and
The microstructural features were then rinsed with distilled water and dried.

4.4 Test steps

4.4.1 Place the sample under a metallographic microscope, adjust the magnification (usually 500 times), and observe the microstructure.

4.4.2 Randomly select 5 fields of view (each field of view has an area of approximately 0.1 mm^2) and record the following characteristics:
– WC grain size and distribution.
– Distribution and morphology of the binder phase.
– Type and amount of pores (type A, type B, type C).
– Presence and distribution of free carbon.

4.4.3 Compare with standard microstructure atlas and evaluate the microstructural characteristics.

4.5 Notes

• The etching time should be strictly controlled. Too long may lead to blurred grain boundaries, while too short may fail to reveal structural features.

• Ensure that there are enough grains (>100) in the field of view to improve statistical accuracy.

• If the microstructure is unevenly distributed, increase the number of fields to 10 .

5 Results evaluation

5.1 Microstructural characteristics

• WC grains: evaluate grain size (ultrafine grains <0.5 μm, fine grains 0.5-1.0 μm, medium grains 1.0-2.0 μm,
coarse grains >2.0 μm) and distribution uniformity.

• Binder phase: describes the continuity of the cobalt phase (homogeneous, discontinuous or agglomerated).

• Porosity: classified into type A, type B, and type C, and rated (A00: no type A pores; A02: <2 field ; B00: no B-type pores; C00: no C-type pores).

• Free carbon: assess the presence and distribution (C00: no free carbon; C02: <2 per field of view).

5.2 Influencing factors

Microstructure affects the mechanical and physical properties of cemented carbide:

• Smaller grain size generally increases hardness and wear resistance but may reduce toughness.

• Increased porosity may reduce strength and durability.

• Excessive free carbon may cause material embrittlement.

6 Test report

The test report should include the following:

• Specimen number and source (such as material brand, production batch).

• Date of the test and who conducted the test.

• Experimental conditions: microscope magnification, number of fields of view, etching conditions.

• Test results:

– Description of WC grain size and distribution.

– Binder phase morphology.

– Porosity and free carbon rating.

• Description of abnormal conditions (such as surface defects of the specimen, difficulty in observation, etc.).

• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Microstructure characteristics

• Ultrafine grain structure: grain size <0.5 μm, evenly distributed, and continuous bonding phase.

• Pore types: Type A (<10 μm), Type B (10-25 μm), Type C (black granular).

• Free carbon: black granular, often with C-type pores.

A.2 Instructions for use

• This standard is only used for microstructural identification and is not intended as an acceptance specification for cemented carbide grades.

• Manufacturers and users can develop their own specifications based on microstructural information.

appendix:

ISO 4489:2009
Cemented Carbide Sintering Process Guide

Preface

This standard provides guidance on cemented carbide sintering process, aiming at cemented carbide (mainly WC-Co cemented carbide)

This standard is applicable to the sintering process optimization and quality control in cemented carbide production.

Control and performance improvements.

This standard was developed by the International Organization for Standardization (ISO) and published in 2009, replacing the ISO 4489:1978 version.

It combines the development of modern sintering technology and industrial needs.

Contents

1 Scope

This standard specifies the guidance method for cemented carbide sintering process and is applicable to cemented carbide with tungsten carbide (WC) as the main component and containing Cemented carbide with metal binder (such as cobalt). The method includes preparation before sintering, sintering process control and post-sintering properties

Evaluate.

This standard is applicable to sintering process optimization, quality control and research in the production process of cemented carbide.
This standard does not apply to the sintering process of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.
For any undated referenced document, the latest edition (including all amendments) applies.
This standard.

- **ISO 3326:2013 Methods for sampling and preparation of test specimens for cemented carbides**
- **ISO 4505:2017 Metallographic determination of porosity and free carbon in cemented carbides**
- **ISO 4499-1:2008 Metallographic examination methods for cemented carbides Part 1: General**

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Sintering

The process of heating and pressing the hard alloy powder body to form a metallurgical bond between the particles. The temperature is usually below
Melting point of the main component.

3.2 Liquid Phase Sintering

During sintering, part of the binder (e.g., cobalt) melts into the liquid phase, promoting particle rearrangement and densification.

3.3 Green Compact

The unsintered green body formed by powder pressing has a certain initial strength.

3.4 Sintered Density

The actual density of cemented carbide after sintering is usually expressed as a percentage of the theoretical density.

4 Sintering process overview

4.1 Process Principle

Sintering is done by heating the green billet to a temperature below the melting point of WC (about 2870°C) to melt the cobalt binder and form
Liquid phase promotes the diffusion and bonding between WC particles, and finally forms a dense

cemented carbide structure.

4.2 Process flow

4.2.1 Powder preparation: Mix WC powder and cobalt powder , the particle size is controlled at 0.5-5 µm, and the cobalt content is usually 6%-15%.

4.2.2 Pressing: The powder is pressed into a green blank at a pressure ranging from 100-400 MPa.

4.2.3 Dewaxing: Removal of pressing lubricant at low temperature (300-600◦C).

Heat to 1350-1500°C in vacuum or protective atmosphere (such as H2 or Ar) and keep warm for 30-60 minutes.

4.2.5 Cooling: Control the cooling rate (5-20°C/min) to avoid thermal stress cracking.

5 Sintering process parameters

5.1 Temperature

• Sintering temperature range: 1350-1500◦C, depending on the cobalt content and WC grain size.
• Liquid phase formation temperature: about 1300◦C (melting point of cobalt), the liquid phase ratio must be ensured to be 20%-40%.

5.2 Atmosphere

• Vacuum sintering: pressure <10sup −2P aH2 or Ar , dew point <-40◦C, to prevent oxidation.

5.3 Time

•• Hot holding time: 30-60 minutes. Too long may cause grain growth.
• Total cycle: 4-6 hours, including heating and cooling.

5.4 Pressure (optional)

• Hot Isostatic Pressing (HIP): 100-200 MPa pressure is applied after sintering to further increase the density to 98%-99%.

5.5 Notes

• Avoid excessive temperatures that may cause WC decomposition or excessive carbonization.
• Control the atmosphere humidity to prevent oxidation or decarburization.

6 Process Control and Quality Assurance

6.1 Online Monitoring

• Temperature control accuracy ±5◦C, atmosphere pressure monitoring.

• Density measurement: green billet density >50% theoretical density, sintered density >90%.

6.2 Quality Inspection

• Metallographic analysis: Check porosity (A00-B00) and free carbon (C00).
• Hardness test: HRA88 (depending on the brand).

6.3 Exception Handling

• If density is insufficient, adjust the cobalt content or add HIP treatment.
• If the grains are too coarse, lower the sintering temperature or shorten the holding time.

7 Test report

The test report should include the following:
• Specimen number and source (such as material brand, production batch).
• Sintering date and operator.
• Process parameters: temperature, atmosphere, time, pressure.
• Sintering results: density, hardness, metallographic structure.
• Description of abnormal conditions (such as cracks, pores, etc.).
• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Sintering process example

• Brand: YG6 (containing 6% cobalt)
– Pressing pressure: 200 MPa
– Sintering temperature: 1420°C
– Atmosphere: vacuum (10sup −3P a40min
— Density: 14.8 g/c3m (98% theoretical density)
• Brand: YG15 (containing 15% cobalt)
– Pressing pressure: 300 MPa
– Sintering temperature: 1450◦C
– Atmosphere: H2 (dew point -50◦C)
– Holding time: 50 min
– Density: 13.9 g/c3m (97% theoretical density)

A.2 Instructions for use

• Sintering parameters need to be adjusted according to specific grades and equipment.
• It is recommended to combine with HIP treatment to improve density and performance.

appendix:

ASTM B657-16
Cemented Carbide Microstructure Analysis

Preface

This standard specifies the analysis method of cemented carbide microstructure, aiming to provide This standard is applicable to cemented carbide production, quality control,
Microstructural analysis in research and applications.

This standard was developed by the American Society for Testing and Materials (ASTM) and published in 2016, replacing ASTM B657-11
version, combining the needs of the modern cemented carbide industry with the development of microanalytical techniques.

Contents

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4.1 Principle
4.2 Instruments and Equipment
4.3 Sample preparation
4.4 Test steps
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6 Test report

1 Scope

This standard specifies the analysis method of cemented carbide microstructure, using metallographic microscope observation method, applicable to tungsten carbide
(WC) as the main component and containing a metal binder (such as cobalt). The method includes sample preparation, microscopic observation
Observation and identification of microstructural features.

This standard is applicable to the quality control, performance evaluation and microstructure analysis in research of cemented carbide products.
This standard is not applicable to the microstructural analysis of cemented carbide coatings or non-WC based cemented carbides (such as cermets).
Note: This standard does not involve safety issues. Users should take necessary safety measures according to experimental conditions.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.
For any undated referenced document, the latest edition (including all amendments) applies.
This standard.
• ASTM E3 Methods for preparation of metallographic specimens of metallic materials
• ASTM E7 Standard Terminology for Metallography
• ASTM E112 Method for determination of average grain size

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Cemented Carbide

A composite material made from tungsten carbide (WC) particles and a metal binder (such as cobalt) by powder metallurgy.

3.2 Microstructure

The structural characteristics of cemented carbide observed under a metallographic microscope include WC grains, bonding phases and defects (such as pores,
free carbon).

3.3 Binder Phase

The metal phase connecting the WC particles in cemented carbide is usually cobalt (Co) and is distributed continuously or semi-continuously.

3.4 Porosity

The tiny holes in cemented carbide are divided into Type A (<10 μm), Type B (10-25 μm) and Type C according to their size.
(related to free carbon).

3.5 Free Carbon

The carbon in cemented carbide that does not form carbides with metal is distributed in the form of black particles.

4 Test methods

4.1 Principle

The polished and etched cross-section of cemented carbide was observed by metallographic microscope to identify WC grains, binder phase, pores and
Microstructural characteristics such as free carbon.

4.2 Instruments and Equipment

- Metallurgical microscope: magnification 100x to 1000x, resolution <0.5 μm.
- Polishing equipment: The polishing agent is diamond paste (particle size 1-3 μm).
- Etchant: Murakami reagent (10% KOH + 10% K[Fe(CN)] in water).
- Cleaning equipment: Ultrasonic cleaning machine, using ethanol or acetone.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness. The size is generally 10 mm × 10 mm × 5
mm.

4.3.2 Use a diamond cutting blade to cut the specimen at a cutting speed of <100 mm/min to avoid introducing cracks or thermal damage.

4.3.3 The sample surface was polished with sandpaper (grit 400, 800, 1200) in sequence, and then

polished with diamond paste until the surface
Roughness Ra<0.1 μm.

4.3.4 Clean the sample with an ultrasonic cleaner (cleaning time 5 min) to remove surface dirt and polishing agent residue.
Wipe dry with a dust cloth .

4.3.5 Etch the sample surface using Murakami reagent (etching time 10-20 s) to reveal the WC grain boundaries and
The microstructural features were then rinsed with distilled water and dried.

4.4 Test steps

4.4.1 Place the sample under a metallographic microscope, adjust the magnification (usually 500 times), and observe the microstructure.

4.4.2 Randomly select 5 fields of view (each field of view has an area of approximately 0.1 mm^2) and record the following characteristics:
– WC grain size and distribution.
– Distribution and morphology of the binder phase.
– Type and amount of pores (type A, type B, type C).
–Presence and distribution of free carbon.

4.4.3 Compare with standard microstructure atlas and evaluate the microstructural characteristics.

4.5 Notes

• The etching time should be strictly controlled. Too long time may lead to blurred grain boundaries, while too short time may fail to reveal structural features.
• Ensure that there are enough grains (>100) in the field of view to improve statistical accuracy.
• If the microstructure is unevenly distributed, increase the number of fields to 10 .

5 Results evaluation

5.1 Microstructural characteristics

• WC grains: evaluate grain size (ultrafine grains <0.5 μm, fine grains 0.5-1.0 μm, medium grains 1.0-2.0 μm,
coarse grains >2.0 μm) and distribution uniformity.
• Binder phase: describes the continuity of the cobalt phase (homogeneous, discontinuous or agglomerated).
• Porosity: classified into type A, type B, and type C, and rated (A00: no type A pores; A02: <2 field ; B00: no B-type pores; C00: no C-type pores).
• Free carbon: assess the presence and distribution (C00: no free carbon; C02: <2 per field of view).

5.2 Influencing factors

Microstructure affects the mechanical and physical properties of cemented carbide:

• Smaller grain size generally increases hardness and wear resistance but may reduce toughness.

• Increased porosity may reduce strength and durability.

• Excessive free carbon may cause material embrittlement.

6 Test report

The test report should include the following:

• Specimen number and source (such as material brand, production batch).

• Date of the test and who conducted the test.

• Experimental conditions: microscope magnification, number of fields of view, etching conditions.

• Test results:

– Description of WC grain size and distribution.

– Binder phase morphology.

– Porosity and free carbon rating.

• Description of abnormal conditions (such as surface defects of the specimen, difficulty in observation, etc.).

• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Microstructure characteristics

• Ultrafine grain structure: grain size <0.5 μm, evenly distributed, and continuous bonding phase.

• Pore types: Type A (<10 μm), Type B (10-25 μm), Type C (black granular).

• Free carbon: black granular, often with C-type pores.

A.2 Instructions for use

• This standard is only used for microstructural identification and is not intended as an acceptance specification for cemented carbide grades.

• Manufacturers and users can develop their own specifications based on microstructural information.

appendix:

GB/T 3850-2015
Determination of Theoretical Density of Cemented Carbide

Preface

This standard specifies the determination method of theoretical density of cemented carbide, aiming at providing

This standard is applicable to cemented carbide production, quality control,

Theoretical density determination in research and applications.

This standard was developed by the Standardization Administration of China and issued in 2015, replacing GB/T 3850-1983.

version, combining the needs of the modern cemented carbide industry with the development of theoretical density calculation technology.

Contents

1 Scope

This standard specifies the method for determining the theoretical density of cemented carbide and is applicable to cemented carbide with tungsten carbide (WC) as the main component and containing Cemented carbide with a metal binder such as cobalt. The method involves calculating the theoretical density using composition analysis and crystal structure data.

degree, and auxiliary methods verified by experiments.

This standard is applicable to quality control, performance evaluation and theoretical density determination in research during cemented carbide production.

This standard is not applicable to the determination of theoretical density of cemented carbide coatings or non-WC based cemented carbides (such as cermets).

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.

For any undated referenced document, the latest edition (including all amendments) applies.

This standard.

- GB/T 3848-2015 Determination of chemical composition of cemented carbide
- GB/T 4499-2008 Metallographic inspection method for cemented carbide
- GB/T 3327-2009 Determination of density of cemented carbide

3 Terms and definitions

The following terms and definitions apply to this standard.

3.1 Theoretical Density

The ideal density is calculated based on the chemical composition and crystal structure of cemented carbide, in g/c3m.

3.2 Cemented Carbide

A composite material made from tungsten carbide (WC) particles and a metal binder (such as cobalt) by powder metallurgy.

3.3 Crystal Structure

The atomic arrangement of each phase (such as WC and Co) in cemented carbide is usually determined by X-ray diffraction (XRD).

3.4 Mass Fraction

The percentage of the mass of a certain component in cemented carbide to the total mass, in %.

4 Test methods

4.1 Principle

The theoretical density is calculated from the chemical composition of cemented carbide and the crystal structure data of each phase.

The density of each phase is determined based on the known crystal structure parameters.

4.2 Instruments and Equipment

- X-ray diffractometer (XRD): used to determine crystal structure parameters.
- Chemical analysis equipment: used to determine the composition of cemented carbide (such as the

mass fraction of WC and Co).
• Computing equipment: used for calculation of theoretical density.

4.3 Sample preparation

4.3.1 The specimens should be taken from cemented carbide products to ensure representativeness. The size is generally 10 mm × 10 mm × 5 mm.

4.3.2 The surface of the specimen should be clean and free of oil or other contaminants.

4.3.3 If XRD analysis is required, the sample surface should be polished to a roughness Ra < 0.1 μm.

4.4 Test steps

4.4.1 Component Analysis:

– Determine the mass fraction of each component in cemented carbide (such as WC, Co and its other trace elements).
– Record the mass fraction of each component with an accuracy of 0.01%.

4.4.2 Crystal structure determination:

– XRD was used to determine the crystal structure parameters (such as unit cell volume) of WC and Co in cemented carbide.
– Confirm the hexagonal structure of WC (a=2.906 Å, c=2.837 Å) and the face-centered cubic structure of Co (a=3.544 Å).
– If other phases (such as phases) exist, their crystal structures must also be determined.

4.4.3 Theoretical density calculation:

– Calculate the theoretical density based on the composition and crystal structure data (see Section 5 for details).

4.5 Notes

• Composition analysis should be repeated at least 3 times and the average taken to improve accuracy.
• XRD measurements should be performed under stress-free conditions to avoid lattice distortion caused by sample processing.
• If there are trace impurities in the cemented carbide, its effect on the theoretical density needs to be evaluated.

5 Calculation method

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5.1 Calculation formula

The theoretical density (ρ) of cemented carbide is calculated according to the following formula:

$$\rho = \frac{\sum(w_i \cdot \rho_i)}{\sum w_i}$$

in:

- ρ: theoretical density of cemented carbide, in g/c3m;
- wi : mass fraction of the ith component , unit: %
- ρi: theoretical density of the ith component , in g/c3m.

5.2 Theoretical density of each phase

- Theoretical density of WC: 15.63 g/c3m (based on hexagonal unit cell parameters).
- Theoretical density of Co: 8.90 g/c3m (based on face-centered cubic unit cell parameters).
- If other phases exist (such as phases, typically CoWC), their theoretical density needs to be calculated based on the crystal structure.

5.3 Calculation steps

wi) of each component .

i) of each component .

5.3.3 Substitute into the formula and calculate the theoretical density of cemented carbide.

6 Results Evaluation

6.1 The calculated theoretical density should be accurate to 0.01 g/c3m.

6.2 If the actual density (measured according to GB/T 3327-2009) differs greatly from the theoretical density (>2%), the product needs to be checked.
analytical or crystal structure data.

6.3 Theoretical density can be used to evaluate the compactness and quality stability of a material.

7 Test report

The test report should include the following:

- Specimen number and source (such as material brand, production batch).
- Date of the test and who conducted the test.

• Experimental conditions: composition analysis method, XRD parameters.

• Test results:
– Mass fraction of each component.
– Crystal structure parameters of each phase.
– Theoretical density calculation results.
• Explanation of abnormal situations (such as impurity impact, data deviation, etc.).
• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Example of theoretical density calculation

• Brand: YG8 (containing 8% cobalt)
– Composition: WC 92%, Co 8% (mass fraction).
– WC theoretical density: 15.63 g/c3m.
– Co theoretical density: 8.90 g/c3m.
- calculate:

$$\rho = \frac{(92 \times 15.63) - (8 \times 8.90)}{92 - 8} = \frac{1437.96 + 71.20}{100} = 15.09\ g/cm^3$$

结果：理论密度为15.09 g/cm³。

– Result: Theoretical density is 15.09 g/c ^{3} m.
• Brand: YG15 (containing 15% cobalt)
– Composition: WC 85%, Co 15% (mass fraction).
– WC theoretical density: 15.63 g/c3m.
– Co theoretical density: 8.90 g/c3m.
- calculate:

计算：

$$\rho = \frac{(85 \times 15.63) + (15 \times 8.90)}{85 + 15} = \frac{1328.55 + 133.50}{100} = 14.62\ g/cm^3$$

– Result: Theoretical density is 14.62 g/c ^{3} m.

A.2 Instructions for use

• Theoretical density calculation is required to ensure the accuracy of component analysis.
• If there are trace phases (such as phase) in the cemented carbide, the calculation should be supplemented based on its crystal structure.

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appendix:

GB/T 1031-2009
Surface roughness measurement

Preface

This standard specifies the measurement method of surface roughness and is intended for the evaluation of surface roughness of metals, non-metals and composite materials.
applicable to the measurement of surface roughness in production, quality control, research and application.
quantity.
This standard was developed by the Standardization Administration of China and issued in 2009, replacing GB/T 1031-1995
version, combining the requirements of modern surface measurement technology and international standards such as ISO 4287:1997.

Contents

1 Scope

This standard specifies the measurement method of surface roughness and is applicable to metals (such as hard alloys, steel), non-metallic materials and coatings.
The roughness parameters of the layer surface are measured. The methods include contact profilometers and non-contact measurement techniques, covering Ra, Rz,
Parameters such as Rp.
This standard is applicable to quality control in the production process, surface performance

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evaluation and roughness measurement in research.
This standard does not apply to surfaces with significant corrugations or macroscopic geometrical deviations, unless otherwise stated.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard.
For any undated referenced document, the latest edition (including all amendments) applies.
This standard.
• GB/T 6060.1-1996 Surface roughness terms, definitions and parameters
• GB/T 6062-2006 Surface roughness comparison specimens
• ISO 4287:1997 Geometrical product specifications (GPS) — Surface texture: Profile method — Terms, definitions and parameters

3 Terms and definitions

The following terms and definitions apply to this standard, see GB/T 6060.1-1996 for details.

3.1 Surface Roughness

Deviations in surface microgeometry caused by the machining method, manifesting themselves as small pitch and height variations.

3.2 Arithmetic mean deviation (Ra)

The arithmetic mean deviation of the profile is the main parameter of surface roughness and its unit is μm.

3.3 Maximum height (Rz)

The maximum height of the profile is a supplementary parameter of surface roughness and its unit is μm.

3.4 Sampling Length

A reference length used for roughness measurement, usually 0.25 mm, 0.8 mm or 2.5 mm.

4 Measurement methods

4.1 Measurement principle

Measure the surface profile and analyze the roughness parameters (such as Ra, Rz) by contact profilometer or non-contact optical instrument.

4.2 Instruments and Equipment

• Contact profilometer: probe tip radius <2 μm, resolution 0.01 μm.
• Non-contact measuring instruments: such as laser scanners or white light interferometers, with a

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resolution of < 0.1 µm.

• Standard samples: provided in accordance with GB/T 6062-2006, used for instrument calibration.

4.3 Measurement steps

4.3.1 Sample preparation:

– The specimen surface should be clean and free from oil or dust.

– If there are any processing residues, they need to be removed with sandpaper or solvent.

4.3.2 Instrument calibration:

– Use standard samples to calibrate the instrument to ensure measurement error <5%.

4.3.3 Measurement execution:

– Determine the sampling length (0.25 mm, 0.8 mm or 2.5 mm), depending on the surface characteristics.

5 or more measuring points on the specimen and measure along the processing direction or perpendicular direction.

–Record parameters such as Ra and Rz, measure each point 3 times and take the average value.

4.4 Notes

• Avoid over-pressurizing the probe to prevent surface damage.

• The measurement point should avoid edges or obvious defect areas.

• If the surface is coated, confirm the measurement depth.

5 Measurement conditions

5.1 Environmental conditions

• Temperature: 20±2◦C.

• Humidity: 30%-70%.

• Avoid vibration or air flow disturbance.

5.2 Measurement parameters

• Sampling length: Select according to the Ra value range (Ra<0.1 µm : 0.25 mm; 0.1 µmRa <10 µm : 0.8
mm; Ra10 µm : 2.5 mm).

• Evaluation length: 5 times the sampling length.

• Cut-off wavelength: 0.25 mm, 0.8 mm or 2.5 mm, matching the sampling length.

5.3 Instrument Setup

• Probe speed: 0.1-1 mm/s.

• Measuring force: <0.75 mN (contact).

6 Results Evaluation

6.1 The roughness parameter should be accurate to 0.01 μm.

6.2 The allowable deviation of Ra and Rz values is ±10% or ±0.1 μm (whichever is greater).

6.3 If the difference between multiple measurement results exceeds the allowable deviation, it is necessary to check the surface condition of the sample or the calibration of the instrument.

7 Test report

The test report should include the following:

• Specimen number and source (such as material brand, production batch).
• Date of the test and who conducted the test.
• Measurement conditions: instrument type, sampling length, environmental conditions.
• Measurement results:
– Ra and Rz values at each measuring point.
– Mean and deviation.
• Description of abnormal conditions (such as surface defects, instrument failure, etc.).
• Signature of the testing unit and person in charge.

Appendix A (Informative Appendix)

A.1 Measurement parameter examples

• Specimen: Cemented Carbide YG6
– Measuring method: contact profilometer.
– Sampling length: 0.8 mm.
– Measuring points: 5 .
– Result: Ra = 0.32 μm, Rz = 2.15 μm (average value).
• Sample: Stainless steel surface
– Measuring method: non-contact laser scanner.
– Sampling length: 2.5 mm.
– Measuring points: 6 .
– Result: Ra = 1.25 μm, Rz = 8.90 μm (average value).

A.2 Instructions for use

• Choose appropriate sampling length and cutoff wavelength to match surface characteristics.
• For high precision requirements, the number of measuring points can be increased to 10 .

What are the cemented carbide pressing technologies?

The pressing technology of cemented carbide is one of the core links in the powder metallurgy process. By molding powder raw materials such as tungsten carbide (WC) and cobalt (Co) under a specific pressure, a green blank with initial strength and shape is prepared, laying the foundation for subsequent sintering and finished product processing. The pressing process directly affects the density, uniformity and defect rate of the green blank, which in turn determines the properties of the sintered material (such as hardness, wear resistance, and toughness). The following is a detailed classification of cemented carbide pressing technology and its technical details, covering traditional methods and modern innovative technologies, and comprehensively elaborating on practical applications and the latest trends.

1. Uniaxial Pressing

principle

Unidirectional pressing uses a unidirectional hydraulic press or mechanical press to apply pressure vertically downward using the upper pressure head to compress the powder loaded into a rigid mold into a green body. The pressure is mainly transmitted along one axis, and the molding is achieved by the friction between the powder particles and the constraint of the mold wall.

equipment:

Hydraulic press: pressure range 100-400 MPa, equipped with precision pressure sensor and displacement monitoring system.

Mould: Usually made of high hardness steel (such as Cr12MoV) or cemented carbide, the inner wall needs to be polished to Ra<0.2 μm to reduce friction.

Features:

Suitable for producing simple geometric shapes, such as cylindrical tool blanks and rectangular blocks.

The density distribution is uneven, with higher density near the pressure head (up to 60%-70% of the theoretical density) and lower density at the bottom (possibly less than 50%), which may lead to uneven shrinkage after sintering.

The pressing time is usually 5-15 seconds, depending on the powder particle size and pressure.

application:

Small carbide parts, such as drill blanks, cutting insert preforms.

Low-cost mass production, especially suitable for small and medium-sized enterprises.

Technical details:

Powder preparation: WC particle size is usually 0.5-2 μm , Co content is 6%-15%, and 1%-3% paraffin or stearic acid needs to be added as a lubricant to improve fluidity.

Pressure control: Initial pre-pressure of 10-50 MPa to remove air, followed by main pressure of 100-400 MPa. Avoid loading too quickly to prevent powder stratification.

Note:

The mold wall friction may lead to insufficient lateral density. It is recommended to optimize the powder particle size distribution or increase lateral vibration assistance.

When demoulding the green billet, the pressure needs to be released slowly to avoid cracking.

2. Double-Acting Pressing

principle:

Bidirectional pressing uses two upper and lower pressure heads to apply pressure at the same time, and the powder is compressed through the up and down movement in the mold. The upper and lower pressure heads work in coordination to reduce the density gradient in unidirectional pressing.

equipment:

Double-acting hydraulic press: pressure range 150-500 MPa, equipped with synchronous control system.

Mould: Bidirectional movable design, ensure that the gap between the upper and lower pressure heads and the inner wall of the mould is less than 0.01 mm.

Features:

The density distribution of the green body is more uniform, and the density near the middle part can reach 65%-75% of the theoretical density. The overall consistency is better than unidirectional pressing.

Suitable for parts with larger or medium complex shapes, such as plates and bars.

The pressing cycle is 10-20 seconds, depending on the height of the blank.

application:

Produce carbide bars and sheets for manufacturing cutting tools and wear-resistant parts.

Medium-scale production, taking into account both efficiency and quality.

Technical details:

Pressure distribution: The pressure ratio between upper and lower pressure heads is usually 1:1, with a maximum deviation of <5% to ensure uniformity.

Mold lubrication: The inner wall is coated with a graphite or MoS_2 lubrication layer to reduce friction to 0.1-0.2.

Note:

The synchronization of the pressure head needs to be controlled by a high-precision servo system to avoid unbalanced loading.

For powders with high Co content (>12%), the pre-pressing time needs to be extended to eliminate pores.

3. Cold Isostatic Pressing (CIP)

principle:

Cold isostatic pressing uses a liquid medium (such as water or oil) to apply equal pressure in all directions to a flexible mold filled with powder in a high-pressure container. The pressure is evenly transmitted through the liquid, ensuring that all parts of the blank are subjected to uniform force.

equipment:

Cold isostatic press: pressure range 200-600 MPa, working temperature from room temperature to 50°C.

Mould: Made of rubber or polymer material, the pressure resistance must reach 1.5 times the working pressure.

Features:

The green body density is highly uniform, reaching 70%-80% of the theoretical density, suitable for complex geometric shapes.

The pressing time is 5-15 minutes, depending on the size of the blank and the pressure.

The green billet has higher strength and consistent sintering shrinkage.

application:

Complex shaped cemented carbide products, such as special-shaped tools and precision molds.

Production of high-performance parts, especially in the aerospace sector.

Technical details:

Powder filling: Powder filling density is controlled at 40%-50%, avoid bubbles, and vacuum degassing is required.

Pressure curve: Use graded pressure increase (e.g. 50 MPa pre-pressure followed by increase to 400 MPa) to reduce internal stress.

Note:

The mold tightness is critical, leakage may lead to insufficient pressure.

After pressing, the excess rubber material needs to be cut off, which increases the subsequent processing steps.

4. Hot Isostatic Pressing (HIP)

principle

Hot isostatic pressing is a process that uses an inert gas (such as argon) to apply isotropic pressure at high temperature (1350-1450°C) and high pressure (100-200 MPa) to eliminate micropores in the green body after sintering.

equipment:

Hot Isostatic Press: Equipped with a heating furnace and high-pressure gas system, the accuracy is controlled within ±5°C and ±5 MPa.

Features:
The density can reach 99% of the theoretical density, significantly improving the hardness and wear resistance.
Suitable for post-sintering treatment to eliminate porosity to A00-B00 level.
The cycle is longer, 4-8 hours, and includes heating, pressurization and cooling.

application:
High performance cemented carbide parts for aerospace, such as turbine blades.
Precision cutting tools require extremely high density.
Technical details:
Temperature control: heating rate 5-10°C/min to avoid thermal stress cracks.
Gas purity: Argon purity >99.99%, avoid oxidation.

Note:
High cost, suitable for high-end products.
The cooling rate must be precisely controlled (5-15°C/min) to prevent deformation.

5. Die Pressing

principle
The powder is loaded into a fixed rigid mold and formed by unidirectional or bidirectional pressing, depending on the geometry of the mold.

equipment:
Molding machine: pressure range 100-300 MPa, equipped with automatic feeding system.
Mould: Customized design, hardness above HRC 58.

Features:
Mass production of simple shape blanks, high efficiency, cycle time 5-10 seconds.
Density uniformity depends on mold design, typical density is 60%-70% of theoretical density.

application:
Standardized carbide parts such as cutting inserts and milling cutter blanks.
Low cost production.
Technical details:
Die maintenance: Check for wear every 500 presses and regrind or replace if necessary.
Powder filling: Vibration filling is adopted, and the density deviation is <2%.
Note:
The complex shape of the mold is difficult to process and the stress distribution needs to be simulated in advance.

6. Extrusion Pressing

principle:

The powder is mixed with a binder into a paste and extruded into long strips or shaped bodies through an extruder and a custom die.

equipment:

Extruder: pressure 200-400 MPa, equipped with heating system (50-80°C).

Features:

Suitable for long and thin shapes, such as rods (2-20 mm diameter), tubes.
The density is about 55%-65% of the theoretical density and requires subsequent degreasing.
The cycle time is 10-30 minutes, depending on the extrusion length.

application:

Carbide long cutters and drill rods.
Customized long parts.

Technical details:

Binder ratio: PVA or PMMA accounts for 15%-25% and needs to be evenly dispersed.
Extrusion speed: 0.5-2 m/min. Too fast may cause surface cracks.
Note: The degreasing temperature should be controlled at 300-500°C, and the heating rate should be <5°C/min.

7. Injection Molding

principle:

The powder is mixed with a thermoplastic binder, heated to 150-200°C, injected into a high-precision mold, and then cooled to form.

equipment:

Metal injection molding machine: pressure 50-100 MPa, equipped with injection system.

Features:

Suitable for complex small-sized parts, with an initial density of 50%-60% and up to 98% after sintering.
The cycle is longer, 10-20 minutes/item.

application:

Micro carbide parts, such as precision gears and micro tools.
Technical details:
Binder removal: Two steps, thermal debinding at 200-400°C and chemical debinding at 400-600°C.
Mould accuracy: Tolerance <0.01 mm.

Note:

Binder residue may cause sintering defects and needs to be strictly controlled.

8. Dry Bag Pressing

principle:

The powder is loaded into a fixed rubber mold and pressure is applied through a liquid medium, similar to CIP but the mold is fixed.

equipment:

Dry bag isostatic press: pressure 200-400 MPa.

Features:

Good density uniformity, 70%-75% theoretical density.

The cycle is 5-10 minutes.

application:

Medium size carbide parts such as bearing sleeves.

Technical details: The mold needs to be checked regularly for pressure resistance.

Note:

Avoid uneven pressure caused by mold aging.

9. Multi-Directional Pressing (lateral pressing)

principle:

On the basis of the vertical pressure head, 2-4 lateral pressure heads are added to apply pressure from the horizontal direction to form multi-directional compression. The pressure is coordinated through a precision control system to ensure that all parts of the embryo are balanced.

equipment:

Multi-directional pressing machine: pressure range 200-500 MPa, equipped with 4-6 adjustable pressure heads.

Mould: Multi-directional movable design, with carbide lining, wear resistance HRA 88 or above.

Features:

The density distribution is significantly better than that of bidirectional pressing, and the average density can reach 75%-80% of the theoretical density.

Suitable for medium complex shapes, reducing internal porosity and stress concentrations.

The pressing time is 10-20 seconds, depending on the number of press heads and the size of the embryo.

application:
Complex tool blanks, mold blanks, and parts that require high uniformity .
Technical details:
Pressure distribution: vertical pressure accounts for 50%-60%, lateral pressure accounts for 40%-50%, and the deviation is <3%.
Powder optimization: particle size 1-2 μm , adding 0.5%-1% graphite lubrication.

Note:
The lateral pressure head synchronization needs to be controlled by a servo motor with an error of <0.5 mm.
The inner wall of the mold needs to be coated to reduce the friction to 0.15.

10. Multi -Axial Non-Isostatic Pressing (such as four-way and six-way pressing)
principle:
Non-isotropic pressure is applied by 4 or 6 pressure heads (including vertical and multiple horizontal directions), and the pressure distribution is optimized by the control system instead of being completely isotropic. Each pressure head can adjust the force independently to apply adaptive pressure to different areas of the embryo.
equipment:
Multi-axis press: pressure range 300-600 MPa, equipped with 6-axis hydraulic system and real-time pressure sensor.
Mould: Multi-directional composite structure, inner layer of carbide, outer layer of high-strength steel, pressure resistance up to 800 MPa.
Features:
It provides more pressure directions than bidirectional pressing, and its density uniformity is better than multi-directional pressing, which can reach 85%-90% of the theoretical density.
Because it is non-isostatic, it is suitable for specific shape optimization, and its density is close to CIP but the cost is lower.
The pressing cycle is 15-30 seconds, depending on the complexity of the pressure head coordination.
application:
Multi- edge cutting tools and precision molds require high density and complex geometry.
Medium-scale production, balancing performance and economy.
Technical details:
Pressure configuration: four-way compression (vertical + 3 lateral), pressure ratio 1:0.8:0.7:0.7; six-way compression (vertical + 5 lateral), pressure ratio 1:0.7:0.6:0.6:0.6:0.6.
Powder particle size: 1-3 μm , adding trace amounts of nano-scale additives (such as WC-Co composite powder) to improve density.
Control system: PLC and closed-loop feedback are adopted, pressure deviation is <1%, displacement accuracy is <0.01 mm.
Note:
The coordination of the indenters requires high-precision calibration to avoid microcracks caused

by local overpressure .
Mold design requires finite element analysis (FEA) to simulate multi-directional stress and optimize durability.
Powder mixing requires high shear mixing to ensure isotropic consistency.

Related standard references

ISO 4489:2009 Cemented Carbide Sintering Process Guide: Emphasizes the influence of pressing technology on green body density and sintering properties, and recommends multi-directional pressing for complex shape optimization.
GB/T 3850-2015 Determination of theoretical density of cemented carbide: Multi-directional and multi-axial pressing can significantly increase the density of green billet and reduce the density deviation after sintering (<1%).
GB/T 1031-2009 Surface roughness measurement: The surface roughness of the green billet after pressing (Ra<1.0 μm) directly affects the sintering quality. Multi-directional pressing can improve the surface flatness.

Technical points and optimization

Powder characteristics:
WC particle size is 0.5-5 μm , Co content is 6%-15%, and fine powder (<1 μm) is suitable for multi-directional pressing.
The mixing process uses ball milling or planetary milling for 12-24 hours to ensure uniformity.
Lubricants and adhesives:
Lubricants (such as paraffin 1%-3%) reduce friction, and nano-graphite (0.5%) can be added to further optimize multi-directional pressing.
Binders (such as PVA) are used for extrusion or injection molding and require thermal debinding control.
Mould design:
The multi-directional pressing die needs to adopt a segmented structure with a wear-resistant layer thickness of 2-3 mm.
Finite element analysis simulates multi-directional stress distribution and optimizes the indenter angle (usually 45°-60°).
Post-pressing treatment:
The green blank needs to be dried at 50-80°C to avoid moisture absorption.
Pre-sintering (600-800°C) can remove binder and reduce sintering defects.

Practical application cases

Case 1: Four-way pressing to produce multi- edge tools
Material: WC-10%Co, particle size 1.5 μm .
Pressure: 400 MPa vertically, 300 MPa laterally.
Results: Green billet density is 88% of theoretical density, porosity after sintering is A00, and hardness is HRA 92.
Case 2: Six-way pressing to produce precision molds

Material: WC-12%Co, particle size 2 μm .
Pressure: 500 MPa vertically, 350-400 MPa laterally.
Results: The green billet density is 90% of the theoretical density, the density after sintering is 99%, and the wear resistance is improved by 15%.

Modern trends and innovations

Automation and intelligence: The multi-axis pressing machine integrates AI algorithm to adjust the pressure distribution in real time with a deviation of <0.5%.
Hybrid process: Combination of multi-directional pressing and CIP, first forming and then densification, the density can reach more than 95%.
Green pressing: Develop water-based lubricants to reduce the use of organic solvents and meet environmental protection requirements.
Nanotechnology: Use nano WC powder (<100 nm) with six-way pressing to produce ultra-fine-grained cemented carbide with a hardness of HRA 94 or above.

appendix:

Cemented carbide products covered in this chapter

Types, characteristics and applications of cemented carbide aviation tools

Cemented carbide aviation tools are high-performance cutting tools made of ultra-fine -grained cemented carbide (WC+Ni /Co, grain size <0.5 μm) as the base material, combined with advanced coating technology (such as TiAlN , AlCrN , DLC) and precision machining technology. These tools are designed for the aerospace field and are used to process high-strength, high-temperature alloys (such as Inconel 718, Ti6Al4V), stainless steel and composite materials (such as carbon fiber reinforced composite materials CFRP). Aviation tools must have extremely high hardness (18002200 HV), strength (2.22.5 GPa), wear resistance (friction coefficient <0.3), high temperature resistance (>1000°C) and ultra-high geometric accuracy (±0.010.05 mm, in line with GB/T 345052017) to meet the stringent requirements of high-speed cutting (5002000 m/min), high feed rate (0.10.5 mm/rev) and long life (>60 minutes). This article combines national standards (such as GB/T 183762014, GB/T 79972017) and industry practices (such as Sandvik, 2023; ScienceDirect, 2021) to analyze in detail the types, characteristics and applications of cemented carbide aviation tools.

1. Types of Carbide Aviation Tools

Carbide aviation tools are divided into the following five categories according to processing functions, workpiece materials and geometric shapes. Each type of tool is designed for specific processing needs of aviation parts (such as engine blades, fuselage connection holes, and composite materials structures). The names are refined to start with "Carbide Aviation" to highlight their professionalism:

Carbide aviation milling cutter types

Carbide aviation solid end mills : used for plane, side and slot processing , suitable for general milling tasks.

Carbide aviation ball end milling cutter : used for complex surface and three-dimensional contour processing, such as blade shape.

Carbide aviation round nose milling cutter : takes into account both flat and curved surface processing, suitable for semi-finishing processing.

Carbide aviation wave edge milling cutter : wave cutting edge , reduce vibration, suitable for composite material processing.

Carbide aviation milling cutter shape

Multi -edge (48 edges), diameter Ø 550 mm, length 50150 mm, edge length 1050 mm, shank adopts HSK or BT standard interface to ensure high rigidity.

Carbide aviation milling cutter grades

YN8N (Ni 8 wt %, grain <0.5 μm , corrosion resistant, suitable for high temperature alloys), YG6X

(Co 6 wt %, grain <0.5 μm , high toughness, suitable for composite materials).

Carbide Aviation Drill Bit Types

Carbide Aviation Twist Drill : Standard drilling tool suitable for titanium alloys and stainless steel.

Carbide aviation step drill : completes multi-level hole processing at one time, suitable for fuselage connection holes.

Carbide aviation deep hole drill : aspect ratio>5:1, suitable for deep hole processing of engine parts.

Special carbide drill for aviation composite materials : low cutting force, prevent CFRP delamination.

Carbide aviation drill bit shape

Spiral flute (helix angle 30-40°, optimized chip evacuation), Ø 320 mm, length 50-200 mm, point angle 118-140° (adjusted to material).

Grades : YG6X (high hardness, wear resistance), YN10 (Co/Ni 610 wt %, corrosion resistance, suitable for wet processing).

Carbide aviation reamer :

Carbide aviation drill bits :

Carbide aviation straight groove reamer : high-precision hole processing, suitable for metal materials such as titanium alloy.

Carbide Aviation Spiral Fluted Reamer : Improved chip evacuation, suitable for deep holes and sticky materials.

Carbide aerospace composite reamer : low cutting force, prevents CFRP delamination and burrs.

Shape : Multi -edged (46 edges), diameter Ø 530 mm, length 50100 mm, blade length 2040 mm.

Grade : YN6 (Ni 6 wt %, grain size 0.51.5 μm , excellent wear resistance), YG8 (Co 8 wt %, grain size 0.51.5 μm , good toughness).

Carbide aviation turning tool types

Carbide aviation external cylindrical turning tool : processing the outer surface of shaft parts, such as turbine shaft.

Carbide aviation grooving cutter : for processing narrow grooves and cutting, suitable for complex parts.

Carbide aviation thread cutter : processing high-precision threads of aviation parts.

Carbide aviation turning tool type and shape

Indexable inserts (square, triangle, diamond), sizes 10×10× 5 mm to 20×20× 6 mm, tip radius 0.20.8 mm.

Type and grade of cemented carbide aviation turning tools

YN8N (high temperature resistance, suitable for high temperature alloys), YG6X (high strength, anti-chipping) .

Types of Carbide Aviation Forming Tools

Carbide aviation custom contour cutter : processing complex surfaces such as wing edges.

Carbide aviation composite machining tool : combines drilling and milling functions in one, suitable for efficient machining.

Shape : complex geometry (multiple curved surfaces, special-shaped grooves), size Ø 1050 mm, customized.

Grades : YN8N (corrosion resistant, suitable for composite materials), YG6X (high toughness, suitable for multifunctional processing).

2. Characteristics of cemented carbide aviation tools

2.1 Material properties of cemented carbide aviation tools

Carbide aviation tool substrate

WC (Tungsten Carbide) : 8594 wt %, hardness >2000 HV, providing excellent wear resistance and cutting ability.

Ni/Co (binder phase) : 615 wt %, Ni (YN8N, 610 wt %) enhances corrosion resistance and is suitable for processing high-temperature alloys and wet environments; Co (YG6X, 615 wt %) improves toughness and is suitable for composite materials and impact conditions.

Grain size : Ultrafine grain (<0.5 µm), significantly improves hardness (18002200 HV) and bending strength (2.22.5 GPa), and reduces edge cracking.

Additives : Cr3C2/VC (0.10.5 wt %), inhibit grain growth, reduce η phase (harmful carbide, content <0.5%), and improve material stability.

Carbide aviation tool coating

TiAlN (titanium aluminum nitride) : high temperature resistant (>1000°C), thickness 24 µm , suitable for high-speed cutting of high-temperature alloys, extending tool life by 2030%.

AlCrN (aluminum chromium nitride) : excellent wear resistance, thickness 35 µm , suitable for composite materials and hard metal processing.

DLC (Diamond-Like Carbon Coating) : Low friction coefficient (<0.1), thickness 13 µm , reduces chip sticking and delamination during CFRP processing.

Preparation of cemented carbide aviation tools

Mixing: high energy ball milling (2436 hours, ball to material ratio 15:1, 300400 rpm), ensuring powder particle size D50 <100 µm , oxygen content <0.03% (in accordance with GB/T 345052017).

Binder: polyethylene glycol (PEG, 0.10.2 wt %) or paraffin (0.51 wt %) to optimize powder flowability.

2.2 Performance characteristics of cemented carbide aviation tools

Hardness : 18002200 HV (GB/T 79972017), ensuring excellent wear resistance, wear rate <0.1 mm³ / min (50% lower than ordinary cemented carbide).

Strength : 2.22.5 GPa (GB/T 38512015), strong resistance to chipping , suitable for high feed

processing.
Toughness : Fracture toughness KIC 912 MPa·m ¹ / ² , able to withstand shock and vibration during high-speed cutting.
High temperature resistance : >1000°C, maintaining cutting performance, suitable for dry or minimal lubrication processing (cutting speed 5002000 m/min).
Corrosion resistance : Ni-based grades (such as YN8N) are resistant to acid and alkali corrosion and are suitable for wet processing and corrosive materials.
Geometric accuracy : cutting edge radius <10 μm , surface roughness Ra <0.2 μm , dimensional deviation ±0.010.05 mm, meeting the tolerance requirements of aviation parts (±0.02 mm).
Coating adhesion : Bonding strength >100 N (in accordance with ISO 26443), ensuring that the coating does not peel off during high-speed cutting.

2.3 Machining characteristics of cemented carbide aviation tools

High-speed cutting : supports cutting speeds of 500-2000 m/min (such as Inconel 718 milling 800 m/min, CFRP drilling 200 m/min), improving processing efficiency by 30-50%.
High feed rate : feed rate 0.10.5 mm/rev, suitable for efficient processing of large aviation parts.
Long life : tool life is 60-80 minutes (50% longer than ordinary tools), reducing the frequency of tool changes.
Low surface roughness : Ra <0.8 μm (metal) or Ra <0.4 μm (CFRP) on the machined surface, meeting the surface quality requirements of aviation parts.
Environmental adaptability : supports dry, minimal lubrication (MQL) or wet processing, and adapts to a variety of processing environments.

3. Application of cemented carbide aviation tools

Carbide aviation milling cutter

Application scenarios of cemented carbide aviation milling cutters

Processing of aircraft engine blades and turbine disks (Inconel 718, Ti6Al4V) to ensure the accuracy of complex surfaces.
Machining of composite materials (CFRP) such as wings and cabin structures to prevent delamination and burrs.
Performance :
Cutting speed: 800-2000 m/min (Inconel 718 800 m/min, CFRP 1500 m/min).
Feed rate: 0.20.5 mm/rev.
Lifespan: 80 minutes (superalloy), 100 minutes (CFRP).
Surface roughness: Ra <0.8 μm .

Examples :
Carbide aviation ball end mill (YN8N, Ø 10 mm, TiAlN coating):
Machining Inconel 718 blades, cutting speed 800 m/min, feed rate 0.2 mm/rev.

Results: profile tolerance ±0.02 mm, surface Ra 0.6 μm , tool life 80 minutes (Sandvik, 2023).

Carbide aviation wave edge milling cutter (YG6X, Ø 12 mm, AlCrN coating):
Processing CFRP wing panel, cutting speed 1500 m/min, feed rate 0.3 mm/rev.
Results: No delamination, surface Ra 0.4 μm , life span 100 minutes.

Application scenarios of cemented carbide aviation drill bits
Processing of titanium alloy (Ti6Al4V) fuselage connection holes ensures high precision and low burrs.
Processing of CFRP/aluminum laminate structures to prevent delamination and material tearing.

Performance
Cutting speed: 50200 m/min (Ti6Al4V 50 m/min, CFRP 200 m/min).
Feed rate: 0.10.2 mm/rev.
Lifespan: 60 minutes (metal), 80 minutes (CFRP).
Aperture accuracy: ±0.02 mm.

Examples :
Carbide aviation twist drill (YG6X, Ø 6 mm, AlCrN coating):
Processing Ti6Al4V connecting holes, hole depth 50 mm, cutting speed 50 m/min, feed rate 0.1 mm/rev.
Results: hole diameter deviation ±0.02 mm, no burrs, tool life 60 minutes.

Carbide drill for aviation composite materials (YN10, Ø 8 mm, DLC coating):
Machining CFRP/aluminum stack, cutting speed 200 m/min, feed rate 0.15 mm/rev.
Results: No delamination, hole wall Ra 0.3 μm , life 80 minutes.

Application scenarios of cemented carbide aviation reamers
Finish machining of CFRP/aluminum stack holes to ensure high precision and low roughness.
Processing high-precision holes in engine parts, such as bearing seat holes.

Performance :
Cutting speed: 100300 m/min (CFRP 200 m/min, titanium alloy 100 m/min).
Feed rate: 0.150.3 mm/rev.
Lifespan: 50 minutes (metal), 70 minutes (CFRP).
Surface roughness: Ra <0.4 μm .

Examples :
Carbide aviation spiral flute reamer (YN6, Ø 8 mm, DLC coating):
Machining CFRP holes with a cutting speed of 200 m/min and a feed rate of 0.15 mm/rev.
Results: Aperture tolerance ±0.01 mm, surface Ra 0.3 μm , life 70 minutes.

Carbide aviation straight flute reamer (YG8, Ø 10 mm, TiAlN coating):
Machining Ti6Al4V bearing seat hole, cutting speed 100 m/min, feed rate 0.2 mm/rev.
Results: Aperture deviation ±0.015 mm, Ra 0.4 µm , life 50 minutes.

Application scenarios of cemented carbide aviation turning tools
Machining the outer diameter of high-temperature alloy shaft parts, such as turbine shafts.
Processing of threads and narrow grooves, such as engine connections.

Performance :
Cutting speed: 200-600 m/min (Inconel 718 200 m/min, stainless steel 600 m/min).
Feed rate: 0.2-0.4 mm/rev.
Lifespan: 70 minutes (high temperature alloy), 90 minutes (stainless steel).
Surface roughness: Ra <0.8 µm .

Examples :
Carbide aviation external turning tool (YG6X, blade 12×12× 5 mm, TiAlN coating):
Machining Inconel 718 turbine shaft, cutting speed 200 m/min, feed rate 0.2 mm/rev.
Results: Surface Ra 0.7 µm , tolerance ±0.03 mm, life 70 minutes.
Carbide aviation thread cutter (YN8N, blade 16×16× 5 mm, TiAlN coating):
Machining stainless steel threads, cutting speed 400 m/min, feed rate 0.3 mm/rev.
Results: Thread accuracy IT6, Ra 0.6 µm , life 90 minutes.

Application scenarios of cemented carbide aviation forming tools
Machining of complex composite contours such as wing edges and hull structures.
Processing titanium alloy special-shaped grooves, such as engine case grooves.

Performance :
Cutting speed: 200500 m/min (CFRP 500 m/min, titanium alloy 200 m/min).
Feed rate: 0.150.3 mm/rev.
Lifespan: 60 minutes (CFRP), 50 minutes (titanium alloy).
Contour accuracy: ±0.03 mm.

Examples :
Carbide aviation custom contour cutter (YN8N, Ø 20 mm, AlCrN coating):
Machining CFRP wing edge, cutting speed 500 m/min, feed rate 0.2 mm/rev.
Results: Profile tolerance ±0.03 mm, no delamination, life 60 minutes.
Carbide aviation composite machining tool (YG6X, Ø 15 mm, DLC coating):
Processing Ti6Al4V special-shaped groove, cutting speed 200 m/min, feed rate 0.15 mm/rev.
Results: Groove depth tolerance ±0.02 mm, Ra 0.5 µm , life 50 minutes.

4. Comparison of Carbide Aviation Tools

Tool Type	Brand	shape	coating	Cutting speed m/min	life minute	Accuracy mm	Typical Applications
Carbide aviation solid end mill	YN8N, YG6X	Multi - blade Ø 550 mm	TiAlN , AlCrN	5002000	80100	±0.02	Blades, CFRP plane
Carbide aviation ball end milling cutter	YN8N, YG6X	Ball Head Ø 550 mm	TiAlN , AlCrN	8001500	80100	±0.02	Blade surface
Carbide Aviation Twist Drill	YG6X, YN10	spiral Ø 320 mm	AlCrN , DLC	50200	6080	±0.02	Titanium alloy hole
Cemented Carbide Drills for Aviation Composite Materials	YG6X, YN10	spiral Ø 320 mm	DLC	100200	80	±0.02	CFRP laminated hole
Carbide Aviation Spiral Fluted Reamer	YN6, YG8	Multi - blade Ø 530 mm	DLC, TiAlN	100300	5070	±0.01	CFRP hole finishing
Carbide aviation external turning tool	YN8N, YG6X	blade 1020 mm	TiAlN	200600	7090	±0.03	Turbine shaft
Carbide Aviation Custom Contour Knife	YN8N, YG6X	complex Ø 1050 mm	AlCrN , DLC	200500	5060	±0.03	Wing profile

5. Optimization suggestions

Material selection :

High temperature alloy processing : select YN8N (Ni 8 wt %, grain <0.5 μm), hardness increased by 5%, corrosion resistance increased by 20%.

Composite material processing : Use YG6X (Co 6 wt %) to increase toughness by 10% and reduce the risk of delamination.

Additive : Cr3C2 (0.2 wt %), improves wear resistance by 15%.

Coating Optimization :

TiAlN (3 μm) : High temperature alloy processing, temperature resistance increased by 20%, life increased by 30%.

AlCrN (4 μm) : Composite material and titanium alloy, wear resistance increased by 25%.

DLC (2 μm) : CFRP processing, the friction coefficient is reduced to <0.1, and the sticking is reduced by 50%.

geometry :

Cutting edge optimization : cutting edge radius <10 μm , reducing cutting heat by 20% and improving surface quality.

Helix angle adjustment : The helix angle of composite material tools is 3540°, which improves chip evacuation and reduces delamination.

Strengthened back angle : back angle 1015°, reducing cutting force by 15% and extending tool life.

Processing parameters :

High speed cutting : Inconel 718 cutting speed 800-1000 m/min, feed rate 0.2-0.3 mm/rev.

Low speed and high precision : CFRP cutting speed 100200 m/min, feed rate 0.10.15 mm/rev.

Minimal Quantity Lubrication (MQL) : Reduces cutting heat by 30% and extends tool life by 20%.

Post-processing :

Grinding : Ra <0.4 μm , reducing stress concentration by 30%.

Polishing : Ra <0.2 μm , reducing chip adhesion by 50% and improving surface quality.

Shot peening : surface hardness increased by 5%, fatigue resistance increased by 20%.

6. Standards

GB/T 345052017 : Dimensional accuracy ±0.2 mm, tolerance deviation <±5%.

GB/T 183762014 : Porosity <0.01%, material uniformity >95%.

GB/T 38502015 : Density verification, ensuring density>99%.

GB/T 51692013 : Porosity grade A02B00C00.

GB/T 38512015 : Flexural strength 1.82.5 GPa .

GB/T 79972017 : Hardness 14002200 HV.

7. Conclusion

Cemented carbide aviation tools include five categories: cemented carbide aviation milling cutters, drills, reamers, turning tools and forming tools. They use ultra-fine- grained cemented carbide (YN8N, YG6X) and advanced coatings (TiAlN , AlCrN , DLC) to meet the processing needs of aerospace high-temperature alloys and composite materials:

Carbide aviation milling cutter : suitable for complex surfaces and composite materials, cutting speed 800-2000 m/min, life 80-100 minutes.

Carbide aviation drill : high-precision hole processing, cutting speed 50200 m/min, hole diameter deviation ±0.02 mm.

Carbide aviation reamer : finishing hole, surface Ra <0.4 μm , tolerance ±0.01 mm.

Carbide aviation turning tools : shaft and thread processing, life 7090 minutes.

Carbide aviation forming tools : complex contour processing, accuracy ±0.03 mm.

These tools significantly improve the machining efficiency and quality of aviation parts with their high hardness, high temperature resistance and ultra-high precision, and are widely used in the manufacturing of engines, fuselages and composite structures.

appendix:

Cemented carbide products covered in this chapter

Types, characteristics and applications of cemented carbide mining drill bits

Carbide mining drill bits are high-performance tools made of medium-fine-grained cemented carbide (WC+Co /Ni, grain size 0.52 μm) as the base material, combined with wear-resistant coating technology (such as TiN , TiCN) and precision machining technology. These drill bits are designed for mining, tunneling and geological exploration, and are used to process hard rocks (such as granite, basalt, compressive strength>200 MPa), coal seams and ores. Mining drill bits need to have high hardness (14001800 HV), bending strength (1.82.5 GPa), excellent wear resistance (wear volume <0.2 mm³ / h), impact resistance (KIC 912 MPa·m¹ / ²) and dimensional accuracy (±0.20.5 mm, in line with GB/T 345052017) to cope with high impact (1050 kN), high speed (100500 rpm) and harsh environment (dust, moisture). This article combines national standards (such as GB/T 183762014, GB/T 79972017) and industry practices (such as Sandvik, 2023; ScienceDirect, 2021) to analyze in detail the types, characteristics and applications of cemented carbide mining drill bits, and refines the description to ensure readers' clear understanding, supplementing performance comparisons, typical cases and optimization suggestions .

1. Types of Carbide Mining Drill Bits

Carbide mining drill bits are divided into the following three categories based on function, rock type and geometry. Each type of drill bit is designed for specific needs of mining tasks (such as hard rock drilling, coal mining, and ore excavation). The name is refined to start with "Carbide Mining" to highlight its professionalism:

Carbide Mining Roller Drill Bit Types

Carbide Mining Tri-cone Drill Bits

Used for hard and medium-hard rock drilling, suitable for large open-pit mines.

Carbide Mining Single Cone Drill Bits

Used for small or complex geology, with high flexibility.

shape

Conical or spherical teeth, number of teeth 10-30, drill diameter Ø 100-400 mm, length 200-600 mm, connection API standard thread.

Brand

YN10 (Co 10 wt %, grain 0.51.5 μm , impact resistant), YG8 (Co 8 wt %, grain 0.51.5 μm , wear resistant).

Carbide Mining DTH Drill Bit Types

Carbide Mining Standard DTH Drill Bits

Used in medium hard and soft rock, suitable for blast holes.

Carbide mining high air pressure down-the-hole drill bit

Used in deep holes and hard rocks with high efficiency.

shape

Cylindrical, with spherical or bullet-shaped carbide teeth, number of teeth 820, drill diameter Ø 80-200 mm, length 150-300 mm.

Grade : YG8 (high hardness), YN10 (corrosion resistant, suitable for wet drilling).

Carbide Mining Pick Types

Carbide Mining Conical Picks

For use in coal seams and soft rock, suitable for roadheaders.

Carbide Mining Cylindrical Picks

Used for medium hard rock, suitable for comprehensive mining.

shape

Conical or cylindrical head, head diameter Ø 1030 mm, length 50100 mm, base body made of high-strength steel (such as 42CrMo).

Brand

YG6 (Co 6 wt %, grain size 1.52 μm , impact resistant), YN10 (high toughness).

2. Characteristics of Carbide Mining Drill Bits

2.1 Material properties of cemented carbide mining drill bits

Carbide Mining Drill Bit Body

WC (Tungsten Carbide) : 8592 wt %, hardness >2000 HV, providing excellent wear resistance and cutting ability.

Co/Ni (binder phase) : 815 wt %, Co (YG8, 815 wt %) enhances toughness and is suitable for high impact conditions; Ni (YN10, 610 wt %) improves corrosion resistance and is suitable for wet coal seams and acidic environments.

Grain size : Medium-fine grains (0.51.5 μm , YN10/YG8) balance hardness (14001800 HV) and toughness (KIC 912 MPa·m $^{1/2}$); coarse grains (1.52 μm , YG6) further improve impact resistance.

Additives : Cr3C2 (0.10.5 wt %), inhibits grain growth, reduces η phase (harmful carbides, content <0.5%), and improves material stability.

Carbide Mining Drill Bit Coating (Optional)

TiN (titanium nitride) : wear-resistant, thickness 24 μm , suitable for hard rock drilling, extending service life by 1520%.

TiCN (titanium carbonitride) : impact resistant, 35 μm thick , suitable for coal seams and soft rocks, reduces wear by 25%.

Carbide Mining Drill Bit Preparation

Mixing: high energy ball milling (1624 hours, ball to material ratio 10:1, 200300 rpm), ensuring powder particle size D50 50150 μm , oxygen content <0.03% (in line with GB/T 345052017).

Binder: polyethylene glycol (PEG, 0.10.2 wt %) or paraffin (0.51 wt %) to optimize powder flowability.

2.2 Performance characteristics of cemented carbide mining drill bits

Hardness : 14001800 HV (GB/T 79972017), excellent wear resistance, wear rate <0.2 mm³ / h (40% lower than ordinary cemented carbide).
Strength : 1.82.5 GPa (GB/T 38512015), fracture-resistant, suitable for high-impact environments.
Toughness : Fracture toughness KIC 912 MPa·m $^{1/2}$, resistant to high-frequency shock (1050 kN) and vibration.
Wear resistance : wear <0.2 mm³ / h, tool life 80-120 hours (50-100% longer than ordinary drills).
Corrosion resistance : Ni-based grades (such as YN10) are resistant to moisture and acidic environments and are suitable for wet drilling.
Geometric accuracy : dimensional deviation ±0.20.5 mm, surface roughness Ra <1.6 µm , meeting the drilling tolerance requirements (±0.5 mm).
Coating adhesion : Bond strength >80 N (in accordance with ISO 26443), ensuring that the coating does not peel off under high impact .

2.3 Processing characteristics of cemented carbide mining drill bits

High impact drilling : supports impact force of 1050 kN (such as 30 kN for down-the-hole drilling), suitable for hard rock and ore mining.
High speed : 100-500 rpm (200 rpm for roller bit, 300 rpm for pick), increasing drilling efficiency by 20-30%.
Long life : tool life of 80-120 hours, reducing replacement frequency and downtime costs.
Environmental adaptability : Resistant to dust, moisture and high temperature (>200°C), supports dry or wet drilling.
Low maintenance cost : High wear resistance and toughness reduce tooth wear and extend maintenance cycle by 50%.

3. Application of cemented carbide mining drill bits

Application scenarios of cemented carbide mining rotary drill bits
Hard rock drilling (e.g. granite, basalt), used in open pit and deep shaft mining.
Geological exploration, processing of large diameter holes (Ø 200400 mm).

Performance :
Rotational speed: 150,200 rpm.
Impact force: 2040 kN .
Lifespan: 100-120 hours.
Drilling accuracy: hole diameter deviation ±0.5 mm.

Examples :
Carbide mining tri-cone drill bit (YN10, Ø 250 mm, TiN coating):
Processing of granite (compressive strength 220 MPa), rotation speed 200 rpm, impact force 30 kN .

Results: hole depth 500 m, hole diameter deviation ±0.5 mm, life span 120 hours (ScienceDirect, 2021).

Carbide mining single cone drill bit (YG8, Ø 150 mm, TiCN coating):
Processing of medium hard rock (compressive strength 150 MPa), rotation speed 180 rpm, impact force 25 kN .
Results: Hole depth 300 m, life 100 hours.

Carbide Mining Down-the-Hole Drill Bits :
Application scenarios :
Iron and copper mining, processing blast holes (Ø 80-200 mm).
Tunneling in medium-hard and soft rock.
Performance :
Rotational speed: 100-150 rpm.
Impact force: 2030 kN .
Lifespan: 80100 hours.
Drilling accuracy: hole diameter deviation ±0.4 mm.

Examples :
Carbide mining standard down-the-hole drill bit (YG8, Ø 120 mm, TiCN coating):
Processing iron ore (compressive strength 180 MPa), rotation speed 150 rpm, impact force 25 kN .
Results: hole depth 100 m, hole diameter deviation ±0.4 mm, life 100 hours.

Carbide mining high air pressure down-the-hole drill bit (YN10, Ø 100 mm, TiN coating):
Processing basalt (compressive strength 200 MPa), rotation speed 120 rpm, impact force 30 kN .
Results: Hole depth 150 m, life 90 hours.

Carbide Mining Picks :
Application scenarios :
Coal seam mining, for roadheaders and integrated coal mining equipment.
Excavation of medium hard rock, such as sandstone (compressive strength 100-150 MPa).
Performance :
Rotational speed: 200-300 rpm.
Impact force: 1020 kN .
Lifespan: 80100 hours.
Surface roughness: Ra <1.6 µm .

Examples :
Carbide mining cone picks (YG6, Ø 20 mm, uncoated):
Processing coal seam (compressive strength 50 MPa), rotation speed 300 rpm, impact force 10 kN .
Results: 5000 m of excavation, 80 hours of service life, wear <0.15 mm^3 / h.
Carbide mining cylindrical pick (YN10, Ø 25 mm, TiN coating):

Processing sandstone (compressive strength 120 MPa), rotation speed 250 rpm, impact force 15 kN . Result: Excavation 4000 m, life span 100 hours.

4. Comparison of Carbide Mining Drill Bit Types

Drill bit type	Brand	shape	coating	Speed rpm	life Hour	Accuracy(mm)	Typical Applications
Carbide Mining Tri-cone Drill Bits	YN10, YG8	Conical/spherical teeth, Ø 100400 mm	TiN , TiCN	150200	100120	±0.5	Hard rock, exploration
Carbide Mining Standard DTH Drill Bits	YG8, YN10	Spherical teeth, Ø 80200 mm	TiCN	100150	80100	±0.4	Iron ore, tunnel
Carbide Mining Conical Picks	YG6, YN10	Conical, Ø 1030 mm	None/ TiN	200300	80100	±0.3	Coal seam, soft rock

5. Optimization suggestions

Material selection :
Hard rock drilling : Use YN10 (Co 10 wt %, grain size 0.5-1.5 µm), the hardness increases by 5% and the impact resistance increases by 15%.
Coal mining : YG6 (Co 6 wt %, grain size 1.52 µm) is selected, with 20% increase in toughness and fracture resistance.
Additive : Cr3C2 (0.2 wt %), wear resistance increased by 15%.

Coating Optimization :
TiN (3 µm) : For hard rock drilling, wear resistance increases by 20% and service life increases by 15%.
TiCN (4 µm) : Coal seams and soft rocks, impact resistance increased by 20%.

geometry :
Optimized tooth shape : spherical teeth (hard rock) or conical teeth (soft rock), reducing wear by 20%.
Tooth arrangement : Asymmetric arrangement, reduces vibration by 15% and improves drilling efficiency.
Matrix strengthening : 42CrMo steel matrix, fatigue resistance increased by 30%.

Processing parameters :
Hard rock : rotation speed 150200 rpm, impact force 2030 kN .
Soft rock : rotation speed 200-300 rpm, impact force 1015 kN .
Wet drilling : water flow rate 1020 L/min, reducing wear by 25%.

Post-processing :

Grinding : Ra <1.6 μm , reducing stress concentration by 20%.
Shot peening : surface hardness increased by 5%, fatigue resistance increased by 25%.

6. Standards

GB/T 345052017 : Dimensional accuracy ±0.2 mm, tolerance deviation <±5%.
GB/T 183762014 : Porosity <0.01%, uniformity >95%.
GB/T 38502015 : Density verification.
GB/T 51692013 : Porosity grade A02B00C00.
GB/T 38512015 : Flexural strength 1.82.5 GPa .
GB/T 79972017 : Hardness 14001800 HV.

7. Conclusion

Carbide mining drill bits include three categories: carbide mining roller drill bits, down-the-hole drill bits and picks. They are made of medium-fine-grained carbide (YN10, YG8, YG6) and wear-resistant coatings (TiN , TiCN) to meet the needs of hard rock, coal seam and ore mining:
Carbide Mining Roller Drill Bits : Hard rock drilling, speed 150-200 rpm, life 100-120 hours.
Carbide mining down-the-hole drill bits : ore and tunnel, speed 100-150 rpm, life 80-100 hours.
Carbide mining picks : coal seams and soft rock, speed 200-300 rpm, life 80-100 hours.
These drill bits significantly improve mining efficiency and economy with their high hardness, impact resistance and long life, and are widely used in open-pit mines, underground mines and tunnel projects.

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appendix:

Cemented carbide products covered in this chapter

Types, characteristics and applications of cemented carbide wear-resistant molds

Cemented carbide wear-resistant molds are high-performance tools made of medium-fine-grained cemented carbide (WC+Co /Ni, grain size 0.52 μm) as the base material, combined with precision machining technology and optional coating technology (such as TiN , CrN). These molds are designed for industrial forming, stamping and extrusion, and are used to process metals (such as steel, aluminum), plastics, ceramics and other materials. Cemented carbide wear-resistant molds must have high hardness (14001800 HV), high strength (1.82.5 GPa), excellent wear resistance (wear loss <0.1 mm³ / h), corrosion resistance and dimensional accuracy (±0.010.05 mm, in line with GB/T 345052017) to cope with high pressure (5002000 MPa), high frequency (>10 ⁶ times) and complex working conditions (high temperature, corrosion). This article combines national standards (such as GB/T 183762014, GB/T 79972017) and industry practices (such as Sandvik, 2023; ScienceDirect, 2021) to analyze in detail the types, characteristics and applications of cemented carbide wear-resistant molds, and refines the description to ensure readers' clear understanding, supplements performance comparisons, typical cases and optimization suggestions, and details the product name in the form of "cemented carbide wear-resistant + specific mold name".

1. Types of carbide wear-resistant molds

Carbide wear-resistant molds are divided into the following three categories according to molding function, processing materials and geometric shapes. Each type of mold is targeted at specific needs of industrial manufacturing (such as metal stamping, plastic molding, ceramic extrusion), and the name is refined to start with "carbide wear-resistant" to highlight its professionalism:

Carbide wear-resistant stamping die types

Hard alloy wear-resistant cold punching die
Used for punching and bending of metal sheets, suitable for automotive parts.

Hard alloy wear-resistant hot stamping die
Used for high temperature metal forming, such as aviation forgings.
Shape : complex cavity (punch, die), size 50×50× 20 mm to 200×200× 50 mm, edge radius 0.10.5 mm.
Grade : YG8 (Co 8 wt %, grain 0.51.5 μm , wear resistant), YN10 (Co/Ni 10 wt %, grain 0.51.5 μm , corrosion resistant).

Carbide wear-resistant tensile die type

Carbide wear-resistant wire drawing die
Used for stretching metal wires, such as copper wire and steel wire.

Carbide wear-resistant extrusion die

Used for extrusion of metal or plastic pipes and profiles.

Shape : round or special-shaped hole (Ø 0.150 mm), mold outer diameter Ø 20100 mm, length 30150 mm.

Grade : YG6 (Co 6 wt %, grain size 1.52 µm , impact resistant), YG8 (high hardness).

Carbide wear-resistant forming die types

Carbide wear-resistant plastic molding mold

Used for injection molding, such as mobile phone cases.

Hard alloy wear-resistant powder metallurgy mold

Used for pressing ceramic and cemented carbide blanks.

Shape : Complex curved cavity, size 20×20× 10 mm to 150×150× 50 mm, surface roughness Ra <0.4 µm .

Grade : YN10 (corrosion resistant), YG8 (high strength).

2. Characteristics of cemented carbide wear-resistant molds

2.1 Material properties

Matrix

WC (Tungsten Carbide) : 8592 wt %, hardness >2000 HV, providing excellent wear resistance and compression resistance.

Co/Ni (binder phase) : 615 wt %, Co (YG8, 815 wt %) enhances toughness and is suitable for high pressure conditions; Ni (YN10, 610 wt %) improves corrosion resistance and is suitable for acidic or wet environments.

Grain size : Medium-fine grains (0.51.5 µm , YN10/YG8) balance hardness (14001800 HV) and toughness (KIC 912 MPa·m $^{1/2}$); coarse grains (1.52 µm , YG6) improve impact resistance.

Additives : Cr_3C_2 (0.10.5 wt %), inhibits grain growth, reduces η phase (harmful carbides, content <0.5%), and improves material stability.

Coating (optional)

TiN (titanium nitride) : wear-resistant, thickness 24 µm , suitable for metal stamping, extending life by 2030%.

CrN (chromium nitride) : corrosion resistant, thickness 35 µm , suitable for plastic molding and wet processing.

preparation

Mixing: high energy ball milling (1624 hours, ball to material ratio 10:1, 200300 rpm), ensuring powder particle size D50 50150 µm , oxygen content <0.03% (in line with GB/T 345052017).

Binder: polyethylene glycol (PEG, 0.10.2 wt %) or paraffin (0.51 wt %) to optimize powder flowability.

2.2 Performance characteristics

Hardness : 14001800 HV (GB/T 79972017), excellent wear resistance, wear rate <0.1 mm³ / h (50% lower than ordinary cemented carbide).
Strength : 1.82.5 GPa (GB/T 38512015), strong compressive resistance, withstanding 5002000 MPa.
Toughness : Fracture toughness KIC 912 MPa·m $^{1/2}$, resistant to high frequency impact (>10 ^{6} times).
Wear resistance : wear <0.1 mm³ / h, mold life 10 ^{6} 10 ^{7} times (510 times longer than high-speed steel molds).
Corrosion resistance : Ni-based grades (such as YN10) are resistant to acids and alkalis and are suitable for wet processing and corrosive materials.
Geometric accuracy : dimensional deviation ±0.010.05 mm, surface roughness Ra <0.4 μm , meeting high-precision molding requirements.
Coating adhesion : Bond strength >80 N (in accordance with ISO 26443), ensuring that the coating does not peel off under high pressure.

2.3 Processing characteristics

High pressure molding : supports molding pressure of 500-2000 MPa (such as cold punching 1000 MPa, extrusion 1500 MPa).
High frequency : supports continuous stamping/forming >10 ^{6} times, suitable for mass production.
Long life : The mold life is 10 ^{6} 10 ^{7} times, reducing the replacement frequency and reducing production costs by 3050%.
High surface quality : the surface of the molded part is Ra <0.8 μm , meeting the requirements of precision parts.
Environmental adaptability : Resistant to high temperature (>300°C), moisture and corrosion, suitable for a variety of processing environments.

3. Application of cemented carbide wear-resistant molds

Carbide wear-resistant stamping die :
Application scenarios :
Punching and bending of automobile parts (such as body steel plates, aluminum alloy panels).
High temperature forming of aviation forgings (such as titanium alloy connectors).
Performance :
Molding pressure: 8001200 MPa.
Number of strokes: >10 ^{6} times.
Lifespan: 10 ^{6} 10 ^{7} times.

Accuracy: ±0.02 mm.

Examples :

Hard alloy wear-resistant cold punching die (YG8, 100×100× 30 mm, TiN coating):

Processing 1 mm thick stainless steel plate, pressure 1000 MPa, stroke times 1.5×10 ⁶ times.

Results: Part tolerance ±0.02 mm, surface Ra 0.6 µm , life 1.5×10 ⁶ times (Sandvik, 2023).

Hard alloy wear-resistant hot stamping die (YN10, 150×150× 40 mm, CrN coating):

Processing Ti6Al4V forgings at 1200 MPa pressure and 800°C temperature.

Result: Tolerance ±0.03 mm, life span 10 ⁶ times.

Carbide wear-resistant tensile die :

Application scenarios :

Stretching of metal wires (e.g. copper wire Ø 0.1 mm, steel wire Ø 1 mm).

Aluminum alloy or plastic pipe extrusion (such as automotive pipe fittings).

Performance :

Tensile/extrusion pressure: 10001500 MPa.

Lifespan: $10^6$5 ×10^6 times .

Accuracy: Aperture deviation ±0.01 mm.

Surface roughness: Ra <0.4 µm .

Examples :

Carbide wear-resistant wire drawing dies (YG6, Ø 0.5 mm hole, TiN coating):

Stretching copper wire (Ø 0.5 mm), pressure 1200 MPa, linear speed 10 m/s.

Results: Wire diameter deviation ±0.01 mm, surface Ra 0.3 µm , life span 3×10 ⁶ meters.

Carbide wear-resistant extrusion die (YG8, Ø 20 mm hole, CrN coating):

Extruded aluminum alloy tube (Ø 20 mm), pressure 1500 MPa.

Result: Tube wall tolerance ±0.02 mm, life span 10 ⁶ times.

Hard alloy wear-resistant forming mold :

Application scenarios :

Injection molding (such as mobile phone cases, automotive plastic parts).

Powder metallurgy pressing (such as ceramic parts, cemented carbide billets).

Performance :

Molding pressure: 5001000 MPa.

: 2 × $10^6$$10^7$times .

Accuracy: ±0.010.03 mm.

Surface roughness: Ra <0.4 µm .

Examples :

Carbide wear-resistant plastic molding die (YN10, 80×80× 20 mm, CrN coating):

Injection molding of ABS mobile phone case, pressure 800 MPa, cycle 2×10 ⁶ times.

Results: Part tolerance ±0.01 mm, surface Ra 0.2 µm , life 2.5×10 ⁶ times.

Cemented carbide wear-resistant powder metallurgy mold (YG8, 50×50× 15 mm, TiN coating):

Pressing ceramic blanks at a pressure of 1000 MPa.

Result: Tolerance ±0.02 mm, life span 10 ⁷ times.

4. Comparison of cemented carbide wear-resistant mold types

Mold Type	Brand	shape	coating	Pressure(MPa)	Lifespan (times)	Accuracy(mm)	Typical Applications
Hard alloy wear-resistant cold punching die	YG8, YN10	Chamber, 50200 mm	TiN , CrN	8001200	10 ⁶ 10 ⁷	±0.02	Automobile steel plate
Carbide wear-resistant wire drawing die	YG6, YG8	Hole, Ø 0.150 mm	TiN	10001500	10 ⁶ 5×10 ⁶	±0.01	Copper wire, steel wire
Carbide wear-resistant plastic molding mold	YN10, YG8	Curved surface, 20150 mm	CrN	5001000	2×10 ⁶ 10 ⁷	±0.01	Phone Cases

5. Optimization suggestions

Material selection :
Metal stamping : Use YG8 (Co 8 wt %, grain size 0.51.5 μm), hardness increased by 5%, and wear resistance increased by 20%.
Plastic molding : Use YN10 (Ni 10 wt %) to increase corrosion resistance by 25%.
Additive : Cr3C2 (0.2 wt %), wear resistance increased by 15%.
Coating Optimization :
TiN (3 μm) : Metal stamping, wear resistance increased by 20%, life increased by 30%.
CrN (4 μm) : Plastic molding, corrosion resistance increased by 20%, reduced mold sticking.
geometry :
Cutting edge optimization : cutting edge radius <0.2 mm, reducing stress concentration by 20%.
Cavity polishing : Ra <0.2 μm , reducing adhesion by 30%.
Transition radius : R0.51 mm, crack resistance increased by 15%.
Processing parameters :
Cold punching : pressure 800-1000 MPa, punching speed 100-200 times/min.
Extrusion : pressure 12001500 MPa, temperature <300°C.
Injection molding : pressure 600800 MPa, cycle time 510 seconds.
Post-processing :
Grinding : Ra <0.4 μm , reducing wear by 20%.
Polishing : Ra <0.2 μm , improving the surface quality of parts by 30%.
Shot peening : surface hardness increased by 5%, fatigue resistance increased by 25%.

6. Standards

GB/T 345052017 : Dimensional accuracy ±0.01 mm, tolerance deviation <±5%.
GB/T 183762014 : Porosity <0.01%, uniformity >95%.
GB/T 38502015 : Density verification.
GB/T 51692013 : Porosity grade A02B00C00.

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GB/T 38512015 : Flexural strength 1.82.5 GPa .
GB/T 79972017 : Hardness 14001800 HV.

7. Conclusion

Cemented carbide wear-resistant molds include three categories: cemented carbide wear-resistant stamping molds, drawing molds and forming molds. They use medium and fine-grained cemented carbide (YG8, YN10, YG6) and wear-resistant coatings (TiN , CrN) to meet the processing needs of metals, plastics and ceramics:
Carbide wear-resistant stamping dies : automotive parts and aviation forgings, pressure 8001200 MPa, life 10^{6} 10^{7} times.
Carbide wear-resistant tensile die : wire and tube, pressure 10001500 MPa, accuracy ±0.01 mm.
Carbide wear-resistant forming molds : injection molding and powder metallurgy, life 2×10^{6} 10^{7} times, surface Ra <0.4 μm .
These molds significantly improve industrial molding efficiency and product quality with their high hardness, wear resistance and ultra-high precision, and are widely used in the automotive, electronics, aviation and ceramics industries.

appendix:

Characteristics, applicability and advantages and disadvantages of various pressing processes of cemented carbide

The pressing process of cemented carbide (such as nickel-based or cobalt-based cemented carbide) is to mix tungsten carbide (WC) powder, binder phase (such as Ni, Co) powder and other additives (such as Cr3C2, VC) and press them into blanks (test bars, tool blanks, etc.) to provide uniform and dense blanks (density 5070% theoretical density, porosity <0.01%) for subsequent sintering. The pressing process directly affects the dimensional accuracy (±0.1 mm), density uniformity (>95%), mechanical properties (bending strength 1.82.5 GPa , hardness 14002200 HV) and final test bar quality (in accordance with GB/T 38512015, GB/T 79972017) of the blank. Common pressing processes include die pressing, cold isostatic pressing (CIP), hot isostatic pressing (HIP, pressing + sintering), extrusion and metal injection molding (MIM). The following details the characteristics, applicability and advantages and disadvantages of various pressing processes, with a table for clear comparison, combined with national standards (such as GB/T 345052017, GB/T 183762014) and the latest research (such as Sandvik, 2023; ScienceDirect, 2021).

1. Overview of various pressing processes for cemented carbide

The goal of the cemented carbide pressing process is to produce billets with high density (50-70% theoretical density), uniformity (>95%) and dimensional accuracy (±0.1 mm) to meet the performance requirements of the test bars after sintering (such as bending strength 1.8-2.5 GPa , hardness 1400-2200 HV, corrosion resistance <0.005 mm/year).

The pressing process needs to consider:
Powder properties
WC particle size (0.12 μm), fluidity (<25 s/50 g, GB/T 14822010), and binder phase ratio (615 wt %).
Billet shape
Simple (such as a test bar 5×5×35 mm) or complex (such as a tool, a mold).
Production efficiency
Large batches (>1000 pieces/hour) or small batches (<100 pieces).
cost
Equipment (505 million yuan), molds (1.1 million yuan), energy consumption (0.55 kWh/kg).
This article analyzes the characteristics, applicability, advantages and disadvantages of five main pressing processes, following standards such as GB/T 345052017 (powder preparation) and GB/T 38512015 (strength).

2. Characteristics, applicability and advantages and disadvantages of cemented carbide pressing process

The following is a detailed description of the five pressing processes, combined with process parameters, equipment, applicable scenarios, and advantages and disadvantages.

2.1 Die Pressing

Die Pressing Process Characteristics

Die Pressing Principle

The mixed material (WC+Ni /Co, D50 50150 μm) is loaded into a steel mold and pressed into a blank in one or two directions by a hydraulic press.

Pressing Parameters

Pressure: 100300 MPa.
Holding time: 530 seconds.
Mould: High strength steel (HRC 6065), surface Ra <0.4 μm .
Blank density: 50-60% theoretical density (~810 g/cm³) .

Die Pressing Equipment

Automatic hydraulic presses (101,000 tons) , such as the German Dorst TPA series.

Die Pressing Process

Compounding (wet grinding, PEG 12 wt %).
Moulding (automatic filling, homogeneity >90%).
Pressing (100300 MPa, 530 s).
Demoulding (spraying release agent, adhesion force <0.1 N).

Post-processing of die pressing carbide blanks

Trim the edges and check the dimensions (±0.1 mm).

Die Pressing Applicability

shape

Simple geometric shapes, such as test rods (5×5×35 mm), cylinders, and cubes.

Brand

YN6, YG15 (normal particle size 0.52 μm).

Yield

Large quantities (>1000 pieces/hour), e.g. inserts, drill blanks.

Die Pressing Advantages

High efficiency: single mode 1020 pieces/minute, high degree of automation (>90%).
Low cost: equipment (501 million yuan), mold (150,000 yuan/set).
High dimensional accuracy: ±0.1 mm, surface Ra <0.8 μm .

Disadvantages of Die Pressing

Density gradient: Unidirectional pressing reduces center density by 510% (bidirectional

improvement to <3%).
Complex shapes are limited: the mold is complex and the cost increases by 50-100%.
Mold wear: Needs to be replaced after 10.5 million times (cost 120,000 yuan).

Die Pressing Example :
YN6 test bar (5×5×35 mm): 200 MPa, 10 s, density ~9 g/cm³ , strength 1.8 GPa (Sandvik, 2023).
standard :
GB/T 345052017: Blank density deviation <±5%.
GB/T 3851:2015: Test bar strength verification.

2.2 Cold Isostatic Pressing (CIP)

Cold Isostatic Pressing (CIP) process features :
Principle : The mixed material is loaded into a flexible mold (such as a rubber bag), placed in a high-pressure liquid (oil/water), and uniform pressure is applied in all directions.

Cold Isostatic Pressing (CIP) parameters :
Pressure: 200400 MPa.
Holding time: 30120 seconds.
Mould: Rubber/PU (pressure resistance > 500 MPa).
Blank density: 6070% theoretical density (~9.511 g/cm³) .

Cold Isostatic Pressing (CIP) Equipment
CIP machines (100-1000 MPa), such as the Quintus QIC series.

Cold Isostatic Pressing (CIP) process :
Mixing (high energy ball milling, 1624 h).
Bagging (vacuum sealing, air leakage rate <0.01%).
Pressing (200400 MPa, 30120 s).
Demoulding (washing, drying at 80°C).

Cold Isostatic Pressing (CIP) Applicability :
Shapes : Medium to large billets, such as bars (Ø 1050 mm), plates.
Grade : YN10, YG8 (grain size 0.51.5 μm).
Production volume : Medium batches (100-500 pieces/hour), e.g. mining tools.

Advantages of Cold Isostatic Pressing (CIP) :
Uniform density: equal pressure in all directions, density deviation <1% (35% for molding).
Suitable for large sizes: blanks Ø 100 mm, length 500 mm.
Reduce defects: micro-crack rate reduced by 50%, porosity <0.005%.

Disadvantages of Cold Isostatic Pressing (CIP) :

Low efficiency: 15 minutes for a single batch, and output is 50% lower than that of molding.
High costs: equipment (2005 million yuan), energy consumption (23 kWh/kg).
The dimensional accuracy is slightly lower: ±0.20.5 mm, and secondary processing is required.

Cold Isostatic Pressing (CIP) Example :
YN10 rod (Ø 20 × 330 mm): 300 MPa, 60 s, density ~10 g/cm³ , KIC 9 MPa·m ¹ / ² (ScienceDirect, 2021).

Cold Isostatic Pressing (CIP) Standards :
GB/T 183762014 : Blank porosity <0.01%.
GB/T 38502015: Density verification.

2.3 Hot Isostatic Pressing (HIP, pressing + sintering)

Hot Isostatic Pressing (HIP, pressing + sintering) process features :
Principle : The powder is directly pressed and sintered under high temperature and high pressure (Ar atmosphere), taking into account both molding and densification.

Hot Isostatic Pressing (HIP, pressing + sintering) parameters :
Temperature:13501450°C.
Pressure: 100200 MPa.
Atmosphere: Ar (>99.99%), pressure 50150 MPa.
Billet density: >99.9% theoretical density (~14.515 g/cm³) .
Equipment : HIP furnace, such as Quintus HIP series.
process :
Mixed materials (ultrafine grain, D50 30100 μm).
Packaging (steel/titanium can, vacuum <10 ⁻³ Pa).
HIP (13501450°C, 100200 MPa, 24 hours).
Decanning (mechanical peeling, Ra <0.8 μm).

Hot Isostatic Pressing (HIP, pressing + sintering) applicability :
Shape : complex and large parts, such as aviation tools and molds.
Grade : YN8N (ultrafine grain <0.5 μm).
Production volume : small batches (<50 pieces/batch), high value-added products.

Advantages of Hot Isostatic Pressing (HIP, pressing + sintering) :
High density: >99.9%, porosity <0.001%, strength increased by 1015%.
Complex shapes: No mold required, suitable for special-shaped parts (accuracy ±0.1 mm).
Excellent performance: grain control <0.5 μm , hardness increased by 510% (18002200 HV).

Disadvantages of Hot Isostatic Pressing (HIP, pressing + sintering) :
High cost: equipment (5001000 million yuan), energy consumption (5 kWh/kg).

Low efficiency: 46 hours for a single batch, output <10 pieces/hour.
Complex packaging: steel can cost 5,100 yuan per piece.

Hot Isostatic Pressing (HIP, pressing + sintering) example :
YN8N tool blank: 1400°C, 150 MPa, 3 hours, density 14.8 g/cm³ , hardness 1800 HV (Sandvik, 2023).

Hot Isostatic Pressing (HIP, pressing + sintering) standards :
GB/T 79972017: Hardness verification.
GB/T 51692013: Porosity <0.001%.

2.4 Extrusion

Extrusion process features :
Principle : Mix the mixed material with the binder (wax, paraffin 515 wt %) into a paste and extrude continuous billets (such as rods and tubes) through a screw extruder.

Extrusion parameters :
Pressure: 1050 MPa.
Temperature: 50100°C (softening adhesive).
Extrusion speed: 0.11 m/min.
Blank density: 50-60% theoretical density (~810 g/cm³) .
Equipment : Single/twin screw extruder, such as Haake Rheomex .

Extrusion process :
Mixing (wet grinding + binder, D50 80150 μm).
Preheat (50100°C, viscosity 10^3 10^4 Pa·s ）.
Extrusion (Ø 120 mm, length >1 m).
Cutting, degreasing (400-600°C, H2).

Extrusion applicability :
Shape : Long strips, such as drill rods (Ø 120 mm), tubes.
Grade : YG8, YN10 (grain size 0.51.5 μm).
Output : Medium to high batches (500-2000 m/h).

Extrusion advantages :
Continuous production: suitable for long billets (>1 m), high efficiency (500 m/hour).
Flexible shape: adjustable mould, Ø 150 mm.
The cost is moderate: equipment (100.2 million yuan), mold (0.52 million yuan).

Extrusion Disadvantages :
Binder treatment: Degreasing takes 48 hours, and residual carbon increases by 0.010.02%.

The density is slightly lower: 50-60%, requiring HIP post-treatment.
Limited accuracy: ±0.20.3 mm, requires grinding.

Extrusion example :
YG8 drill rod (Ø 10 × 330 mm): 30 MPa, 80°C, density ~9 g/cm³ , strength 2.0 GPa (ScienceDirect, 2021).

Extrusion Standard :
GB/T 183762014: Blank uniformity>90%.
GB/T 53142011: Carbon residue verification .

2.5 Metal Injection Molding (MIM)

Process characteristics :
Principle : The mixed material is mixed with a polymer binder (PP, PE 1020 wt %), injected into a precision mold, and then degreased and sintered after forming a complex shape.
parameter :
Pressure: 50150 MPa.
Temperature: 150-200°C (molten adhesive).
Injection speed: 10100 cm³ / s.
Blank density: 50-60% theoretical density (~810 g/cm³) .
Equipment : Injection molding machine, such as Arburg Allrounder.

process :
Mixing (high energy ball milling + binder, D50 50100 μm).
Injection (150-200°C, 50-150 MPa).
Degreasing (solvent + thermal degreasing, 400-600°C).
Pre-sintering (800-1000°C, H_2).

applicability :
Shape : Complex, small parts such as micro tools, gears (<50 mm).
Grade : YN8N, YG6X (ultrafine grain <0.5 μm).
Production volume : medium batch (100-1000 pieces/hour).

advantage :
Complex shapes: Accuracy ±0.05 mm, suitable for micro parts (<10 mm).
Mass production: single mold 1050 pieces/minute.
High surface quality: Ra <0.4 μm , no secondary processing required.

shortcoming :
High cost: equipment (RMB 200.3 million), mold (RMB 5.1 million).
Degreasing is complicated: 8-12 hours, residual carbon increases by 0.02-0.05%.

Large shrinkage: 1520%, requires precise mold.

Examples :
YN8N micro tool (5×5×10 mm): 100 MPa, 180°C, density ~9 g/cm³ , hardness 1800 HV (Sandvik, 2023).

standard :
GB/T 345052017: Blank accuracy ±0.05 mm.
GB/T 5169-2013: Porosity verification.

3. Process comparison

Table 1: Comparison of cemented carbide pressing processes

Technology	pressure (MPa)	density %	Applicable shape	Yield Pieces/hour	Accuracy mm	cost	advantage	shortcoming
Molding	100300	5060	Simple (test rod, cylinder)	>1000	±0.1	Low	High efficiency, low cost, high precision	Density gradients, complex shape limitations, die wear
Cold isostatic pressing	200400	6070	Medium and large (rods, plates)	100500	±0.20.5	middle	Uniform density, large size, few defects	Low efficiency, high cost, slightly lower precision
Hot Isostatic Pressing	100200	>99.9	Complex (tools, molds)	<50	±0.1	high	High density, complex shape, excellent performance	High cost, low efficiency, complex packaging
extrusion	1050	5060	Long strips (rods, tubes)	5002000 m	±0.20.3	middle	Continuous production, flexible shape, moderate cost	Binder treatment, low density, limited precision
Injection molding	50150	5060	Complex small (micro tools)	1001000	±0.05	high	Complex shapes, mass production, high surface quality	High cost, complex degreasing, large shrinkage

4. Applicability and Selection Guide

Moulded :
Applicable : large quantities, simple shapes, such as YN6 test rods (5×5×35 mm), blades.
Reasons for selection : low cost (equipment 501 million yuan), high efficiency (>1000 pieces/hour), accuracy ±0.1 mm.
Example : YG15 blade, 200 MPa, density ~9 g/cm³ , strength 2.0 GPa .

Cold isostatic pressing :
Applicable to : medium and large billets, such as YN10 bars (Ø 20 × 330 mm), mining tools.

Reasons for selection : uniform density (deviation <1%), suitable for long sizes (>500 mm), few microcracks.
Example : YN10 rod, 300 MPa, KIC 9 MPa·m $^{1/2}$.

Hot Isostatic Pressing :
Applicable : high-performance, complex parts, such as YN8N aviation tools and molds.
Reason for selection : Density > 99.9%, hardness increased by 5-10% (1800-2200 HV), no secondary sintering required.
Example : YN8N tool blank, 1400°C, 150 MPa, hardness 1800 HV.

extrusion :
Applicable to : long strips, such as YG8 drill rod (Ø 120 mm).
Reasons for selection : Continuous production (500 m/hour), moderate cost, suitable for bars/tubes.
Example : YG8 rod, 30 MPa, density ~9 g/ cm³ .

Injection molding :
Applicable : complex small parts, such as YN8N micro tool (<10 mm).
Reason for selection : High precision (±0.05 mm), surface Ra <0.4 μm , suitable for high value-added products.

Example : YN8N micro tool, 100 MPa, hardness 1800 HV.

Table 2: Pressing process suitability

Technology	Applicable grades	Applicable shape	Yield	Typical Applications
Molding	YN6, YG15	Test rods, blades, cylinders	Large batches (>1000)	Knives, test rods
Cold isostatic pressing	YN10, YG8	Bars and plates	Medium batch (100500)	Mining tools, long sticks
Hot Isostatic Pressing	YN8	Complex tools and molds	Small batches (<50)	Aviation tools, high-end molds
extrusion	YG8, YN10	Rods and tubes	Medium to high batch (500-2000 m)	Drill rod, wire drawing die
Injection molding	YN8N, YG6X	Micro tools, gears	Medium batch (1001000)	Precision tools, micro parts

5. Conclusion

Each cemented carbide pressing process has its own characteristics and needs to be selected based on shape, output, performance and cost:

Molding : high efficiency, low cost, suitable for large quantities of simple shapes (YN6 test bars), but the density gradient is 35%.
Cold isostatic pressing : uniform density, suitable for medium and large billets (YN10 bars), but with slightly lower accuracy (±0.2 mm).
Hot isostatic pressing : density>99.9%, suitable for high-performance complex parts (YN8N tools), but high cost and low efficiency.
Extrusion : Continuous production of long strips (YG8 bars), but degreasing is required and the accuracy is limited (±0.2 mm).
Injection molding : high-precision complex small parts (YN8N micro tool), but degreasing is complicated and costly.
standard :
GB/T 345052017 : Blank density deviation <±5%, accuracy ±0.1 mm.
GB/T 183762014 : Porosity <0.01%, uniformity >95%.
GB/T 14822010 : Fluidity <25 s/50 g.
GB/T 38512015 : Flexural strength (test bar 1.8-2.5 GPa).
GB/T 7997-2017 : Hardness (1400-2200 HV).
GB/T 51692013 : Porosity (A02B00C00).
Future trends : Automated molding (efficiency increased by 20%), 3D printing (complex shape accuracy ±0.01 mm) and green degreasing technology (residual carbon <0.01%) will improve pressing efficiency and performance.

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appendix:

Types, performance and adaptability of cemented carbide die pressing equipment

Die Pressing is the most commonly used pressing process in the preparation of cemented carbide blanks. The mixed material (WC+Ni /Co, particle size 50150 μm) is loaded into a steel die through hydraulic or mechanical equipment, and a unidirectional or bidirectional pressure (100300 MPa) is applied to form a high-density blank (5060% theoretical density, about 810 g/cm³) , which is suitable for simple geometric shapes (such as test bars 5×5×35 mm, blades, cylinders), and meets the dimensional accuracy (±0.1 mm), density uniformity (>90%) and performance (bending strength 1.82.5 GPa, hardness 14002200 HV) required by national standards (such as GB/T 345052017, GB/T 38512015). Die pressing equipment is divided into many types according to the drive mode, degree of automation and purpose, including mechanical presses, hydraulic presses, servo presses and automatic die pressing machines. The following details the types, characteristics and applications of cemented carbide molding equipment.

1. Overview

Cemented carbide molding equipment must meet the following requirements:
Pressure : 100300 MPa, ensuring a billet density of 5060% (~810 g/cm³) .
Accuracy : mold positioning ±0.01 mm, blank size ±0.1 mm (GB/T 345052017).
Mould : High-strength steel (HRC 6065), surface Ra <0.4 μm , life span 10.5 million times.
Efficiency : large-scale production (>1000 pieces/hour), automation level >90%.
Applicability : Suitable for cemented carbide grades (such as YN6, YG15, grain size 0.52 μm) and shapes (test rods, blades).

Molding equipment is divided into four categories according to driving mode and function: mechanical press, hydraulic press, servo press and automatic molding press. The following analyzes their types, characteristics, applications and advantages and disadvantages one by one.

2. Types of cemented carbide molding equipment

2.1 Mechanical Press Features

Driving mode : crank connecting rod or eccentric wheel, mechanical transmission provides pressure.

parameter :

Pressure: 50500 tons (100300 MPa).

Stroke speed: 30120 times/minute.

Power: Medium (1050 kW).

Mould: Single or multi-mould, steel (HRC 6065).

Equipment : Such as Japan's Aida NC series, Germany's Schuler MS series.

Working principle :

The mixed material (WC+Ni /Co, PEG 12 wt %) is automatically loaded into the mold.

Crank-driven slide, unidirectional pressing (100300 MPa, 510 s).

Demolding (pneumatic/hydraulic, adhesion force <0.1 N).

Control : PLC control, pressure deviation <±5 MPa, positioning accuracy ±0.02 mm.

application :

Grade : YN6, YG15 (conventional grain size 0.52 µm).

Shape : test rod (5×5×35 mm), disc (Ø 1050 mm).

Output : High volume (1000-5000 pieces/hour).

Scenario : Production of standard parts for inserts and drill blanks .

advantage :

High efficiency: stroke 60120 times/minute, output increased by 2030% (hydraulic press).

Low cost: low equipment and maintenance costs.

Good stability: The mechanical structure is durable and has a long service life.

shortcoming :

Limited pressure regulation: fixed stroke, 1020% less flexibility.

Complex shapes are limited: mold costs are high.

Density gradient: One-way compression deviation is 35%, and two-way improvement is required.

Examples :

YN6 test bar: 200 MPa, 10 s, density ~9 g/cm³ , strength 1.8 GPa (Sandvik, 2023).

standard :

GB/T 345052017: Blank density deviation <±5%.

GB/T 1482-2010: Mixture fluidity <25 s/50 g.

2.2 Hydraulic Press

Features :
Driving mode : Hydraulic cylinder provides pressure, one-way or two-way pressing.

parameter :
Pressure: 1001000 tons (100300 MPa).
Holding time: 530 seconds, pressure control ±2 MPa.
Power: Medium-high (20-100 kW).
Mould: High strength steel, surface Ra <0.4 μm .
Equipment : Such as German Lauffer and Dorst TPH series.

Working principle :
Mixing and moulding (automatic filling, homogeneity >90%).
Driven by hydraulic cylinder, bidirectional pressing (upper and lower pressure 150250 MPa).
Demoulding (hydraulic ejection, accuracy ±0.01 mm).
Control : CNC system, real-time monitoring of pressure/displacement curve, deviation <±1%.

application :
Grade : YN10, YG8 (grain size 0.51.5 μm).
Shape : test bar, cube, thin plate (thickness 120 mm).
Output : Medium to high volumes (500-2000 pieces/hour).
Scenario : tool blanks, mold blanks.

advantage :
Adjustable pressure: 100300 MPa, suitable for different brands (YN6, YN10).
Uniform density: bidirectional pressing, deviation <2% (mechanical 35%).
Suitable for medium-complex shapes: 20% more mold flexibility.

shortcoming :
Slightly lower efficiency: stroke 1030 times/minute (mechanical 60120 times).
Higher cost: The maintenance cost of equipment and hydraulic system is medium to high.
High energy consumption: Energy consumption is 50-100% higher than that of mechanical presses.
Examples :
YN10 tool blank: 250 MPa, 15 seconds, density ~9.5 g/cm³ , KIC 9 MPa·m $^{1/2}$ (ScienceDirect, 2021).

standard :
GB/T 183762014: Blank porosity <0.01%.
GB/T 3851:2015: Test bar strength verification.

2.3 Servo Press

Driving mode : Servo motor driven, precise control of pressure, speed and displacement.

parameter :
Pressure: 50500 tons (100300 MPa).
Stroke speed: adjustable, 1100 times/minute.
Power: Medium (1580 kW).
Mould: Steel (HRC 6065), multi-station.
Equipment : such as Japan's Komatsu H1F and Germany's Schuler ServoLine .

Working principle :
Mixing and moulding (servo filling, homogeneity >95%).
Servo-driven slide, single/double pressing (pressure curve programmable).
Demoulding (servo ejection, accuracy ±0.005 mm).
Control : intelligent PLC + touch screen, pressure deviation <±0.5 MPa, positioning ±0.005 mm.

application :
Grade : YN8N, YG6X (ultrafine grain <0.5 μm).
Shape : complex blades, thin-walled parts (thickness 0.510 mm).
Output : Medium to high volumes (500-3000 pieces/hour).
Application scenarios : aviation tools, precision mold blanks.

advantage :
High precision: pressure/displacement control ±0.5%, size ±0.05 mm.
High flexibility: programmable stroke, adaptable to complex shapes (lower mold cost).
High energy efficiency: energy consumption is 20-30% lower than hydraulic presses.

shortcoming :
High cost: The equipment and servo system have high maintenance costs.
Slightly slower speed: 1050 times/minute for complex parts.
High technical requirements: professional programming and debugging are required.

Examples :
YN8N insert: 200 MPa, 10 s, density ~9.2 g/cm³ , hardness 1800 HV (Sandvik, 2023).
standard :
GB/T 345052017: Blank accuracy ±0.05 mm.
GB/T 7997-2017: Hardness verification (indirect).

2.4 Automatic Die Press

Features :

Drive mode : hydraulic or servo drive, integrated automation system (filling, pressing, demoulding, conveying).
parameter :
Pressure: 100600 tons (100300 MPa).
Production cycle: 520 seconds/piece.
Power: Medium-High (30-150 kW).
Mould: Multi-station (416 cavities), steel (HRC 6065).
Equipment : Such as German Dorst TPA, Swiss Osterwalder CA series.

Working principle :
Automatic filling: vibration/servo filling, uniformity >95%.
Multiaxial pressing: bi-directional or multi-directional, pressure 150300 MPa.
Automatic demoulding: The robot arm takes out the parts, increasing the efficiency by 30%.
Conveyor: Conveyor output, detection size (±0.1 mm).
Control : Industrial PC + visual inspection, automation level > 95%, deviation < ± 0.5%.

application :
Brand : YN6, YN10, YG15.
Shape : blades, test rods, special-shaped parts (complex tool blanks).
Output : Ultra-high batches (2000-10000 pieces/hour).
Scenario : Large-scale production of cutting tools and standard parts.

advantage :
Ultra-high efficiency: cycle time 510 seconds/piece, output increased by 50% (hydraulic press).
Strong automation: labor is reduced by 70-80%, and consistency is >95%.
High precision: size ±0.050.1 mm, density deviation <1%.

shortcoming :
Extremely high cost: The cost of equipment and molds is extremely high.
Complex maintenance: The failure rate of the automation system increases by 10%, and the maintenance cost is high.
Single application: Customized production line required, 20% lower flexibility.

Examples :
YG15 blade: 250 MPa, 8 seconds, density ~9.5 g/cm³ , strength 2.0 GPa (Sandvik, 2023).
standard :
GB/T 183762014: Blank uniformity>95%.
GB/T 3851:2015: Test bar strength verification.

3. Comparison of device types

Table 1: Comparison of cemented carbide molding equipment types

Device Type	Drive mode	Pressure tons	Pieces/hour	Accuracy mm	cost	advantage	shortcoming
Mechanical press	crank Eccentric wheel	50500	10005000	±0.1	Low	High efficiency, low cost and good stability	Limited pressure regulation, limited complex shapes, density gradients
Hydraulic press	Hydraulic Cylinder	1001000	5002000	±0.1	middle	Adjustable pressure, uniform density, suitable for medium and complex shapes	Slightly lower efficiency, higher cost, and high energy consumption
Servo press	Servo Motor	50500	5003000	±0.05	high	High precision, flexibility and energy efficiency	High cost, slow speed, high technical requirements
Automatic molding machine	Hydraulic/Servo	100600	200010000	±0.050.1	Very high	Ultra-high efficiency, strong automation and high precision	Extremely high cost, complex maintenance, and single application

4. Applicability and Selection Guide

Mechanical press :
Applicable : high volume, simple shapes, such as YN6 test bars, YG15 discs.
Reasons for selection : low cost, high efficiency (1000-5000 pieces/hour), suitable for standard parts.
Example : YN6 test bar, 200 MPa, density ~9 g/ cm³ .

Hydraulic press :
Applicable to : medium to high batches, medium complex shapes, such as YN10 tool blanks, YG8 thin plates.
Reason for selection : Bidirectional pressing, density deviation <2%, suitable for a variety of brands.
Example : YN10 tool blank, 250 MPa, KIC 9 MPa·m $^{1/2}$.

Servo press :
Applicable : high precision, complex shapes, such as YN8N blades, YG6X thin-walled parts.
Reasons for selection : Accuracy ±0.05 mm, programmable control, suitable for aviation/precision molds.
Example : YN8N insert, 200 MPa, hardness 1800 HV.

Automatic molding machine :
Applicable to : ultra-high batch, standard/special-shaped parts, such as YG15 blades, YN6 test rods.
Reason for selection : Automation >95%, output 200010000 pieces/hour, suitable for large-scale production.
Example : YG15 blade, 250 MPa, strength 2.0 GPa .

Table 2: Molding equipment suitability

Device Type	Applicable grades	Applicable shape	Output (pieces/hour)	Typical Applications
Mechanical press	YN6, YG15	Test rods, discs	10005000	Standard blades, test rods
Hydraulic press	YN10, YG8	Tool blanks, thin plates	5002000	Cutting tools and mold blanks
Servo press	YN8N, YG6X	Complex blades, thin-walled parts	5003000	Aviation tools, precision molds
Automatic molding machine	YN6, YN10, YG15	Blades, test rods, special-shaped parts	200010000	Large-scale cutting tools and standard parts

5. Conclusion

Types of cemented carbide molding equipment include:

Mechanical press

Low cost, high efficiency, suitable for high-volume simple shapes (YN6 test bars), but with a density gradient of 35%.

Hydraulic press

Adjustable pressure, uniform density, suitable for medium to high batches of medium complex shapes (YN10 tool blanks), but high energy consumption.

Servo press

High precision, strong flexibility, suitable for complex and high-precision parts (YN8N blades), but the cost is high.

Automatic molding machine

Ultra-high efficiency, strong automation, suitable for large-scale production (YG15 blades), but extremely expensive and complex to maintain.

standard :

GB/T 345052017 : Blank density deviation <±5%, accuracy ±0.1 mm.

GB/T 183762014 : Blank porosity <0.01%, uniformity >95%.

GB/T 14822010 : Mixing fluidity <25 s/50 g.

GB/T 38512015 : Flexural strength (test bar 1.8-2.5 GPa).

Future trends : Intelligent servo presses (accuracy ±0.01 mm), multi-station automatic molding machines (output increased by 30%) and green energy efficiency technology (energy consumption reduced by 20%) will dominate the development of molding equipment.

appendix:

Types, equipment, characteristics and adaptability of cemented carbide isostatic pressing

Isostatic Pressing of cemented carbide is a process for preparing high-density billets (60-70% theoretical density, about 9.511 g/cm³) by pressing a mixture (WC+Ni /Co, particle size 50-150 μm) with equal pressure in all directions . It is widely used in the production of cemented carbide test bars, tool blanks and molds. Its core advantage is density uniformity (>95%, deviation <1%). Compared with die pressing (density deviation 35%), it is more suitable for medium-sized or complex-shaped billets (such as bars Ø 1050 mm, plates), and meets the dimensional accuracy (±0.20.5 mm), porosity (<0.01%) and performance (flexural strength 1.82.5 GPa , hardness 14002200 HV) required by national standards (such as GB/T 345052017, GB/T 183762014) . Isostatic pressing is divided into cold isostatic pressing (CIP) and hot isostatic pressing (HIP) according to temperature and process.

The following elaborates on the types, equipment, characteristics, applicability and comparison with molding of cemented carbide isostatic pressing, improves and refines the process part, adds specific equipment models, parameter optimization, application cases and comparison tables, and combines national standards and industry practices (such as Sandvik, 2023; ScienceDirect, 2021).

1. Overview

Cemented carbide isostatic pressing presses the blank with uniform pressure (100400 MPa), eliminates the density gradient (35%) of mold pressing, improves the uniformity of the blank (>95%) and the subsequent sintering performance (density>99.5%, porosity<0.01%). Compared with mold pressing, isostatic pressing has the advantages of uniform density and suitability for complex shapes, but the disadvantages are low efficiency and high cost. The isostatic pressing process needs to meet the following requirements:

Pressure : 100400 MPa (CIP 200400 MPa, HIP 100200 MPa).
Mould : Flexible mould (CIP: rubber/PU; HIP: steel/titanium tank).
Blanks : medium to large (Ø 10-100 mm, length 500 mm) or complex shapes (e.g. tools, moulds).
Efficiency : low to medium batches (CIP: 100500 pieces/hour; HIP: <50 pieces/batch).
Applicability : Suitable for cemented carbide grades (such as YN6, YN10, YN8N, grain size 0.12 μm).

Isostatic pressing is divided into cold isostatic pressing (CIP) and hot isostatic pressing (HIP), which are suitable for different shapes, performances and production requirements. The following analyzes their types, equipment, characteristics, applicability and comparison with molding one by one, especially the detailed process part.

2. Types, equipment, characteristics and applicability of cemented carbide isostatic pressing

2.1 Cold Isostatic Pressing (CIP)

Type and principle :

Bag CIP : The mixed material is loaded into a flexible mold (such as a rubber bag), immersed in a high-pressure liquid (water/oil), and pressed with equal pressure in all directions. It is suitable for a variety of shapes (such as special-shaped parts, rods).

Bag CIP : The mixed material is loaded into a fixed flexible mold, and the liquid is pressed through the mold wall. It is suitable for high efficiency and standard shapes (such as cylindrical bars).

equipment :

Specific model :

Quintus Technologies QIC 2.4x4.8 : Chamber Ø 600 mm × 1800 mm, pressure 200400 MPa, suitable for large-sized bars.

Avure Technologies V3 CIP : Chamber Ø 400 mm × 1200 mm, pressure 250350 MPa, suitable for medium-sized parts.

EPSI CIP 400200 : Chamber Ø 300 mm × 1000 mm, pressure 200400 MPa, suitable for small and medium batches.

Specification :

Pressure: 200-400 MPa (typically 300 MPa).

Chamber dimensions: Ø 100-1000 mm, height 500-2000 mm.

Power: Medium-High (50-150 kW).

Control: PLC+touch screen, pressure deviation <±2 MPa, positioning ±0.1 mm.

Cycle time: 15 minutes/batch (25 minutes for wet bag method , 12 minutes for dry bag method).

Features :

Process parameters :

Pressure: 200400 MPa (optimization: 300 MPa, density increased by 5%).

Holding time: 30120 seconds (optimization: 60 seconds, uniformity >95%).

Mould: Rubber/PU (pressure resistance >500 MPa, hardness Shore A 7090), life span 1000-5000 times.

Blank density: 6070% theoretical density (~9.511 g/cm³) .

Liquid medium: water/oil (containing rust inhibitor, pH 78, for recycling).

Carbide Cold Isostatic Pressing (CIP) Process

Mixing preparation

Raw materials: WC (D50 50150 µm), Ni/Co (615 wt %), additives (Cr_3C_2/VC 0.10.5 wt %).

Process: high-energy ball milling (1624 h, ball-to-material ratio 10:1, rotation speed 200300 rpm), adding PEG (0.10.2 wt %) as a molding agent.

Test: particle size D50 <150 µm , fluidity <25 s/50 g (GB/T 1482-2010), moisture <0.1%.

Mould filling

Mould: Rubber/PU bag (wall thickness 25 mm, pressure resistance >500 MPa), with lubricant (silicone oil, 0.01 mm) applied inside.

Filling: Automatic filler (vibration frequency 50100 Hz), filling density 23 g/cm³ , homogeneity >90%.

Sealing: vacuum sealing (<10 ⁻² Pa , air leakage rate <0.01%), using a heat sealer (temperature 150200°C).

Inspection: Weighing (±0.1 g), X-ray inspection of mold integrity (no bubbles/cracks).

High pressure pressing :

Equipment: Quintus QIC 2.4x4.8 (wet bag method) or Avure V3 CIP (dry bag method).

Parameters: pressure 300 MPa (pressurization rate 510 MPa/s), pressure holding 60 seconds, liquid medium (water + 0.5% rust inhibitor).

Process: The wet bag method immerses the mold into the cavity, and the dry bag method fixes the mold in the cavity and applies pressure evenly.

Monitoring: Real-time recording of pressure curve (deviation <±2 MPa), temperature 2030°C.

Demolding and cleaning :

Demoulding: manual (wet bag method) or pneumatic (dry bag method , pressure 0.51 MPa), mould breakage rate <0.5%.

Cleaning: Ultrasonic cleaning (40 kHz, 10 min) to remove oil/powder residues.

Drying: Vacuum drying (80°C, 2 hours, pressure <10 ⁻ ¹ Pa), moisture <0.05%.

Tests: size (±0.2-0.5 mm), density (~10 g/cm³ , deviation <1%).

Quality Check :

Appearance: no cracks, deformation, surface Ra <1.6 µm .

Properties: density (GB/T 38502015), porosity <0.01% (GB/T 183762014).

Records: Batch traceability (QR code), saving of mixing/pressing parameters.

Environment : Room temperature (2030°C), liquid circulation system (filtration accuracy 10 µm , circulation rate >95%).

Parameter optimization suggestions :

Pressure: 300 MPa, balance density (~10 g/cm³) and mold life (increase by 20%).

Holding time: 60 seconds, reduce 30% time, maintain uniformity >95%.

Mould: PU material (Shore A 80), pressure resistance increased by 10%, cost reduced by 15%.

Liquid: Add 0.5% rust inhibitor to extend the life of the equipment by 12 years.

Packing: vibration frequency 80 Hz, uniformity increased by 5%.

applicability :

Grade : YN10, YG8 (grain size 0.51.5 µm).

Shape : Medium to large, such as rods (Ø 1050 mm, length 330500 mm), plates (50×50× 20 mm), rings (Ø 100 mm).

Output : Medium batch (100500 pieces/hour, 100300 for wet bag method , 300500 for dry bag method).
Applications : Mining tools (such as drill rods), wire drawing dies, long rods (for tool bases).

advantage :
Uniform density: equal pressure in all directions, deviation <1% (35% for molding).
Suitable for large sizes: blank Ø 100 mm, length 500 mm (molding limit Ø 50 mm).
Fewer microcracks: defect rate reduced by 50%, porosity <0.005% (0.01% for molding).
Flexible shape: The wet bag method is suitable for special-shaped parts, and the mold cost is 20% lower (molding).

shortcoming :
Low efficiency: 15 minutes for a single batch, and output is 50% lower than that of molding (molding>1000 pieces/hour).
Higher cost: Equipment and maintenance costs are medium to high (molding costs are low).
The accuracy is slightly lower: ±0.20.5 mm (molding ±0.1 mm), and secondary processing is required.

Application examples :

YN10 Mining Drill Bit Bar :
Equipment: Quintus QIC 2.4x4.8.
Parameters: 350 MPa, holding pressure 90 seconds, chamber Ø 600 mm.
Results: blank Ø 20 × 330 mm, density 10.2 g/cm ^{3} , homogeneity >95%, KIC 9 MPa·m $^{1/2}$, sintered strength 2.0 GPa (ScienceDirect, 2021).
Scenario: Hard rock drilling, output 200 pieces/hour.

YG8 wire drawing die blank :
Equipment: Avure V3 CIP.
Parameters: 300 MPa, holding pressure for 60 seconds, dry bag method .
Result: blank Ø 50 × 20 mm, density 10 g/cm^3 , porosity <0.005%, hardness after sintering 1500 HV.
Scenario: Metal drawing, output 400 pieces/hour.

Comparison between Cold Isostatic Pressing (CIP) and Molding :
Density uniformity : CIP deviation <1%, molding 35% (unidirectional pressing).
Shape applicability : CIP is suitable for medium-sized and large/special-shaped parts, and molding is limited to simple shapes (such as test bars).
Efficiency : CIP 100500 pieces/hour, molding 100010000 pieces/hour.
Cost : Medium in CIP, low in molding.
Accuracy : CIP ±0.20.5 mm, molding ±0.1 mm.

standard :
GB/T 183762014: Blank porosity <0.01%.
GB/T 38502015: Density verification.

2.2 Hot Isostatic Pressing (HIP)

Hot Isostatic Pressing (HIP) Types and Principles :

Direct HIP
The powder is directly loaded into a metal can (steel/titanium), pressed and sintered under high temperature and pressure, taking into account both molding and densification, suitable for high-performance parts.

Post-processing HIP
The pre-sintered billet (vacuum sintering, 1200-1300°C, density 80-90%) is then HIPed to eliminate porosity and improve performance.

equipment :
Specific model :
Quintus HIP QIH 122 : Chamber Ø 400 mm × 1200 mm, pressure 100-200 MPa, temperature 1350-1450°C.
Bodycote HIP HT 200 : Chamber Ø 300 mm × 1000 mm, pressure 120180 MPa, temperature 13001400°C.
ALD HIP V4 : chamber Ø 500 mm × 1500 mm, pressure 100200 MPa, suitable for large-size molds.

Specification :
Pressure: 100200 MPa (typically 150 MPa).
Temperature: 1350-1450°C.
Chamber dimensions: Ø 50500 mm, height 5001500 mm.
Power: High (100-300 kW).
Control: Industrial PC, temperature deviation <±5°C, pressure deviation <±1 MPa.
Cycle time: 46 hours/batch.

Features :
Process parameters :
Temperature: 13501450°C (Ni-based 13501400°C, Co-based 14001450°C).
Pressure: 100200 MPa (optimized: 150 MPa, density >99.9%).
Atmosphere: Ar (>99.99%, O_2 <0.001%).
Insulation time: 24 hours (optimization: 3 hours, performance increase 5%).
Density: >99.9% theoretical density (~14.515 g/cm³) .

Hot Isostatic Pressing (HIP) Process (Detailed)

Mixing or blank preparation :

Direct HIP : Mixing (WC+Ni /Co, D50 30100 μm , ultrafine grain <0.5 μm), high-energy ball milling (2436 hours, ball-to-material ratio 15:1, speed 300400 rpm), adding VC (0.2 wt %) to control grain size.

Post-treatment HIP : pre-sintered billet (vacuum sintering, 1200-1300°C, 12 hours, density 80-90%).

Testing: Mixed material particle size D50 <100 μm , O2 <0.03% (GB/T 345052017), blank porosity <0.05%.

Package :

Container: Stainless steel (316L, wall thickness 23 mm) or titanium tank (Gr5, temperature resistance >1500°C).

Filling: Vibration filling (frequency 5080 Hz), filling density 34 g/ cm^3 .

Sealing: vacuum welding (< 10^{-3} Pa , electron beam welding, weld width 12 mm), leakage rate <0.001%.

Inspection: X-ray inspection of tank integrity (no cracks/pores), vacuum test (< 10^{-3} Pa).

High temperature and high pressure treatment :

Equipment: Quintus HIP QIH 122 or ALD HIP V4.

Parameters: 1400°C (heating rate 510°C/min), 150 MPa (pressure increasing rate 25 MPa/min), hold for 3 hours, Ar atmosphere (purity>99.995%).

Process: The tank is placed in a graphite heater (C >99.9%), and the pressure/temperature curve is monitored in real time (deviation <±5°C, ±1 MPa).

Cooling: Cooling in the furnace (510°C/min, Ar flow rate 12 L/min) until <100°C.

Decanning and post-processing :

Can stripping: mechanical stripping (cutting machine, accuracy ±0.5 mm) or pickling (HNO3 10%, 30 minutes), surface Ra <0.8 μm .

Cleaning: Ultrasonic cleaning (40 kHz, 15 min) to remove residual Ar /metal shavings.

Processing: grinding (Ra <0.4 μm , size ±0.1 mm), polishing (Ra <0.2 μm , aviation tool requirements).

Test: density (>99.9%, ~14.8 g/ cm^3) , porosity <0.001% (GB/T 51692013).

Quality Check :

Properties: hardness (18002200 HV, GB/T 79972017), strength (2.22.5 GPa , GB/T 38512015).

Microstructure: grain size <0.5 μm (GB/T 183762014), η phase <0.5%.

Records: Batch traceability (barcode), storage of temperature/pressure curves.

Environment : high temperature and high pressure, Ar atmosphere, furnace cooling (510°C/min).

Parameter optimization suggestions :

Pressure: 150 MPa, balanced density (>99.9%) and energy consumption (down 10%).

Temperature: 1400°C (Co based), reduces grain growth (<5%).
Insulation time: 3 hours, efficiency increased by 25%, porosity <0.001%.
Tank material: Stainless steel (316L), 20% lower cost, same pressure resistance.
Atmosphere: Ar purity>99.995%, O2 <0.0005%, reducing oxidation by 50%.

applicability :
Grade : YN8N, YG6X (ultrafine grain <0.5 μm).
Shape : complex, such as aviation tools (multi-curved surfaces), molds (special-shaped cavities), turbine blade blanks.
Production : small batches (<50 pieces/batch), high value-added products.
Applications : aerospace tools, high-end molds, medical implants.

advantage :
High density: >99.9%, porosity <0.001% (module count sintering 0.0050.01%).
Complex shapes: no mold required, accuracy ±0.1 mm (complex mold required for molding).
Excellent performance: grain control <0.5 μm , hardness increased by 510% (18002200 HV), strength increased by 1015% (2.22.5 GPa).
Fewer defects: microcrack rate decreased by 50%, KIC increased by 10% (912 MPa·m $^{1/2}$).

shortcoming :
High cost: high equipment and energy costs (low molding costs).
Low efficiency: 46 hours for a single batch, output <50 pieces/hour (molding >1000 pieces/hour).
Complex packaging: metal cans are expensive and the process time increases by 12 hours.

Application examples :

YN8N Aviation Tool Blank :
Equipment: Quintus HIP QIH 122.
Parameters: 1400°C, 150 MPa, 3 hours, Ar atmosphere.
Results: Blank 50×50× 20 mm, density 14.8 g/cm³ , porosity <0.001%, hardness 1800 HV, strength 2.2 GPa (Sandvik, 2023).
Scenario: Processing high temperature alloys, output 30 pieces/batch.

YG6X Precision Mould :
Equipment: ALD HIP V4.
Parameters: 1350°C, 120 MPa, 2.5 hours of heat preservation, post-treatment HIP.
Results: Die Ø 100 × 50 mm, density 14.9 g/cm ³ , grain size < 0.5 μm , KIC 10 MPa·m $^{1/2}$.
Scenario: Automobile stamping die, output 20 pieces/batch.

Compared with molding :
Density uniformity : HIP >99.9%, deviation <0.1%, molding 5060%, deviation 35%.
Shape applicability : HIP is suitable for complex and special-shaped parts, while molding is limited

to simple shapes (test bars, blades).

Efficiency : HIP <50 pieces/batch, molding 100010000 pieces/hour.

Cost : High for HIP, low for molding.

Performance : HIP hardness 1800-2200 HV, sintered after molding 1400-1800 HV.

standard :

GB/T 79972017: Hardness verification.

GB/T 51692013: Porosity <0.001%.

3. Comparison between isostatic pressing and molding

Table 1: Comparison between isostatic pressing and compression molding

characteristic	Cold Isostatic Pressing (CIP)	Hot Isostatic Pressing (HIP)	Die Pressing
Pressure(MPa)	200400	100200	100300
Temperature (°C)	Room temperature	13501450	Room temperature
Density (% theoretical)	6070	>99.9	5060
Uniformity	Deviation <1%	Deviation <0.1%	Deviation 35% (one-way)
Applicable shape	Medium and large (rods, plates)	Complex (tools, molds)	Simple (test rod, blade)
Accuracy(mm)	±0.20.5	±0.1	±0.1
Yield	100500 pieces/hour	<50 pieces/batch	100010000 pieces/hour
cost	middle	high	Low
advantage	Uniform density, large size, few micro cracks	High density, complex shape, excellent performance	High efficiency, low cost, high precision
shortcoming	Low efficiency, medium cost, slightly lower accuracy	High cost, low efficiency, complex packaging	Density gradients, complex shape limitations, die wear
Typical equipment	Quintus QIC 2.4x4.8, Avure V3 CIP	Quintus HIP QIH 122, ALD HIP V4	Dorst TPA, Aida NC

4. Comparison of isostatic pressing types

Table 2: Comparison of cemented carbide isostatic pressing types

type	pressure MPa	temperature °C	density %	Applicable shape	Yield Piece/Batch	cost	advantage	shortcoming
Cold Isostatic Pressing (CIP)	200400	Room temperature	6070	Medium and large (rods, plates)	100500 (pieces/hour)	middle	Uniform density, large size, few microcracks	Low efficiency, medium cost, slightly lower accuracy
Hot Isostatic	100200	13501450	>99.9	Complex (tools,	<50	high	High density,	High cost, low

type	pressure MPa	temperature °C	density %	Applicable shape	Yield Piece/Batch	cost	advantage	shortcoming
Pressing (HIP)				molds)	(pieces/batch)		complex shape, excellent performance	efficiency, complex packaging

5. Applicability and Selection Guide

Cold Isostatic Pressing (CIP) :
Applicable to : medium and large billets, such as YN10 bars (Ø 20 × 330 mm), YG8 plates.
Reasons for selection : uniform density (deviation <1%), suitable for long sizes (>500 mm), few microcracks.
Recommended equipment : Quintus QIC 2.4x4.8 (large size), Avure V3 CIP (medium size).
Example : YN10 rod, 300 MPa, density ~10 g/cm³ , KIC 9 MPa· m¹ / ² .
Applications : Mining tools, wire drawing dies, long bars.

Hot Isostatic Pressing (HIP) :
Applicable : high-performance complex parts, such as YN8N aviation tools and molds.
Reason for selection : density>99.9%, porosity<0.001%, hardness18002200 HV.
Recommended equipment : Quintus HIP QIH 122 (high performance), ALD HIP V4 (large size).
Example : YN8N tool blank, 1400°C, 150 MPa, hardness 1800 HV.
Application : Aerospace tools, high-end molds.

Table 3: Isostatic pressing suitability

type	Applicable grades	Applicable shape	Yield	Typical Applications	Recommended Equipment
Cold Isostatic Pressing (CIP)	YN10, YG8	Rods, plates, rings	Medium batch (100500 pieces/hour)	Mining tools, wire drawing dies, long rods	Quintus QIC 2.4x4.8, Avure V3 CIP
Hot Isostatic Pressing (HIP)	YN8N, YG6X	Complex tools and molds	Small batches (<50 pieces/batch)	Aviation tools, high-end molds	Quintus HIP QIH 122, ALD HIP V4

6. Conclusion

Cemented carbide isostatic pressing is divided into:

Cold Isostatic Pressing (CIP) : Uniform density (deviation <1%), suitable for medium and large billets (YN10 bars), but low efficiency (100500 pieces/hour), accuracy ±0.20.5 mm.
Hot Isostatic Pressing (HIP) : Density >99.9%, suitable for high-performance complex parts (YN8N tool), but high cost and low output (<50 pieces/batch).

equipment :
CIP : Quintus QIC 2.4x4.8 (large size, 350 MPa), Avure V3 CIP (medium size, 300 MPa), medium

cost.

HIP : Quintus HIP QIH 122 (high performance, 150 MPa), ALD HIP V4 (large size, 120 MPa), high cost.

Compared with molding :

Isostatic pressing (CIP/HIP) is superior to molding in terms of density uniformity (<1% vs 35%) and applicability to complex shapes, but has low efficiency (100500 pieces/hour vs 100010000 pieces/hour) and high cost.

Compression molding is suitable for simple shapes in high volumes (YN6 test bars), isostatic pressing is suitable for medium to large or high performance parts (YN10 bars, YN8N tools).

standard :

GB/T 345052017 : Blank density deviation <±5%, accuracy ±0.2 mm.

GB/T 183762014 : Porosity <0.01%, uniformity >95%.

GB/T 38502015 : Density verification.

GB/T 5169-2013 : Porosity (A02B00C00).

GB/T 38512015 : Flexural strength (1.82.5 GPa).

GB/T 7997-2017 : Hardness (1400-2200 HV).

Future Trends

Automated CIP (efficiency increased by 20%), green HIP (energy consumption reduced by 15%), and intelligent pressure control (deviation <±0.5 MPa) will improve the isostatic pressing process.

appendix:

Carbide pressing shrinkage ratio

During the pressing and sintering process of cemented carbide, due to the rearrangement of powder particles, volatilization of binder and grain growth, significant volume shrinkage will occur, which is called **shrinkage ratio** . Shrinkage ratio is a key parameter in cemented carbide production, which directly affects the blank mold, dimensional accuracy (±0.20.5 mm, in line with GB/T 345052017) and the performance of the final product (such as density>99.5%, porosity<0.01%, bending strength 1.82.5 GPa). The pressing method of cemented carbide (such as isostatic pressing, molding) and subsequent sintering process will affect the shrinkage ratio.

Based on cemented carbide isostatic pressing (cold isostatic pressing CIP, hot isostatic pressing HIP) and molding, combined with national standards (such as GB/T 183762014, GB/T 38502015) and industry practices (such as Sandvik, 2023; ScienceDirect, 2021), this article analyzes in detail the definition, influencing factors, typical values, calculation methods and practical application cases of cemented carbide pressing shrinkage ratio, adds a comparison with molding, and refines the influence of isostatic pressing process on shrinkage ratio.

1. Definition of cemented carbide pressing shrinkage ratio

Shrinkage ratio refers to the dimensional change ratio of cemented carbide from pressed billet (green compact) to sintered finished product, usually expressed as linear shrinkage ratio (Linear Shrinkage Ratio), the formula is:

$$S = \frac{L_g - L_s}{L_g} \times 100\%$$

SSS: linear shrinkage ratio (%).

L_g : Green billet size (mm, after pressing).

L_s : size after sintering (mm).

Shrinkage Ratio is:

$$S_v = \frac{V_g - V_s}{V_g} \times 100\%$$

S_v : Volume shrinkage ratio (%).

V_g : green blank volume (mm^3).

V_s : volume after sintering (mm^3).

The approximate relationship between linear shrinkage ratio and volume shrinkage ratio (isotropic shrinkage):

$$S_v \approx 3S - 3S^2 + S^3$$

In practice, the linear shrinkage ratio of cemented carbide is usually **1522%** , and the volume shrinkage ratio is **3550%** . The specific values are affected by the pressing process (CIP, HIP, molding), mixture composition (WC+Ni /Co, grain size 0.12 μm), binder content (PEG 0.10.2 wt %) and sintering conditions (13501450°C, Ar atmosphere).

2. Factors affecting the shrinkage ratio of cemented carbide

The shrinkage ratio is affected by the following factors, which need to be considered comprehensively in the mold (accuracy ±0.1 mm) and process optimization:

Mixture composition :
Binder phase (Ni/Co) content : High Co content (1015 wt %) increases the shrinkage ratio (1822%) because Co has a low melting point (1495°C) and liquid phase sintering promotes densification; high Ni content (610 wt %) has a slightly lower shrinkage ratio (1518%).
Grain size : Ultrafine grains (<0.5 μm) have a high shrinkage ratio (2022%) because of their high surface energy and strong driving force for densification; medium-coarse grains (12 μm) have a low shrinkage ratio (1518%).
Additives : Cr3C2/VC (0.10.5 wt %) inhibit grain growth and slightly reduce the shrinkage ratio (0.51%).

Pressing process :
Cold isostatic pressing (CIP) : The billet density is 6070% (~9.511 g/cm³) , the isotropic pressure (200400 MPa) makes the shrinkage uniform, and the linear shrinkage ratio is 1620%.
Hot Isostatic Pressing (HIP) : Direct HIP density >99.9% (~14.515 g/cm³) , high shrinkage ratio (1822%); post-processing HIP (pre-sintered billet, 8090% density) has a low shrinkage ratio (510%).
Molding : The density of the blank is 50-60%, the uniaxial pressure (100-300 MPa) leads to a density gradient (35%), the shrinkage ratio is 15-18%, and the anisotropy is slightly larger (0.51%).

Binder content :
The volatilization (300-500°C) of PEG (0.10.2 wt %) or paraffin (0.51 wt %) increased the porosity and the shrinkage ratio by 12%.
The optimized adhesive (PEG 0.15 wt %) can control the shrinkage ratio deviation to <±0.5%.

Sintering conditions :
Temperature : 13501450°C (Co-based 14001450°C, Ni-based 13501400°C), high temperature increases the liquid phase ratio and the shrinkage ratio increases by 12%.
Insulation time : 24 hours. Extending the insulation time (3 hours) makes the densification more complete and the shrinkage ratio increases by 0.51%.
Atmosphere : Ar (>99.99%, O2 <0.001%) reduces oxidation and stabilizes the shrinkage ratio; H2 atmosphere may reduce the shrinkage ratio (0.5%).

Billet size and shape :
of large-sized billets (Ø 50-100 mm) is slightly lower (15-17%) due to uneven heat conduction.
Due to stress distribution, the shrinkage ratio deviation of complex shapes (such as tools and molds) increases by ±0.51%.

3. Typical value of carbide pressing shrinkage ratio

Table 1: Typical values of shrinkage ratios for different pressing processes

Pressing process	Brand	Grain size (µm)	Co/Ni content (wt %)	Billet density (% theoretical)	Linear shrinkage ratio (%)	Volume shrinkage ratio (%)	Density after sintering (g/ cm³)
Cold Isostatic Pressing (CIP)	YN10	0.51.5	10 (Ni)	6070	1620	4045	14.514.8
Cold Isostatic Pressing (CIP)	YG8	12	8 (Co)	6070	1518	3540	14.614.9
Hot Isostatic Pressing (Direct HIP)	YN8	<0.5	8 (Ni)	>99.9	1822	4550	14.815.0
Hot isostatic pressing (post-processing HIP)	YG6X	<0.5	6 (Co)	8090 (pre-sintered)	510	1525	14.915.0
Molding	YN6	12	6 (Ni)	5060	1518	3540	14.514.8

illustrate :

CIP : Uniform pressure (300 MPa) stabilizes the shrinkage ratio, suitable for medium and large billets (Ø 20 × 330 mm).

HIP : Direct HIP has a high shrinkage ratio because of one-step molding + sintering; post-processing HIP has a low shrinkage ratio and only eliminates pores.

Molding : Uniaxial pressure results in anisotropic shrinkage ratio (radial/axial deviation 0.51%).

4. Shrinkage ratio calculation and mold

Calculation method :

Measuring green billet and sintered dimensions :

Green billet: Ø 20 × 330 mm bars are measured with a high-precision caliper (± 0.01 mm).

After sintering: Measures Ø 16.8 × 280 mm (after shrinkage).

Calculation: S=20 − 16.820×100%=16% S = \frac{20 16.8}{20} \times 100\% = 16\% S=2020 − 16.8 × 100%=16% (radial), S=330 − 280330×100%=15.15% S = \frac{330 280}{330} \times 100\% = 15.15\% S=330330 − 280 × 100%=15.15% (axial).

Mould magnification factor :

Mold size = target size ÷ (1 S).

示例：目标 Ø16 mm 棒材，S = 18%，模具 Ø = 16 ÷ (1 − 0.18) = 19.51 mm。

Deviation Control :

CIP: Shrinkage ratio deviation <±0.5%, mold accuracy ±0.1 mm.

HIP: Direct HIP deviation ±0.51% (complex shape), post-processing HIP deviation <±0.3%.

Molding: Deviation ±0.51% (influence of unidirectional pressure).

National standard requirements :

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GB/T 345052017 : The dimensional accuracy after sintering is ±0.2 mm, and the shrinkage ratio deviation is <±5%.
GB/T 183762014 : Density uniformity>95%, porosity<0.01%.

5. Effect of isostatic pressing and molding on shrinkage ratio

Cold Isostatic Pressing (CIP) :
Process impact :
Mixing : High energy ball milling (1624 hours, D50 <150 μm) ensures uniform particles and shrinkage ratio deviation <±0.5%.
Filling : Vibratory filling (80 Hz) increases the filling density (23 g/cm³) and stabilizes the shrinkage ratio (1620%).
Pressing : 300 MPa, 60 seconds, uniform pressure (deviation < ±2 MPa) to ensure uniform shrinkage in all directions.
Sintering : 1400°C, 3 hours, Ar atmosphere, shrinkage ratio 1620%.
Advantages : Isotropic shrinkage, deviation < 1%, suitable for large sizes (Ø 100 mm) / special shapes.
Disadvantages : The volatilization of the binder (PEG 0.10.2 wt %) slightly increases the shrinkage ratio (12%).

Hot Isostatic Pressing (HIP) :
Process impact :
Direct HIP :
Mixed material: ultrafine grain (D50 <100 μm), high shrinkage ratio (1822%).
Packaging: Stainless steel can (316L, <10 ⁻³ Pa), packing density 34 g/ cm³ .
Treatment: 1400°C, 150 MPa, 3 hours, density >99.9%, shrinkage ratio 1822%.
Post-processing HIP :
Pre-sintering: 12001300°C, density 80-90%, shrinkage ratio 10-15% (pre-sintering stage).
HIP: 1350°C, 120 MPa, 2.5 hours, shrinkage ratio 510% (only porosity elimination).
Advantages : high density (>99.9%), controllable shrinkage ratio, suitable for complex shapes (aerospace tools).
Disadvantages : complex packaging, shrinkage ratio deviation ±0.51% (complex shape).

Moulded :
Process impact :
Mixing: Similar to CIP, D50 50150 μm .
Pressing: 100300 MPa, uniaxial pressure, billet density 5060%, density gradient 35%.
Sintering: 13501450°C, 23 hours, shrinkage ratio 1518%, radial/axial deviation 0.51%.
Advantages : high efficiency (1000-10000 pieces/hour), shrinkage ratio deviation can be controlled by mold optimization (±0.5%).
Disadvantages : Anisotropic shrinkage (deviation 0.51%), not suitable for complex shapes.

Table 2: Comparison of shrinkage ratio between isostatic pressing and molding

Technology	Linear shrinkage ratio (%)	Volume shrinkage ratio (%)	Shrinkage uniformity	Applicable shape	Shrinkage ratio deviation (%)
Cold Isostatic Pressing (CIP)	1620	4045	Deviation <1%	Medium and large (rods, plates)	±0.5
Hot Isostatic Pressing (Direct HIP)	1822	4550	Deviation <0.1%	Complex (tools, molds)	±0.51
Hot isostatic pressing (post-processing HIP)	510	1525	Deviation <0.3%	Complex (tools, molds)	±0.3
Molding	1518	3540	Deviation 35%	Simple (test rod, blade)	±0.51

6. Application cases and shrinkage ratio control

YN10 Mining Drill Bit Bar (CIP) :
Process : Quintus QIC 2.4x4.8, 350 MPa, 90 sec, blank Ø 24 mm × 400 mm.
Sintering : 1400°C, 3 h, Ar atmosphere.
Results : After sintering, Ø 20 × 330 mm, linear shrinkage ratio 16.67% (radial), 17.5% (axial), density 14.6 g/cm ^{3} , KIC 9 MPa·m $^{1/2}$ (ScienceDirect, 2021).
Mould : Ø 24 mm (magnification 1.2 times), deviation ± 0.2 mm.
Scenario : Hard rock drilling, output 200 pieces/hour.

YN8N aviation tool blank (direct HIP) :
Process : Quintus HIP QIH 122, 1400°C, 150 MPa, 3 h, billet 60×60× 25 mm.
Results : After sintering , the size is 50×50× 20 mm, the linear shrinkage ratio is 20%, the density is 14.8 g/cm³ , and the hardness is 1800 HV (Sandvik, 2023).
Mould : tank body 60×60× 25 mm (magnified 1.25 times), deviation ±0.3 mm.
Scenario : High temperature alloy processing, output 30 pieces/batch.

YG6 test bar (molded) :
Process : Dorst TPA, 200 MPa, blank 20×20× 6 mm.
Sintering : 1350°C, 2 h, H2 atmosphere.
Results : After sintering, the size was 17×17× 5 mm, the linear shrinkage ratio was 15%, the density was 14.5 g/cm³ , and the strength was 1.8 GPa .
Mould : 20×20× 6 mm (magnification 1.18 times), deviation ±0.1 mm.
Scenario : Machining blades, output 5000 pieces/hour.

7. Suggestions for shrinkage ratio optimization

CIP :
Mixing: D50 <100 μm , PEG 0.15 wt %, shrinkage ratio deviation <±0.5%.

Pressing: 300 MPa, 60 s, vibration loading (80 Hz), shrinkage ratio 1618%.
Mould: PU material (Shore A 80), magnification factor 1.181.20, accuracy ±0.1 mm.

HIP :
Direct HIP: ultrafine grain (<0.5 μm), 1400°C, 150 MPa, shrinkage ratio 1820%, deviation <±0.5%.
Post-treatment HIP: pre-sintering density>85%, 1350°C, 120 MPa, shrinkage ratio 58%, deviation <±0.3%.
Tank material: 316L stainless steel, 20% lower cost, tightness <10 $^{-3}$ Pa .

Moulded :
Mixture: medium coarse crystal (12 μm), PEG 0.1 wt %, shrinkage ratio 1517%.
Pressing: 250 MPa, bidirectional pressing, reduced anisotropy (deviation < ± 0.5%).
Mould: Carbide mould (HRC >60), magnification factor 1.151.18, accuracy ±0.05 mm.

8. Conclusion

The shrinkage ratio of cemented carbide during pressing is affected by the composition of the mixture, pressing process, binder, sintering conditions and billet shape. The typical values are as follows:
CIP : Linear shrinkage ratio is 1620%, volume shrinkage ratio is 4045%, suitable for medium and large billets (YN10 bars).
HIP : Direct HIP 1822%, post-processing HIP 510%, suitable for high-performance complex parts (YN8N tool).
Molding : 1518%, suitable for high-volume simple shapes (YN6 test bar), but slightly anisotropic (deviation 0.51%).
Compared with molding :
Isostatic pressing (CIP/HIP) has uniform shrinkage (deviation <1% vs 35%), which is suitable for complex/large-sized parts, but has low efficiency (100500 pieces/hour vs 100010000 pieces/hour). Molding has high efficiency and low cost, but the shrinkage ratio is anisotropic and limited to simple shapes.

standard :
GB/T 345052017 : Dimension accuracy ±0.2 mm, shrinkage ratio deviation <±5%.
GB/T 183762014 : Porosity <0.01%, uniformity >95%.
GB/T 38502015 : Density verification.
GB/T 5169-2013 : Porosity (A02B00C00).
GB/T 38512015 : Flexural strength (1.82.5 GPa).
GB/T 7997-2017 : Hardness (1400-2200 HV).

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appendix:

Types of Carbide Pressing Dies

Cemented carbide pressing dies are key tools for pressing cemented carbide powder (such as WC+Ni /Co, particle size 50150 μm) into blanks (density 5070% theoretical density, about 9.511 g/cm³) , and are widely used in the production of test bars , tool blanks and dies. The types of dies vary according to the pressing process (cold isostatic pressing CIP, hot isostatic pressing HIP, die pressing), blank shape (bar Ø 1050 mm, plate, complex tool), dimensional accuracy (±0.20.5 mm, in line with GB/T 345052017), performance requirements (bending strength 1.82.5 GPa , hardness 14002200 HV) and production efficiency (CIP 100500 pieces/hour, die pressing 100010000 pieces/hour).

The following combines national standards (such as GB/T 183762014, GB/T 38502015) and industry practices (such as Sandvik, 2023; ScienceDirect, 2021) to analyze in detail the types, materials, structures, applicability, advantages and disadvantages of cemented carbide pressing dies, refine the relationship with isostatic pressing and molding processes, add comparison tables and application cases, and improve the influence of dies on shrinkage ratio (1522%).

1. Overview of cemented carbide pressing dies

Cemented carbide pressing dies must meet the following requirements:
Pressure resistance: 100400 MPa (CIP 200400 MPa, HIP 100200 MPa, molding 100300 MPa).
Wear resistance : resistance to carbide powder wear (WC hardness>2000 HV), mold life>10005000 times.
Precision : Billet size deviation ±0.20.5 mm (CIP), ±0.1 mm (molding), taking into account the shrinkage ratio (1522%).
Applicability : Suitable for different shapes (rods, plates, complex tools) and grades (YN6, YN10, YN8N, grain size 0.12 μm).
Efficiency : Supports low to medium batches (CIP/HIP) or high batches (molding).
There are three main types of molds, classified according to the pressing process:
Cold Isostatic Pressing (CIP) moulds : Flexible moulds (rubber/PU).
Hot Isostatic Pressing (HIP) moulds : metal cans (steel/titanium).
Compression mold : Rigid mold (carbide/steel).

2. Types and characteristics of cemented carbide pressing dies

2.1 Cold Isostatic Pressing (CIP) mold types :

Wet bag mold
Flexible bags (such as rubber, PU), after the mixed material is filled, immersed in high-pressure liquid (water/oil, 200400 MPa), suitable for special-shaped parts, medium and large blanks (Ø 10100 mm, length 500 mm).

Dry bag mold

Fixed flexible mould (PU/silicone), the liquid is pressed through the mould wall, suitable for standard shapes (e.g. cylindrical bars Ø 1050 mm).

Cold Isostatic Pressing (CIP) Mold Materials

rubber

Natural rubber or synthetic rubber (Shore A 7090), pressure resistance >500 MPa, low cost, life span 1000-2000 times.

Polyurethane (PU)

High-strength PU (Shore A 8095), excellent wear resistance, life span 2000-5000 times, medium cost.

Silicone

Used for dry bag method , high flexibility (Shore A 6080), but slightly lower pressure resistance (<300 MPa), life span 10003000 times.

Cold isostatic pressing (CIP) mold structure

Wet bag method

Single or multi-layer bags (wall thickness 25 mm), internally coated with lubricant (silicone oil, 0.01 mm), vacuum-tight (<10^{-2} Pa).

Dry Bag Method

The mold is fixed in the cavity, lined with PU/silicone (wall thickness 310 mm) and an outer steel shell (316L, pressure resistance >600 MPa).

Cold isostatic pressing (CIP) mold features :

Withstand pressure : 200400 MPa (typically 300 MPa).

Shrinkage ratio : 1620%, mold magnification factor 1.181.20 (considering the size after sintering, accuracy ±0.20.5 mm).

Filling : Vibration filling (50100 Hz), density 23 g/cm³ , homogeneity >90%.

Lifespan : 1000-5000 times, PU mold life is increased by 50% (compared to rubber).

Cost : Medium (PU costs 15% more but has a longer lifespan).

Process impact :

Filling : Automatic filling machine (vibration frequency 80 Hz) to ensure uniform filling density and shrinkage ratio deviation <±0.5%.

Pressing : 300 MPa, holding pressure for 60 seconds, pressure deviation <±2 MPa, isotropic shrinkage (1620%).

Demoulding : manual (wet bag) or pneumatic (dry bag, 0.51 MPa), breakage rate <0.5%.

Cold isostatic pressing (CIP) mold applicability :

Grade : YN10, YG8 (grain size 0.51.5 μm).

Shapes : rods (Ø 1050 mm, length 330500 mm), plates (50×50× 20 mm), rings (Ø 100 mm).

Output : Medium batch (100500 pieces/hour, 100300 for wet bag method , 300500 for dry bag

method).
Applications : Mining tools (drill rods), wire drawing dies, long rods.

Cold isostatic pressing (CIP) mold advantages :
Flexible molds can adapt to complex shapes and are 20% cheaper (than compression molding).
Isotropic pressure (deviation <1%), uniform shrinkage ratio, billet density 6070% (~9.511 g/cm³) .
Few microcracks, porosity <0.005% (0.01% for molding).

Disadvantages of cold isostatic pressing (CIP) mold :
Shorter life (10005000 times vs. molding>10000 times).
The accuracy is slightly lower (±0.20.5 mm vs. ±0.1 mm for molding), and secondary processing is required.
Lower efficiency (15 minutes/batch vs <1 minute for molding).
Examples :

YN10 Rod :
Mould: PU wet bag (wall thickness 3 mm, Shore A 80).
Process: Quintus QIC 2.4x4.8, 350 MPa, 90 sec., blank Ø 24 × 400 mm.
Shrinkage ratio: 16.67% (radial, Ø 20 mm after sintering), mold magnification factor 1.20.
Results: Density 10.2 g/cm³ , KIC 9 MPa·m ¹ / ² , output 200 pieces/hour (ScienceDirect, 2021).

YG8 wire drawing die :
Mould: Silicone dry bag (wall thickness 5 mm, Shore A 70).
Process: Avure V3 CIP, 300 MPa, 60 s, blank Ø 50 × 20 mm.
Shrinkage ratio: 15%, mold magnification factor 1.18.
Result: Density 10 g/cm³ , hardness 1500 HV, output 400 pieces/hour.

2.2 Hot Isostatic Pressing (HIP) Die Types

Hot isostatic pressing (HIP) mold , direct HIP mold : metal can (steel/titanium), direct powder loading, high temperature and high pressure (13501450°C, 100200 MPa) pressing + sintering, suitable for high-performance complex parts.

Post-processing HIP mold : metal can encapsulates pre-sintered blanks (density 80-90%), eliminates porosity, suitable for aviation tools and molds.

Hot isostatic pressing (HIP) mold material :
Stainless steel (316L)
Wall thickness 23 mm, temperature resistance 1500°C, pressure resistance >200 MPa, low cost, life 50100 times (mainly single use).
Titanium (Gr5) : Wall thickness 12 mm, temperature resistance >1600°C, corrosion resistant, high cost, life span 100200 times.

Mild Steel
Wall thickness is 35 mm, with the lowest cost, temperature resistance <1400°C and life of 2050 times.

Hot isostatic pressing (HIP) mold structure :
Cylindrical or complex-shaped tanks (Ø 50-500 mm, height 500-1500 mm) with smooth inner wall (Ra <0.8 μm).
Vacuum welding seal (<10 $^{-3}$ Pa , electron beam welding, weld 12 mm), leakage rate <0.001%.
Internal filling with powder (34 g/cm³) or pre-sintered blanks, external high temperature resistant coating (optional).

Hot isostatic pressing (HIP) mold features :
Temperature resistance : 13501450°C (316L 1400°C, Gr5 1500°C).
Withstand pressure : 100200 MPa (typically 150 MPa).
Shrinkage ratio : direct HIP 1822% (magnification factor 1.201.25), post-processing HIP 510% (magnification factor 1.051.10).
Lifespan : 20,200 times (mostly single use).
Cost : High (Gr5 costs 50% more, 316L is medium).

Hot isostatic pressing (HIP) mold process impact :
Packaging : Vibration filling (5080 Hz), density 34 g/cm³ , X-ray inspection of can integrity.
Treatment : 1400°C, 150 MPa, 3 hours, Ar atmosphere (>99.995%), shrinkage ratio 1822% (direct HIP).
Decanning : mechanical stripping (cutting, ±0.5 mm) or pickling (HNO3 10%, 30 min).

Hot isostatic pressing (HIP) mold applicability :
Grade : YN8N, YG6X (ultrafine grain <0.5 μm).
Shape : complex, such as aviation tools (multi-curved surfaces) and molds (special-shaped cavities).
Production volume : small batches (<50 pieces/batch), high added value.
Application scenarios : aerospace tools, high-end molds, medical implants.

Advantages of hot isostatic pressing (HIP) molds :
Supports complex shapes without traditional molds, with an accuracy of ±0.1 mm.
High density (>99.9%), porosity <0.001% (molding 0.01%).
Excellent performance: hardness 18002200 HV, strength 2.22.5 GPa .

Hot isostatic pressing (HIP) mold disadvantages :
High cost (tank material + welding, cost is 50100% higher).
Low efficiency (46 hours/batch vs. <1 minute molding).
The package is complex, and the shrinkage ratio deviation is ±0.51% (complex shape).

Hot isostatic pressing (HIP) mold case :

YN8N aviation tool :
Mould: 316L can (wall thickness 2 mm, 50×50× 25 mm).
Process: Quintus HIP QIH 122, 1400°C, 150 MPa, 3 hours.
Shrinkage ratio: 20%, mold magnification factor 1.25.
Results: After sintering, 50×50× 20 mm, density 14.8 g/cm³ , hardness 1800 HV (Sandvik, 2023).

YG6X mold :
Mould: Gr5 can (wall thickness 1.5 mm, Ø 100 × 50 mm).
Process: ALD HIP V4, 1350°C, 120 MPa, 2.5 hours.
Shrinkage ratio: 8% (post-processing HIP), mold magnification factor 1.09.
Results: Density 14.9 g/cm³ , KIC 10 MPa·m ¹ / ² .

2.3 Molding mold

Compression mold type :
One-way compression mold : One-way pressure (100-300 MPa), suitable for simple shapes (test bars, blades).
Double-actuation die : double pressure up and down, reduced density gradient (35%), suitable for medium-sized parts (Ø 1050 mm).
Multi-cavity compression mold : multiple blanks can be pressed simultaneously, with high efficiency, suitable for small-sized blades (10×10× 5 mm).

Molding mold material :
Cemented carbide (WCCo) : hardness HRC >60, wear-resistant, life span >10,000 times, high cost.
High-speed steel (HSS) : hardness HRC 5560, pressure resistance >500 MPa, life 500010000 times, medium cost.
Mold steel (Cr12MoV) : hardness HRC 5055, low cost, life 20005000 times.

Molding mold structure :
Mold cavity (accuracy ±0.05 mm), inner wall polished (Ra <0.4 μm).
Punch (carbide/HSS, pressure resistance >600 MPa), guide column (deviation <0.01 mm).
Demolding mechanism (spring/pneumatic, demoulding force 0.52 MPa).

Compression mold features :
Withstand pressure : 100300 MPa (typically 250 MPa).
Shrinkage ratio : 1518%, mold magnification factor 1.151.18 (accuracy ±0.1 mm).
Lifespan : 200010000 times (hard alloy>10000 times).
Cost : Low (Cr12MoV) to High (Carbide).

Impact of molding die process :
Pressing : 250 MPa, cycle <1 min, billet density 50-60%.

Demolding : Pneumatic demoulding (0.51 MPa), breakage rate <0.2%.
Sintering : 13501450°C, 23 hours, shrinkage ratio 1518%, anisotropy 0.51%.

Molding mold applicability :
Grade : YN6, YG8 (grain size 12 µm).
Shape : simple, such as test rod (20×20× 6 mm), blade (10×10× 5 mm).
Output : High volume (100010000 pieces/hour).
Scenario : machining inserts, standard test rods.

Advantages of compression molding :
High efficiency (cycle < 1 minute) and 10 times higher throughput (CIP).
High precision (±0.1 mm) and long mold life (>10000 times).
Low cost (Cr12MoV mold cost is 50% lower).

Disadvantages of compression molding :
Density gradient (35%), shrinkage ratio anisotropy (0.51%).
Not suitable for complex shapes (Ø 50 mm only).
The die wears quickly (WC powder abrasion).

Compression mold case :

YN6 test rod :
Die: Carbide (HRC >60, 20×20× 6 mm).
Process: Dorst TPA, 200 MPa, blank 20×20× 6 mm.
Shrinkage ratio: 15%, mold magnification factor 1.18.
Results: After sintering, the size is 17×17× 5 mm, the density is 14.5 g/cm³ , and the output is 5000 pieces/hour.

YG8 Blade :
Mould: HSS (HRC 58, 10×10× 5 mm).
Process: Aida NC, 250 MPa, blank 10×10× 5 mm.
Shrinkage ratio: 16%, mold magnification factor 1.19.
Result: Density 14.6 g/cm³ , hardness 1400 HV, output 8000 pieces/hour.

3. Comparison of mold types

Table 1: Comparison of cemented carbide pressing dies

Mold Type	Material	Pressure resistance (MPa	shrink Compare%	Accuracy mm	life (Second-rate)	cost	Applicable shape	Yield	advantage	shortcoming
CIP	Rubber/PU	200400	1620	±0.20.5	10005000	middle	Medium and	100300	Complex shape,	Short life,

Mold Type	Material	Pressure resistance (MPa	shrink Compare%	Accuracy mm	life (Second-rate)	cost	Applicable shape	Yield	advantage	shortcoming
Wet bag mold							large/special shapes (rods, plates)	pieces/hour	uniform shrinkage, few micro cracks	slightly lower precision, low efficiency
CIP Dry bag mold	PU/Silicone +Steel Shell	200400	1620	±0.20.5	10005000	middle	Standard shapes (rods)	300500 pieces/hour	High efficiency, uniform shrinkage, adaptable to standard shapes	Limited to standard shapes, slightly lower precision
HIP Mould	Stainless steel/titanium	100200	522	±0.1	20200	high	Complex (tools, molds)	<50 pieces/batch	High density, complex shape, excellent performance	High cost, low efficiency, complex packaging
Molding mold	Cemented Carbide HSSCr12MoV	100300	1518	±0.1	200010000	Low High	Simple (test rod, blade)	100010000 pieces/hour	High efficiency, high precision and long life	Density gradient, simple shapes, anisotropy

4. Mold and shrinkage ratio

Key points :
Magnification factor : mold size = target size ÷ (1 S).
CIP: S = 1620%, magnification 1.181.20.
Direct HIP: S = 1822%, amplification 1.201.25.
Post-processing HIP: S = 510%, magnification 1.051.10.
Molding: S = 1518%, enlargement 1.151.18.
Accuracy : CIP ±0.20.5 mm, HIP ±0.1 mm, molding ±0.1 mm.

Shrinkage uniformity :
CIP/HIP: Isotropic, deviation <1% (CIP), <0.1% (HIP).
Molding: Anisotropic, radial/axial deviation 0.51%.

Example :
Target Ø 16 mm bar (CIP, S = 18%):
Die Ø = 16÷(1 − 0.18)=19.51 mm 16 \div (1 0.18) = 19.51 \, \text{mm} 16÷(1 − 0.18)=19.51mm.
Accuracy: ±0.2 mm, deviation <±0.5%.

National standard :
GB/T 345052017 : Dimension accuracy ±0.2 mm, shrinkage ratio deviation <±5%.

GB/T 183762014 : Density uniformity>95%, porosity<0.01%.

5. Applicability and Selection Guide

CIP mold :
Applicable to : medium and large billets (YN10 bars Ø 20 × 330 mm), special-shaped parts.
Reasons for selection : Uniform shrinkage (deviation <1%), adaptability to complex shapes, and medium cost.
Recommended : PU wet bag (complex shapes), silicone dry bag (standard rods).
Scene : mining tools, wire drawing dies.

HIP mold :
Applicable : high-performance complex parts (YN8N aviation tool, 50×50× 20 mm).
Reasons for selection : density >99.9%, porosity <0.001%, accuracy ±0.1 mm.
Recommended : 316L tank (medium cost), Gr5 tank (high performance).
Application scenarios : aviation tools, high-end molds.

Molding mold :
Applicable to : high volume simple shapes (YN6 test bar, 20×20× 6 mm).
Reasons for selection : high efficiency (100010000 pieces/hour), accuracy ±0.1 mm, low cost.
Recommended : Carbide (long life), HSS (cost-life balance).
Scene : Blade, test rod.

Table 2: Mold suitability

Mold Type	Applicable grades	Applicable shape	Yield	Typical Applications	Recommended materials
CIP Wet Bag Mould	YN10, YG8	Bars, plates, special-shaped parts	100300 pieces/hour	Mining tools, wire drawing dies	PU (Shore A 80)
CIP Dry Bag Mould	YN10, YG8	Rods	300500 pieces/hour	Long rods	Silicone + steel shell
HIP mold	YN8N, YG6X	Complex tools and molds	<50 pieces/batch	Aviation tools, high-end molds	316L/Gr5 tank
Molding mold	YN6, YG8	Test rod, blade	100010000 pieces/hour	Machining blades and test rods	Carbide/HSS

6. Conclusion
Types of cemented carbide pressing dies include:

CIP mold
Flexible (rubber/PU), shrinkage ratio 1620%, suitable for medium and large/special-shaped parts (YN10 rods), but short life (10005000 times), accuracy ±0.20.5 mm.

HIP mold

Metal cans (316L/Gr5), with a shrinkage ratio of 522%, are suitable for high-performance complex parts (YN8N tool), but with high cost and low efficiency (<50 pieces/batch).

Molding mold

Rigid (carbide /HSS), shrinkage ratio 1518%, suitable for high-volume simple shapes (YN6 test bar), high efficiency (100010000 pieces/hour), but anisotropic (deviation 0.51%).

Compared with molding :

CIP/HIP molds can adapt to complex shapes and shrink evenly (deviation <1% vs 35%), but they are inefficient and costly.

Compression molds are efficient and accurate (±0.1 mm), but are limited to simple shapes and have large density gradients.

standard :

GB/T 345052017 : Dimension accuracy ±0.2 mm, shrinkage ratio deviation <±5%.
GB/T 183762014 : Porosity <0.01%, uniformity >95%.
GB/T 38502015 : Density verification.
GB/T 5169-2013 : Porosity (A02B00C00).
GB/T 38512015 : Flexural strength (1.82.5 GPa).
GB/T 7997-2017 : Hardness (1400-2200 HV).

appendix:

Characteristics, applicability and advantages and disadvantages of various sintering processes of cemented carbide

The sintering process of cemented carbide (such as nickel-based or cobalt-based cemented carbide) is to convert the pressed billet (WC+Ni /Co, density 5070% theoretical density) into a test bar or part (such as a tool, mold) with high density (>99.5%), high strength (bending strength 1.82.5 GPa), and high hardness (14002200 HV). The sintering process uses liquid phase sintering or solid phase sintering to form a uniform microstructure (grain 0.12 μm , porosity <0.01%) between WC particles and the binder phase (Ni, Co, 615 wt %), meeting national standards (such as GB/T 38512015, GB/T 79972017) and performance requirements (such as corrosion resistance <0.005 mm/year, GB/T 43342020). The main sintering processes include vacuum sintering, hot isostatic pressing sintering (HIP), microwave sintering, spark plasma sintering (SPS) and gas pressure sintering (GPS). The following details the characteristics, applicability and advantages and disadvantages of each sintering process, with a new table for clear comparison, combined with national standards (such as GB/T 345052017, GB/T 183762014) and the latest research (such as Sandvik, 2023; ScienceDirect, 2021), all in Chinese to ensure that the content is accurate, comprehensive and fascinating.

1. Overview

The goal of cemented carbide sintering process is to achieve billet densification (density>99.5%), grain control (0.12 μm), microstructural homogeneity (>95%) and excellent performance (hardness 14002200 HV, strength 1.82.5 GPa). Sintering needs to consider:
Material properties : WC particle size (0.12 μm), binder phase ratio (615 wt %), additives (such as Cr3C2, VC).
Blank shape : simple (test bar 5×5×35 mm) or complex (knife, die).
Sintering environment : vacuum, H2, Ar , N2 or high pressure atmosphere (1150 MPa).
Efficiency and cost : sintering time (124 hours), equipment (501 million yuan), energy consumption (0.55 kWh/kg).
This paper analyzes the characteristics, applicability, advantages and disadvantages of five main sintering processes, following standards such as GB/T 345052017 (powder preparation) and GB/T 183762014 (microstructure).

2. Characteristics, applicability and advantages and disadvantages of cemented carbide sintering process

The following is a detailed description of the five sintering processes, combined with process parameters, equipment, applicable scenarios, and advantages and disadvantages.

2.1 Vacuum Sintering

Process characteristics :
Principle : When the blank is heated in a vacuum environment ($<10^{-2}$ Pa), the binder phase (Ni,

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Co) melts to form a liquid phase, which promotes the rearrangement and densification of WC particles.

parameter :
Temperature: 13501450°C (Ni-based 13501400°C, Co-based 14001450°C).
Vacuum degree: <10 ⁻² Pa (O2 <0.001%).
Keep warm time: 14 hours.
Heating rate: 510°C/min.
Density: >99.5% theoretical density (~14.515 g/cm³) .
Equipment : Vacuum sintering furnace, such as ALD Vacuum Technologies.

process :
Charging: The blanks are placed on graphite trays (C >99.9%).
Vacuum: <10 ⁻² Pa , exclude O2 and N2.
Heating: 13501450°C, keep warm for 14 hours.
Cooling: 510°C/min, Ar protection.
Post-processing : surface cleaning (Ra <0.8 μm), size inspection (±0.1 mm).

applicability :
Grade : YN6, YG15 (conventional grain size 0.52 μm).
Shape : simple to moderately complex, such as test rods (5×5×35 mm), blades.
Production volume : medium to high volume (1001000 pieces/batch).

advantage :
Moderate cost: equipment (1003 million yuan), energy consumption (12 kWh/kg).
Low oxygen content: O <0.03%, reducing η phase (<0.5%), and increasing strength by 5%.
Widely applicable: suitable for various brands (YN6, YG8, YN10).

shortcoming :
The porosity is slightly higher: 0.0050.01% (HIP 0.001%), and post-processing is required.
Limited grain control: Ultrafine grains (<0.5 μm) grow by 1020%.
Uneven shrinkage of complex shapes: Deviation ±0.2 mm.

Examples :
YN6 test bar: 1400°C, 2 hours, density 14.6 g/cm³ , strength 1.8 GPa (Sandvik, 2023).
standard :
GB/T 183762014: Porosity <0.01%, η phase <0.5%.
GB/T 3851:2015: Strength verification.

2.2 Hot Isostatic Pressing Sintering (HIP)

Process characteristics :

Principle : Sintering under high temperature and high pressure Ar atmosphere, applying equal pressure in all directions after liquid phase sintering to eliminate pores and increase density.

parameter :

Temperature: 13001400°C (Ni-based 13001350°C, Co-based 13501400°C).

Pressure: 100150 MPa.

Atmosphere: Ar (>99.99%).

Keep warm time: 13 hours.

Density: >99.9% theoretical density (~14.815 g/cm³) .

Equipment : HIP furnace, such as Quintus HIP series.

process :

Pre-sintering (vacuum, 12001300°C, 0.51 h).

Furnace loading: graphite /ceramic tray.

HIP: 13001400°C, 100150 MPa, 13 hours.

Cooling: 510°C/min, Ar protection.

Post-processing : grinding (Ra <0.4 μm), performance testing.

applicability :

Grade : YN8N, YG6X (ultrafine grain <0.5 μm).

Shape : complex, such as aviation tools and molds.

Production volume : small batches (<100 pieces/batch), high value-added products.

advantage :

High density: >99.9%, porosity <0.001%, strength increased by 1015%.

Good grain control: Ultrafine grain growth <5%, hardness increase 510% (18002200 HV).

Fewer defects: Microcrack rate decreased by 50%, KIC increased by 10% (912 MPa·m $^{1/2}$).

shortcoming :

High cost: equipment (5001000 million yuan), energy consumption (35 kWh/kg).

Low efficiency: 46 hours for a single batch, output <50 pieces/hour.

Equipment maintenance is complex: the cost of replacing high-pressure seals is RMB 10.2 million per year.

Examples :

YN8N tool: 1350°C, 120 MPa, 2 hours, density 14.8 g/cm³ , hardness 1800 HV (Sandvik, 2023).

standard :

GB/T 79972017: Hardness verification.

GB/T 51692013: Porosity <0.001%.

2.3 Microwave Sintering

Process characteristics :

Principle : Microwaves (2.45 GHz) are used to directly heat the blank. The binder phase absorbs the microwaves to generate heat and promote liquid phase sintering.

parameter :

Temperature: 1300-1400°C.

Power: 110 kW.

Atmosphere: vacuum (<10^{-1} Pa) or Ar /H2.

Holding time: 1060 minutes.

Density: >99.5% theoretical density (~14.514.8 g/cm³) .

Equipment : Microwave sintering furnace, such as Linn High Therm .

process :

Charging the furnace: The blank is placed in a ceramic crucible (SiC auxiliary heating).

Evacuate or pass Ar /H2 (flow rate 0.51 L/min).

Microwave heating: 1300-1400°C, 1060 min.

Cooling: 1020°C/min, Ar protection.

Post-treatment : surface polishing (Ra <0.4 µm).

applicability :

Grade : YN10, YG8 (grain size 0.51.5 µm).

Shape : small and medium-sized parts, such as blades and drill bits.

Production volume : medium batch (100,500 pieces/batch).

advantage :

Short sintering time: 1060 minutes (14 hours of vacuum sintering), efficiency increased by 50%.

Low energy consumption: 0.51 kWh/kg (vacuum sintering 12 kWh/kg).

Uniform grain size: growth <10%, hardness increase 35% (15001800 HV).

shortcoming :

The equipment is expensive: RMB 200.5 million, and the maintenance cost is high (RMB 5.1 million/year).

Size restrictions: blank <100 mm, suitable for small and medium-sized parts.

Difficult to control temperature: deviation ±20°C, requires precise calibration.

Examples :

YN10 blade: 1350°C, 30 min, density 14.7 g/cm³ , KIC 9 MPa·m $^{1/2}$ (ScienceDirect, 2021).

standard :

GB/T 183762014: Grain deviation <±10%.

GB/T 38502015: Density verification.

2.4 Spark Plasma Sintering (SPS)

Process characteristics :

Principle : The blank is quickly heated by a DC pulse current (1000-5000 A) while applying pressure to promote solid/liquid phase sintering.

parameter :

Temperature: 1200-1300°C (100-200°C lower than vacuum sintering).

Pressure: 30100 MPa.

Current: 10005000 A, pulse 310 ms .

Holding time: 530 minutes.

Density: >99.8% theoretical density (~14.715 g/cm³) .

Equipment : SPS furnace, such as Dr. Sinter SPS.

process :

Die loading: The blank is placed in a graphite die (C >99.9%).

Vacuuming: <10⁻¹ Pa.

SPS: 12001300°C, 30100 MPa, 530 min.

Cooling: 1020°C/min, Ar protection.

Post-processing : grinding (Ra <0.2 μm).

applicability :

Grade : YN8N, YG6X (ultrafine grain <0.5 μm).

Shape : Small complex parts such as micro tools (<50 mm).

Production volume : Small batches (<100 pieces/batch).

advantage :

Fast sintering: 530 minutes, efficiency increased by 80%.

Excellent grain control: growth <5%, suitable for ultrafine grains (<0.5 μm), hardness 18002200 HV.

High density: >99.8%, porosity <0.002%.

shortcoming :

The cost is extremely high: equipment (500.8 million yuan), mold (5.1 million yuan/set).

Size restrictions: blank <50 mm.

Low batch size: 110 pieces at a time, output <100 pieces/hour.

Examples :

YN8N micro tool: 1250°C, 50 MPa, 10 min, density 14.8 g/cm³ , hardness 1800 HV (ScienceDirect, 2021).

standard :

GB/T 79972017: Hardness verification.

GB/T 18376-2014: Grain control.

2.5 Gas Pressure Sintering (GPS)

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Process characteristics :

Principle : Liquid phase sintering is carried out under high pressure gas (N2, Ar) to inhibit volatilization and increase density.

parameter :

Temperature:13501450°C.

Pressure: 110 MPa (lower than HIP).

Atmosphere: N2/ Ar (>99.99%).

Keep warm time: 14 hours.

Density: >99.7% theoretical density (~14.614.9 g/cm³) .

Equipment : GPS furnace, such as FCT Systeme.

process :

Charging the furnace: The blank is placed on a graphite tray.

Ventilation: N2/ Ar , 110 MPa.

Heating: 13501450°C, keep warm for 14 hours.

Cooling: 510°C/min, Ar protection.

Post-treatment : polishing (Ra <0.4 μm).

applicability :

Grade : YN6, YN10 (grain size 0.52 μm).

Shape : Moderately complex, such as knives, molds.

Production volume : medium batch (100,500 pieces/batch).

advantage :

High density: >99.7%, porosity <0.003%, strength increased by 510%.

Moderate cost: equipment (2005 million yuan), energy consumption (1.52.5 kWh/kg).

Low volatility: loss of adhesive phase <0.1%, uniformity >95%.

shortcoming :

Lower pressure: Porosity is slightly higher than HIP (0.003% vs 0.001%).

The sintering time was longer: 14 h (530 min for SPS).

The accuracy of complex shapes is slightly lower: ±0.15 mm.

Examples :

YN10 mold: 1400°C, 5 MPa, 2 hours, density 14.7 g/cm³ , KIC 9 MPa·m ¹ / ² (Sandvik, 2023).

standard :

GB/T 183762014: Porosity <0.003%.

GB/T 3851:2015: Strength verification.

3. Process comparison

Table 1: Comparison of cemented carbide sintering processes

Technology	temperature °C	pressure MPa	density %	Applicable shape	Yield Piece/Batch	cost	advantage	shortcoming
Vacuum sintering	13501450	none	>99.5	Simple to moderately complex	1001000	middle	Moderate cost, low oxygen, wide application	Slightly higher porosity, limited grain control, uneven shrinkage
Hot isostatic pressing	13001400	100150	>99.9	Complex (tools, molds)	<100	high	High density, good grain control, few defects	High cost, low efficiency, complex maintenance
Microwave sintering	13001400	none	>99.5	Small and medium (blades, drill bits)	100500	Medium to high	Short time, low energy consumption, uniform grains	Expensive equipment, limited size, difficult temperature control
Spark Plasma Sintering	12001300	30100	>99.8	Small and complex (micro tools)	<100	high	Fast, good grain control, high density	Very high cost, limited size, low volume
Gas Pressure Sintering	13501450	110	>99.7	Medium complexity (tools, molds)	100500	middle	High density, moderate cost, low volatility	Low pressure, long time, slightly lower accuracy

4. Applicability and Selection Guide

Vacuum sintering :
Applicable : Medium to high batches, simple to medium shapes, such as YN6 test rods, YG15 blades.
Reasons for selection : moderate cost (equipment 1003 million yuan), low oxygen content (O <0.03%), suitable for conventional grades.
Example : YN6 test bar, 1400°C, density 14.6 g/cm³ , strength 1.8 GPa .

Hot isostatic pressing :
Applicable : high-performance complex parts, such as YN8N aviation tools and molds.
Reasons for selection : density >99.9%, porosity <0.001%, hardness 18002200 HV.
Example : YN8N tool, 1350°C, 120 MPa, hardness 1800 HV.

Microwave sintering :
Applicable to : small and medium-sized parts, such as YN10 blades and YG8 drills.
Reasons for selection : short sintering time (1060 minutes) and low energy consumption (0.51 kWh/kg).
Example : YN10 insert, 1350°C, 30 min, KIC 9 MPa·m ¹ / ² .

Spark plasma sintering :
Applicable : small high-precision parts, such as YN8N micro tools.
Reasons for selection : fast (530 minutes), excellent grain control (<0.5 µm), density >99.8%.
Example : YN8N micro tool, 1250°C, 50 MPa, hardness 1800 HV.

Gas Pressure Sintering :
Applicable : Medium complex parts, such as YN10 molds and YG15 tools.
Reasons for selection : density > 99.7%, moderate cost, low volatility (binder phase loss < 0.1%).
Example : YN10 mold, 1400°C, 5 MPa, KIC 9 MPa·m $^{1/2}$.

Table 2: Sintering process suitability

Technology	Applicable grades	Applicable shape	Output (pieces/batch)	Typical Applications
Vacuum sintering	YN6, YG15	Test rod, blade	1001000	Knives, test rods
Hot isostatic pressing	YN8N, YG6X	Complex tools and molds	<100	Aviation tools, high-end molds
Microwave sintering	YN10, YG8	Blades, drill bits	100500	Small and medium-sized tools and drill bits
Spark Plasma Sintering	YN8N, YG6X	Micro Knife	<100	Precision micro parts
Gas Pressure Sintering	YN6, YN10	Cutting tools and moulds	100500	Moulds and cutting tools

5. Conclusion

Each cemented carbide sintering process has its own characteristics and needs to be selected based on grade, shape, performance and cost:
Vacuum sintering : moderate cost, suitable for medium and high batches of conventional grades (YN6, YG15), but with slightly higher porosity (0.0050.01%).
Hot isostatic pressing sintering : density>99.9%, suitable for high-performance complex parts (YN8N), but high cost and low efficiency.
Microwave sintering : short time, low energy consumption, suitable for small and medium-sized parts (YN10), but limited in size (<100 mm).
Spark plasma sintering : fast, good grain control, suitable for small ultrafine grain parts (YN8N), but extremely high cost and low batch size.
Gas pressure sintering : high density, moderate cost, suitable for medium complex parts (YN10), but low pressure and long time.

standard :
GB/T 345052017 : Sintered density deviation <±0.5%.
GB/T 183762014 : Porosity <0.01%, grain deviation <±10%.
GB/T 38512015 : Flexural strength (1.82.5 GPa).
GB/T 7997-2017 : Hardness (1400-2200 HV).
GB/T 51692013 : Porosity (A02B00C00).

GB/T 43342020 : Corrosion resistance (<0.005 mm/year).

Future Trends

Intelligent temperature control (deviation <±5°C), green sintering (energy consumption reduced by 20%) and nanocrystalline sintering (grains <0.1 μm) will improve performance and efficiency.

appendix:

Brief Introduction of Typical Cemented Carbide Sintering Furnace

Cemented carbide sintering furnaces are key equipment for high-temperature sintering of cemented carbide (WC+Co /Ni) billets. By precisely controlling high temperature (13501500°C), atmosphere (such as H2, Ar), pressure (0.1200 MPa) and process flow, pressed billets (density 5070%) are converted into high-density (>99%), high-performance cemented carbide products (such as mining drills, aviation tools, and wear-resistant molds). These sintering furnaces must have high-precision temperature control (±35°C), uniform heating (temperature difference <±10°C), atmosphere stability (O2 <10 ppm), high reliability, and efficient production capacity to ensure product hardness (14002200 HV), strength (1.82.5 GPa), porosity (<0.01%), and dimensional accuracy (±0.010.5 mm, in line with GB/T 345052017). This article combines national standards (such as GB/T 183762014, GB/T 38502015) and industry practices (such as ALD, PVA TePla , Quintus, 2023) to introduce in detail the types, characteristics, process parameters, performance data, applications and selection recommendations of typical cemented carbide sintering furnaces.

1. Types of cemented carbide sintering furnaces

Cemented carbide sintering furnaces are divided into the following three categories according to process requirements and sintering methods. Each category has specific sintering requirements for cemented carbide products (such as mining drills, aviation tools, and wear-resistant molds):

Cemented carbide vacuum sintering furnace :

Single-chamber vacuum sintering furnace for cemented carbide : small and medium batches, suitable for complex shaped products (such as aviation tools Ø 550 mm).

Multi-chamber vacuum sintering furnace for cemented carbide : large-scale continuous production, suitable for mining drill bits (Ø 100-400 mm).
Structure : Single/multi-chamber, chamber Ø 3001000 mm × 5002000 mm, graphite/ molybdenum heating elements, vacuum degree 10^{-3} 10^{-5} Pa, equipped with condenser and dewaxing system.
Application : dewaxing and sintering in one, suitable for high-precision products.

Cemented carbide hot isostatic pressing furnace (HIP) :

Cemented carbide high temperature HIP sintering furnace : sintering high performance products in one step to eliminate micropores.
Cemented carbide low temperature HIP sintering furnace : post-sintering treatment to enhance performance.
Structure : High-pressure chamber (Ø 200-800 mm × 500-1500 mm), pressure 100-200 MPa, graphite/ molybdenum heating elements, Ar atmosphere, equipped with high-pressure pump and safety valve.
Application : Aviation tools, wear-resistant molds, requiring high density (>99.9%).

Cemented carbide atmosphere sintering furnace :
Cemented carbide sintering furnace in hydrogen atmosphere : low-cost mass production, suitable for mining picks.
Cemented carbide inert gas sintering furnace : high-precision products, reduced oxidation, suitable for molds.
Structure : Push boat/roller type, chamber Ø 5001500 mm × 10003000 mm, H_2/ Ar atmosphere, graphite/ceramic heating elements, equipped with gas purification system.
Application : Large size blanks, low cost processing.

2. Characteristics of cemented carbide sintering furnace

2.1 Structure and material properties

Cavity Material :
316L stainless steel/ molybdenum : temperature resistance >1500°C, corrosion resistance, suitable for vacuum/high pressure.
Graphite/ceramic lining : thermal uniformity ±10°C, heat loss reduced by 20%.

Heating elements :
Graphite : temperature resistance >2000°C, suitable for vacuum/atmosphere sintering, life span >5000 hours.
Molybdenum /Tungsten : high purity (contamination <0.01%), suitable for HIP, life span >4000 hours.

Insulation Material :

Carbon fiber felt : thermal conductivity <0.1 W/ m·K , insulation efficiency 95%.
Alumina fiber : temperature resistance >1600°C, energy saving 1520%.

Control system :
PLC+touch screen, temperature control accuracy ±35°C, pressure control ±0.1 MPa, atmosphere flow rate ±0.5 L/min.
Support remote monitoring, fault diagnosis rate>98%.

Security System :
Over-temperature/over-pressure protection, pressure relief valve response time <0.1 second.
Gas detection (O2, H2), automatic shutdown when concentration exceeds the standard.

2.2 Performance characteristics

Temperature range : 12001500°C (vacuum/HIP), 8001400°C (atmosphere).
Temperature control accuracy : ±35°C, uniformity ±510°C (multi-point temperature measurement).
Vacuum degree : 10^{-3} 10^{-5} Pa (vacuum furnace), 10^{-2} Pa (dewaxing stage).
Pressure range : 0.1200 MPa (HIP), 0.010.1 MPa (atmosphere).
Atmosphere control : H2 (99.999%), Ar (99.99%), O2 <510 ppm.
Cooling rate : 520°C/min (forced cooling, Ar /N2 injection), thermal stress reduction 30%.

Product performance :
Hardness: 14002200 HV (GB/T 79972017).
Strength: 1.82.5 GPa (GB/T 38512015).
Density:>99%（GB/T 38502015）.
Porosity: <0.01% (GB/T 51692013).

2.3 Process characteristics

Dewaxing efficiency : vacuum/low pressure H2, dewaxing rate>99.5%, residual carbon <0.05%.
Sintering cycle : 824 hours (vacuum 1216 hours, HIP 36 hours, atmosphere 1020 hours).
Shrinkage control : Shrinkage ratio 1522% (YG8 1618%, YN10 1820%), deviation <±0.5%.
Energy consumption : 12 kWh/kg (vacuum/HIP), 0.51 kWh/kg (atmosphere).
Automation : automatic loading and unloading, atmosphere adjustment, production efficiency increased by 3040%.
Product consistency : hardness deviation <±50 HV, density deviation <±0.1 g/ cm^3 .

3. Process parameters of cemented carbide sintering furnace

Cemented carbide vacuum sintering furnace :
Dewaxing stage :

Temperature: 200600°C, heating rate 25°C/min.
Vacuum degree: 10^{-2} Pa , H2 flow rate 510 L/min.
Time: 24 hours, dewaxing rate>99%.
Sintering stage :
Temperature: 13501450°C, heating rate 510°C/min.
Vacuum degree: 10^{-4} 10^{-5} Pa, keep warm for 24 hours.
Cooling: 10°C/min (Ar forced cooling), to 100°C.
Typical parameters :
YG8 mining drill bit: 1400°C, 10^{-4} Pa, 12 hours, density 14.6 g/ cm³ .
YN10 aviation tool: 1450°C, 10^{-5} Pa, 14 hours, hardness 1800 HV.

Cemented carbide hot isostatic pressing furnace (HIP) :
Sintering stage :
Temperature: 13501450°C, heating rate 58°C/min.
Pressure: 100150 MPa (Ar), keep warm for 13 hours.
Cooling: 15°C/min (high pressure Ar), to 200°C.
Post-processing stage (low temperature HIP):
Temperature: 13001350°C, pressure 80100 MPa.
Time: 12 hours, porosity reduced to <0.001%.
Typical parameters :
YG6X aviation tool: 1400°C, 120 MPa, 4 hours, density 14.9 g/ cm³ .
YG8 wear-resistant mold: 1350°C, 100 MPa, 3 hours, strength 2.2 GPa .

Cemented carbide atmosphere sintering furnace :
Dewaxing stage :
Temperature: 200500°C, heating rate 35°C/min.
H2 flow: 2050 L/min, O2 <10 ppm.
Time: 35 hours, residual carbon <0.1%.
Sintering stage :
Temperature: 13001400°C, heating rate 510°C/min.
Atmosphere: H2 (99.999%), keep warm for 35 hours.
Cooling: 510°C/min (N2 protection), to 100°C.
Typical parameters :
YG6 pick: 1350°C, H2 30 L/min, 12 hours, hardness 1400 HV.
YN10 mold: 1400°C, Ar 20 L/min, 15 hours, accuracy ±0.01 mm.

4. Performance data of cemented carbide sintering furnace

Cemented carbide vacuum sintering furnace :
Product performance :
Density: 14.514.9 g/cm³ (YG8/YG6X), deviation ±0.1 g/ cm³ .
Hardness: 1400-2000 HV, deviation ±50 HV.

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Strength: 1.82.3 GPa , porosity <0.01%.
Equipment performance :
Temperature control accuracy: ±3°C (PID control, 10-point temperature measurement).
Vacuum degree: 10 $^{-5}$ Pa (molecular pump), leakage rate <10 $^{-8}$ Pa·m³ / s.
Energy consumption: 1.5 kWh/kg, production capacity: 50200 kg/furnace.
Consistency : Batch hardness deviation <2%, dimensional deviation ±0.020.5 mm.

Cemented carbide hot isostatic pressing furnace (HIP) :
Product performance :
Density: 14.815.0 g/cm³ (YG6X/YN10), deviation ±0.05 g/ cm³ .
Hardness: 18002200 HV, deviation ±30 HV.
Strength: 2.22.5 GPa , porosity <0.001%.
Equipment performance :
Temperature control accuracy: ±5°C, pressure control ±0.1 MPa.
Pressure stability: ±0.5% (100150 MPa), Ar consumption 50100 L/furnace.
Energy consumption: 2 kWh/kg, production capacity: 20100 kg/furnace.
Consistency : Batch density deviation <0.5%, accuracy ±0.010.05 mm.

Cemented carbide atmosphere sintering furnace :
Product performance :
Density: 14.514.8 g/cm³ (YG6/YN10), deviation ±0.15 g/ cm³ .
Hardness: 1400-1800 HV, deviation ±60 HV.
Strength: 1.82.2 GPa , porosity <0.02%.
Equipment performance :
Temperature control accuracy: ±5°C, air flow rate ±0.5 L/min.
H2 consumption: 100200 L/furnace, O2 <10 ppm.
Energy consumption: 0.8 kWh/kg, production capacity: 100500 kg/furnace.
Consistency : Batch hardness deviation <3%, size deviation ±0.10.5 mm.

5. Application of cemented carbide sintering furnace

Cemented carbide vacuum sintering furnace :
Application scenarios :
Sintered mining drill bits (such as roller drill bits Ø 100-400 mm) require high toughness.
Aviation tools (e.g. ball end mills Ø 550 mm) require high precision.
Performance :
Temperature: 13501450°C, 10 $^{-4}$ 10 $^{-5}$ Pa.
Cycle: 1216 hours, density>99%.
Accuracy: ±0.020.5 mm, hardness 14002000 HV.
Examples :

Single chamber vacuum sintering furnace for cemented carbide (ALD VKPgr , Ø 400 × 1200

mm):
Sintering of YG8 mining drill bit (Ø 20 × 330 mm), 1450°C, 10^{-4} Pa, 12 h.
Results: density 14.6 g/cm³ , hardness 1400 HV, shrinkage ratio 16%, porosity <0.01% (ScienceDirect, 2021).
Multi-chamber vacuum sintering furnace for cemented carbide (PVA TePla COD, Ø 600 × 1500 mm):
Sintering of YN10 aviation tool (Ø 10 × 100 mm), 1400°C, 10^{-5} Pa, 14 h.
Results: Density 14.8 g/cm³ , hardness 1800 HV, accuracy ±0.02 mm, KIC 10 MPa·m $^{1/2}$.

Cemented carbide hot isostatic pressing furnace (HIP) :
Application scenarios :
Aviation tools (such as milling cutters) can eliminate micropores and improve density.
Wear-resistant molds (such as cold stamping molds 100×100× 30 mm) can enhance anti-fatigue performance.
Performance :
Temperature: 13501450°C, 100150 MPa.
Cycle: 36 hours, density>99.9%.
Accuracy: ±0.010.05 mm, hardness 18002200 HV.
Examples :
Hard alloy high temperature HIP sintering furnace (Quintus QIH, Ø 300 × 1000 mm):
Sintering of YG6X aviation tool (Ø 12 × 80 mm), 1400°C, 120 MPa, 4 hours.
Results: Density 14.9 g/cm³ , hardness 2000 HV, porosity <0.001%, strength 2.3 GPa .
Cemented carbide low temperature HIP sintering furnace (ALD HP, Ø 250 × 800 mm):
Post-treatment of YG8 wear-resistant mold (100×100× 30 mm), 1350°C, 100 MPa, 3 h.
Results: Porosity <0.001%, strength 2.2 GPa , lifespan increased by 20%.

Cemented carbide atmosphere sintering furnace :
Application scenarios :
Mining picks (e.g. conical picks Ø 20 mm), mass-produced.
Wear-resistant molds (such as plastic molding molds 80×80× 20 mm), low-cost processing.
Performance :
Temperature: 13001400°C, H_2/ Ar atmosphere.
Cycle: 1020 hours, density>99%.
Accuracy: ±0.1-0.5 mm, hardness 1400-1800 HV.
Examples :
Cemented carbide sintering furnace in hydrogen atmosphere (ECM Lilas, Ø 800 × 2000 mm):
Sintering of YG6 pick (Ø 20 × 50 mm), 1350°C, H_2 30 L/min, 12 hours.
Results: Density 14.5 g/cm³ , hardness 1400 HV, life 80 hours, porosity <0.02%.
Inert gas sintering furnace for cemented carbide (Centorr , Ø 600 × 1500 mm):
Sintering of YN10 plastic molding mold (80×80× 20 mm), 1400°C, Ar 20 L/min, 15 hours.
Results: Density 14.7 g/cm³ , accuracy ±0.01 mm, hardness 1600 HV.

6. Comparison of cemented carbide sintering furnace types

Sintering furnace type	temperature °C	pressure MPa	atmosphere	cycle Hour	density %	Accuracy mm	Energy consumption kWh/kg	Typical Applications
Cemented Carbide Single Chamber Vacuum Sintering Furnace	13501450	10⁻³ 10⁻⁵ Pa	vacuum	1216	>99	±0.020.5	1.5	Mining drill bits and cutters
Cemented carbide high temperature HIP sintering furnace	13501450	100150	Ar	36	>99.9	±0.010.05	2	Aviation tools and molds
Cemented Carbide Sintering Furnace in Hydrogen Atmosphere	13001400	0.1	H2	1020	>99	±0.10.5	0.8	Picks, dies

7. Selection recommendations

According to product type

Aviation tools (high precision, complex shapes) :

Recommended: Carbide vacuum sintering furnace (single chamber) or high temperature HIP sintering furnace.

Reason: Vacuum degree 10 ⁻⁵ Pa ensures low contamination, HIP pressure 120 MPa eliminates micropores, accuracy ±0.010.05 mm.

Model: ALD VKPgr (Ø 400 × 1200 mm, 50100 kg/furnace), Quintus QIH (Ø 300 × 1000 mm, 2050 kg/furnace).

Mining drill bits/cutters (large size, mass production) :

Recommended: Carbide multi-chamber vacuum sintering furnace or hydrogen atmosphere sintering furnace.

Reason: Multi-chamber supports continuous production (200500 kg/furnace), and the H2 atmosphere cost is low (0.8 kWh/kg).

Models: PVA TePla COD (Ø 600 × 1500 mm, 200 kg/furnace), ECM Lilas (Ø 800 × 2000 mm, 300 kg/ furnace).

Wear-resistant mold (high density, anti-fatigue) :

Recommended: high temperature HIP sintering furnace for cemented carbide or low temperature HIP post-treatment.

Reason: HIP ensures density >99.9%, porosity <0.001%, and strength increase by 1020%.

Models: ALD HP (Ø 250 × 800 mm, 2050 kg/furnace), Quintus QIH (Ø 300 × 1000 mm).

According to production demand

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Small and medium batches (<100 kg/furnace) : Single-chamber vacuum sintering furnace or small HIP furnace, high flexibility, suitable for R&D or customized products.

Large batch (>200 kg/furnace) : multi-chamber vacuum sintering furnace or atmosphere sintering furnace, high production capacity, unit cost reduced by 2030%.

According to cost budget
low cost
Cemented carbide hydrogen atmosphere sintering furnace, energy consumption 0.8 kWh/kg, equipment cost 3050% lower (about 501 million US dollars).
high performance
The cemented carbide high temperature HIP sintering furnace has an energy consumption of 2 kWh/kg and high equipment cost (about 2005 million US dollars), but the product performance is improved by 20%.

According to process requirements :
High precision (±0.010.05 mm) : vacuum sintering furnace (10^{-5} Pa) + HIP (120 MPa), shrinkage deviation <±0.5%.
Low pollution : Mo /Tungsten heating elements and Ar atmosphere are used to reduce pollution by 30%.
Fast production : HIP furnace (36 hours) or multi-chamber vacuum furnace (continuous production).
Environment and Safety :
H2 atmosphere : Gas detection (O2 <10 ppm) and pressure relief system (response <0.1 sec) are required.
HIP high pressure : Choose equipment with safety valve and pressure monitoring (leakage rate <10^{-8} Pa·m³ / s).

8. Optimization suggestions

equipment :
Heating element : Molybdenum /Tungsten (HIP/Vacuum), pollution reduction by 30%, life span>4000 hours.
Insulation material : Carbon fiber felt + alumina fiber, heat loss reduced by 20%, energy saving 15%.
Chamber : 316L stainless steel + graphite lining, corrosion resistance increased by 25%, life span > 10 years.

Process Optimization :
Temperature control : Upgraded PID+AI algorithm, accuracy ±3°C, uniformity ±5°C.
Dewaxing : Vacuum (10^{-2} Pa) + H2 (510 L/min), dewaxing rate>99.5%, residual carbon <0.05%.

HIP : 1350°C, 120 MPa, 2 hours of heat preservation, cycle shortened by 20%, density increased by 0.5%.

Atmosphere Control :
H2 purity : >99.999%, O2 <5 ppm, oxidation rate reduced by 50%.
Ar circulation : flow rate 2050 L/min, recovery rate>80%, cost reduction 15%.

Cooling Optimization :
Forced cooling : high-pressure Ar injection (1520°C/min), thermal stress reduction by 30%.
Multi-stage cooling : 800°C/400°C/100°C segmented, accuracy improved by 10%.

Maintenance and Automation :
Online monitoring : Real-time monitoring of temperature, pressure and atmosphere, reducing the failure rate by 20%.
Automatic loading and unloading : Robotic system reduces labor costs by 30% and increases efficiency by 40%.
Maintenance cycle : Graphite components should be inspected every 5,000 hours and the chamber should be cleaned annually, which can extend the service life by 25%.

9. Standards

GB/T 345052017 : Dimensional accuracy ±0.01 mm, tolerance deviation <±5%.
GB/T 183762014 : Porosity <0.01%, uniformity >95%.
GB/T 38502015 : Density>99%.
GB/T 51692013 : Porosity grade A02B00C00.
GB/T 38512015 : Flexural strength 1.82.5 GPa .
GB/T 79972017 : Hardness 14002200 HV.

10. Conclusion

Cemented carbide sintering furnaces include three categories: cemented carbide vacuum sintering furnaces, hot isostatic pressing sintering furnaces and atmosphere sintering furnaces, which can meet the sintering needs of mining drills, aviation tools and wear-resistant molds:

Cemented Carbide Vacuum Sintering Furnace
Complex shape, 13501450°C, 10^{-5} Pa, density>99%, accuracy±0.020.5 mm.

Cemented Carbide Hot Isostatic Pressing Sintering Furnace
High performance products, 100-150 MPa, density>99.9%, porosity<0.001%.

Cemented Carbide Atmosphere Sintering Furnace
Mass production, 13001400°C, H2/ Ar , low cost, suitable for pick cutters.

These sintering furnaces significantly improve the performance and production efficiency of cemented carbide products with high-precision temperature control, atmosphere stability and efficient processes, and are widely used in mining, aviation and mold manufacturing. Product accuracy, output, cost and process requirements must be considered when selecting a model.

appendix:

What is the sintered density of cemented carbide?

Brief Introduction of Sintered Density of Cemented Carbide

The sintered density of cemented carbide refers to the material density that is finally achieved by the blank (pressed powder, initial density is usually 50-70% of theoretical density) during the high-temperature sintering process of cemented carbide (such as WC+Co , WC +Ni) through particle rearrangement, diffusion and pore elimination. It is usually expressed as actual density (g/ cm³) or relative density (percentage of theoretical density). Sintered density directly affects the performance of cemented carbide, including hardness (1400-2200 HV), strength (1.8-2.8 GPa), wear resistance and porosity (<0.01%). It is a key indicator for evaluating sintering quality and must comply with national standards (such as GB/T 3850-2015, GB/T 1837-6-2014). High sintered density (>99% theoretical density) ensures that the product has no micropores and excellent performance, and is suitable for applications such as wear-resistant molds, mining tools and deep-sea seals.

1. Definition of sintered density of cemented carbide

Actual density
The mass per unit volume of cemented carbide after sintering (g/cm³) is calculated by the Archimedean method (GB/T 38502015) or by direct measurement.
Relative density
The ratio of actual density to theoretical density (ideal density in a fully dense state), usually expressed as a percentage. For example, the theoretical density of YG8 (WC+8%Co) is about 14.7 g/cm³ , and the actual density after sintering is 14.65 g/cm³ , and the relative density is 99.66%.
Theoretical density
based on the mass fraction of cemented carbide components (WC, Co/Ni, additives) and the density of each component (WC: 15.63 g/cm ³ , Co: 8.9 g/cm ³ , Ni: 8.9 g/cm ³).

The significance of cemented carbide sintering density
Performance impact
High sintering density (>99%) reduces porosity (<0.01%, GB/T 51692013), improves hardness (increased by 510%), strength (increased by 1020%) and wear resistance (wear loss reduced by 2030%).

Quality Control
The sintering density reflects the degree of optimization of the sintering process (such as temperature, pressure, and atmosphere). Low density (<95%) may lead to micropores and insufficient strength, thus affecting the life of the product.

Application Requirements
High-density cemented carbide (such as >99.9%, HIP sintering) is suitable for deep-sea seals and

aviation tools; medium density (>98%) is suitable for mining picks.

2. Factors affecting the sintering density of cemented carbide

Powder characteristics:
Grain size: Fine grains (0.52 μm) promote diffusion and increase density by 12%; coarse grains (>5 μm) may cause residual pores.
Homogeneity: Powders are uniformly mixed (ball milling for 1624 hours, D50 50150 μm), with reduced segregation and density deviation <±0.1 g/ cm³ .
Binder: PEG/paraffin (0.52 wt %) optimized for compression molding, with 510% higher initial density.

Pressing process:
Pressure: Cold isostatic pressing (200-300 MPa) increases the density of the blank (60-70%), and the density increases by 13% after sintering.
Die: Uniform pressure distribution, reduced blank defects, and 10% increase in density consistency.

Sintering process:
Temperature: 13501500°C (vacuum/HIP), too low (<1300°C) leads to insufficient density (<95%), too high (>1550°C) leads to grain growth and density decrease of 0.51%.
Insulation time: 24 hours (vacuum), 13 hours (HIP), density increases by 0.20.5% if extended by 1 hour.
Atmosphere: H2/ Ar (O2 <510 ppm) to prevent oxidation, the density of Ni/Co-based alloy increased by 0.5%; vacuum (10^{-4} 10^{-5} Pa) to remove the binder, the density increased by 1%.
Pressure: HIP (100150 MPa) eliminates micropores and achieves a density of >99.9%; conventional sintering (0.1 MPa) achieves a density of 9899%.

Sintering furnace performance:
Temperature control accuracy: ±35°C, uniformity ±510°C, density deviation <±0.05 g/ cm³ .
Vacuum degree: 10^{-5} Pa (vacuum furnace), dewaxing efficiency>99.5%, residual carbon <0.05%.
Cooling rate: 520°C/min, controlled thermal stress, 5% increase in density consistency.

3. Relationship between sintering density and sintering process

Vacuum sintering:
Process: dewaxing (200600°C, 10^{-2} Pa) → sintering (13501450 ° C, 10^{-4} 10^{-5} Pa) → cooling (1015°C/min).
Density: 9899.5% (YG8: 14.514.65 g/cm³) , porosity <0.01%.
Applicable to: mining drill bits, molds, low cost.

Hot Isostatic Pressing (HIP):
Process: sintering (13501450°C, 100150 MPa, Ar) → post-treatment (13001350°C, 80100 MPa)

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→ cooling (1520°C/min).
Density: >99.9% (YG8: 14.6514.7 g/cm³) , porosity <0.001%.
Application: Aviation tools, deep sea seals, high performance requirements.

Atmosphere sintering:
Process: dewaxing (200500°C, H_2 2050 L/min) → sintering (13001400°C, H_2/ Ar) → cooling (510°C/min).
Density: 9899% (YG6: 14.414.5 g/cm³) , porosity <0.02%.
Applicable to: pick cutting, mass production, low cost.

4. Sintered density performance data

Sintering type	Brand	Actual density (g/cm³)	Relative density (% theoretical)	Porosity(%)	Hardness (HV)	Strength (GPa)	Typical Applications
Vacuum sintering	YG8	14.514.65	98.699.7	<0.01	14001800	1.82.3	Mining drill bits
HIP sintering	YG6X	14.814.9	>99.9	<0.001	18002200	2.22.8	Aviation tools
Atmosphere sintering	YN10	14.414.5	98.099.0	<0.02	14001600	1.82.2	Chemical seals

Examples:
Vacuum sintering: YG8 drill bit (Ø 20 × 330 mm), 1450°C, 10^{-4} Pa, 12 hours, density 14.6 g/cm³ (99.3%), hardness 1400 HV.
HIP sintering: YG6X tool (Ø 12 × 80 mm), 1400°C, 120 MPa, 4 hours, density 14.9 g/cm³ (>99.9%), porosity <0.001%.
Atmosphere sintering: YN10 seal (Ø 50 mm), 1350°C, H_2 30 L/min, 12 hours, density 14.5 g/cm³ (98.6%), excellent corrosion resistance.

5. Suggestions for sintering density optimization

Powder Optimization:
Medium-fine grain WC (0.5-1.5 μm) is selected , and the density increases by 12%.
Adding Cr_3C_2 (0.20.5 wt %) inhibits grain growth and increases density by 0.5%.

Pressing process:
Increasing the pressing pressure (250300 MPa), the initial density increased by 510%.
Optimize the mold, reduce billet defects, and increase density consistency by 10%.

Sintering process:
Temperature: Control 14001450°C (YG8/YG6X), avoid overburning, density increase by 0.5%.
Atmosphere: H_2 purity>99.999%, O_2 <5 ppm, Ni-based alloy density increased by 0.5%.
HIP: 1350°C, 120 MPa, 2 hours, density >99.9%.

Equipment Optimization:
Upgraded temperature control (±3°C), density deviation <±0.05 g/ cm³ .
Using molybdenum /tungsten heating elements, pollution is reduced by 30% and density is increased by 0.2%.

Post-processing:
After HIP treatment (1300°C, 100 MPa), the porosity was reduced to <0.001%.
Polishing (Ra <0.2 μm) reduces surface defects and increases wear resistance by 20%.

6. Standards
GB/T 38502015: Density measurement, deviation <±0.1 g/ cm³ .
GB/T 183762014: Porosity <0.01%, uniformity >95%.
GB/T 51692013 : Porosity grade A02B00C00.
GB/T 38512015: flexural strength 1.82.8 GPa .
GB/T 7997-2017: Hardness 1400-2200 HV.

7. Conclusion
The sintering density of cemented carbide is the core indicator for measuring sintering quality, which directly affects the hardness, strength and durability of the product. High sintering density (>99%) is achieved by optimizing powder, pressing and sintering processes (such as HIP 1350°C, 120 MPa), ensuring porosity <0.001%, which is suitable for high-performance applications (such as deep-sea seals, aviation tools). Vacuum sintering (9899.5%), HIP (>99.9%) and atmosphere sintering (9899%) meet different needs respectively, and the process needs to be selected according to the application scenario.

appendix:

What is Carbide Porosity?

Introduction to Porosity of Cemented Carbide

The porosity of cemented carbide refers to the percentage of the volume of tiny pores (pores or voids) remaining inside the material during the sintering process of cemented carbide (such as WC+Co , WC+Ni) to the total volume. It is usually expressed as a percentage (such as <0.01%), or classified as A, B, or C grades according to the national standard GB/T 5169-2013 (such as A02B00C00).

Porosity is a key indicator for evaluating the quality of cemented carbide sintering, which directly affects the material's density (14.5-15.0 g/cm³) , hardness (1400-2200 HV), strength (1.8-2.8 GPa), wear resistance and corrosion resistance. Low porosity (<0.001%, such as HIP sintering) ensures high performance and is suitable for high-demand applications such as aviation tools and deep-sea seals; higher porosity (0.01-0.02%, such as atmosphere sintering) is suitable for cost-sensitive mining picks.

This article combines national standards (such as GB/T 183762014, GB/T 51692013) and industry practices to introduce in detail the definition, measurement, influencing factors and optimization measures of cemented carbide porosity.

1. Definition of Porosity of Cemented Carbide

Porosity

The ratio of the internal pore volume to the total volume of cemented carbide is usually calculated indirectly through microscopic observation (metallographic analysis, GB/T 5169-2013) or density measurement (Archimedes method, GB/T 3850-2015).

Formula: Porosity (%) = (1 actual density/theoretical density) × 100.

For example, the theoretical density of YG8 is 14.7 g/cm³ , the actual density is 14.65 g/cm³ , and the porosity is ≈ 0.34%.

Porosity Type:

Type A pores: diameter <10 μm , tiny pores that affect strength.

Type B pores: diameter 1025 μm , larger pores, reduced wear resistance.

Type C pores: pores formed by carbide aggregation or inclusions, which affect corrosion resistance.

Grade standard (GB/T 51692013):

A02: Class A pores <0.02 mm² / cm² .

B00: No Class B pores.

C00: No C-type pores.

The significance of cemented carbide porosity

Performance impact

High porosity (>0.1%) leads to lower density (<98%), lower hardness (5-10%), weakened strength (10-20%), and worse wear resistance (wear increase of 20-30%), which can easily cause fatigue fracture or corrosion.

Quality Control

Porosity reflects the effectiveness of the sintering process (such as temperature, pressure, and atmosphere). Low porosity (<0.001%) indicates sufficient sintering and a dense material.

Application Requirements

High performance applications (aerospace tools, deep sea seals): Porosity <0.001% (HIP sintering), ensuring no micropores, high pressure/corrosion resistance.

General application (mining picks, molds): porosity <0.02% (atmosphere sintering), meeting the balance between cost and performance.

2. Porosity measurement method

Metallographic analysis (GB/T 51692013):

step:

Sample preparation: cutting and polishing (Ra <0.2 μm).

Microscopic observation: optical microscope (1001000×), counting the number and area of A/B/C type pores.

Classification and rating: A02, B00 and other grades are determined according to pore diameter and distribution.

Advantages: intuitive, able to distinguish pore types.

Limitations: Only the surface is observed, multiple sampling points are required.

Density measurement (GB/T 38502015):

step:

Measurement of actual density: Archimedean method (weighing in water, accuracy ±0.01 g/cm³) .

Calculate porosity: (1 actual density / theoretical density) × 100.

Pros: Quick, holistic assessment.

Limitations: Cannot distinguish pore types.

Other methods:

X-ray CT: 3D non-destructive testing, accuracy ±0.001%, suitable for high-precision applications.

Ultrasonic testing: detects large pores (>25 μm), used for large-sized products.

3. Factors affecting the porosity of cemented carbide

Powder characteristics:

Grain size: Fine grains (0.52 μm) promote diffusion and reduce porosity by 50%; coarse grains (>5

μm) are prone to residual pores.
Homogeneity: Uneven powder mixing (inadequate ball milling <16 hours) resulted in local pores, and the porosity increased by 0.10.2%.
Binder: Excessive amount of PEG/paraffin (0.52 wt %) resulted in incomplete dewaxing and an increase in porosity of 0.050.1%.
Pressing process:
Pressure: Cold isostatic pressing (200-300 MPa) increases the density of the blank (60-70%) and reduces the porosity by 0.1-0.2%.
Defects: Mold wear or uneven pressure causes cracks in the blank and the porosity increases by 0.20.5%.
Sintering process:
Temperature: 13501500°C (vacuum/HIP), too low (<1300°C) the porosity is >0.1%, too high (>1550°C) the grains grow and the porosity increases by 0.05%.
Insulation time: 24 hours (vacuum), 13 hours (HIP), the porosity decreases by 0.010.02% when extended by 1 hour.
Atmosphere: H_2/ Ar (O_2 <510 ppm) to prevent oxidation, porosity reduced by 0.02%; vacuum (10^{-4} 10^{-5} Pa) for thorough dewaxing, porosity reduced by 0.05%.
Pressure: HIP (100-150 MPa) eliminates micropores and the porosity is <0.001%; conventional sintering (0.1 MPa) has a porosity of 0.01-0.02%.
Sintering furnace performance:
Temperature control accuracy: ±35°C, uniformity ±510°C, porosity deviation <±0.005%.
Vacuum degree: 10^{-5} Pa, dewaxing efficiency>99.5%, residual carbon <0.05%, porosity reduction 0.02%.
Cooling rate: 520°C/min, controlled thermal stress, increased porosity consistency by 10%.

4. Relationship between porosity and sintering process

Vacuum sintering:
Process: dewaxing (200600°C, 10^{-2} Pa) → sintering (13501450 ° C, 10^{-4} 10^{-5} Pa) → cooling (1015°C/min).
Porosity: <0.01% (A02B00), YG8 density 14.514.65 g/ cm^3 .
Application: Mining drill bits, molds, medium porosity.
Hot Isostatic Pressing (HIP):
Process: sintering (13501450°C, 100150 MPa, Ar) → post-treatment (13001350°C, 80100 MPa) → cooling (1520°C/min).
Porosity: <0.001% (A00B00), YG6X density 14.814.9 g/ cm^3 .
Application: aviation knives, deep sea seals, high performance.
Atmosphere sintering:
Process: dewaxing (200500°C, H_2 2050 L/min) → sintering (13001400°C, H_2/ Ar) → cooling (510°C/min).
Porosity: <0.02% (A04B02), YN10 density 14.414.5 g/ cm^3 .
Application: Chemical seals, picks, low cost.

5. Porosity performance data

Sintering type	Brand	Porosity(%)	GB/T 5169 Grade	Density(g/ cm³)	Hardness (HV)	Strength (GPa)	Typical Applications
Vacuum sintering	YG8	<0.01	A02B00C00	14.514.65	14001800	1.82.3	Mining drill bits
HIP sintering	YG6X	<0.001	A00B00C00	14.814.9	18002200	2.22.8	Aviation tools
Atmosphere sintering	YN10	<0.02	A04B02C00	14.414.5	14001600	1.82.2	Chemical seals

Examples:

Vacuum sintering: YG8 drill bit (Ø 20 × 330 mm), 1450°C, 10^{-4} Pa, 12 hours, porosity <0.01%, density 14.6 g/cm³ , hardness 1400 HV.

HIP sintering: YG6X tool (Ø 12 × 80 mm), 1400°C, 120 MPa, 4 hours, porosity <0.001%, density 14.9 g/cm³ , strength 2.3 GPa .

Atmosphere sintering: YN10 seal (Ø 50 mm), 1350°C, H2 30 L/min, 12 hours, porosity <0.02%, density 14.5 g/cm³ , excellent corrosion resistance.

6. Porosity Optimization Recommendations

Powder Optimization:

Select fine-grained WC (0.51.5 μm), and the porosity will be reduced by 50%.

Extending the ball milling time (1624 hours) increased the uniformity by 10% and decreased the porosity by 0.1%.

Control the binder (PEG/paraffin <1.5 wt %) and the residual carbon <0.05%.

Pressing process:

Increasing the pressure (250300 MPa), the density of the blank increased by 510% and the porosity decreased by 0.1%.

Optimize the mold, reduce cracks, and reduce porosity by 0.2%.

Sintering process:

Temperature: 14001450°C (YG8/YG6X), porosity decreases by 0.010.02%.

Atmosphere: H2 purity >99.999%, O2 <5 ppm, porosity reduced by 0.02%.

HIP: 1350°C, 120 MPa, 2 hours, porosity <0.001%.

Equipment Optimization:

Temperature control (±3°C), porosity deviation <±0.005%.

Vacuum (10^{-5} Pa), complete dewaxing, porosity reduced to 0.02%.

Using molybdenum /tungsten heating elements, contamination is reduced by 30% and porosity is reduced by 0.01%.

Post-processing:

After HIP treatment (1300°C, 100 MPa), the porosity was reduced to <0.001%.

Polishing (Ra <0.2 μm) reduces surface porosity and increases corrosion resistance by 20%.

7. Standards

GB/T 51692013: Porosity grade A02B00C00 (high performance), A04B02C00 (general).
GB/T 183762014: Porosity <0.01%, uniformity >95%.
GB/T 38502015: Density measurement, deviation <±0.1 g/ cm^3 .
GB/T 38512015: flexural strength 1.82.8 GPa .
GB/T 7997-2017: Hardness 1400-2200 HV.

8. Conclusion

The porosity of cemented carbide is the core indicator of sintering quality, which affects density, hardness, strength and durability. Low porosity (<0.001%) is achieved by optimizing powder, pressing and sintering processes (such as HIP 1350°C, 120 MPa), which is suitable for aviation tools and deep-sea seals; medium porosity (<0.02%) meets the needs of mining picks, etc. Vacuum sintering (<0.01%), HIP (<0.001%) and atmosphere sintering (<0.02%) are suitable for different scenarios, and the process needs to be selected according to the application.

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appendix:

Corrosion resistance and evaluation of cemented carbide

Cemented carbide (such as WC+Co , WC+Ni) is widely used in mining tools, aviation tools, deep-sea seals and chemical pumps due to its high hardness (14002200 HV), high strength (1.82.8 GPa) and excellent wear resistance. However, in corrosive environments (such as acid, alkali, salt solution, H2S, CO2, seawater), the corrosion resistance of cemented carbide becomes a key performance indicator, which directly affects its service life and reliability. Corrosion resistance is mainly determined by material composition, microstructure (such as porosity <0.01%), sintering process and surface treatment, and must comply with national standards (such as GB/T 183762014, NACE MR0175).

Combined with industry practices, this article introduces in detail the corrosion resistance mechanism, influencing factors, evaluation methods and optimization measures of cemented carbide, and appropriately recommends the production capabilities of CTIA GROUP LTD in the fields of nickel-based cemented carbide corrosion-resistant seals, pump bodies, etc.

1. Definition of Cemented Carbide Corrosion Resistance

The corrosion resistance of cemented carbide refers to the ability of the material to resist chemical or electrochemical erosion in corrosive media (such as acid, alkali, salt solution, H2S, CO2, seawater), which is usually expressed as corrosion rate (mm/y), mass loss ($mg/cm^2 \cdot h$) or surface morphology change.

Compliant standards:
NACE MR0175: Resistant to H2S/CO2 corrosion, suitable for oil and gas environments.
ISO 12944: Resistance to marine/industrial corrosive environments.
GB/T 183762014: Porosity <0.01%, ensuring corrosion resistance.

Corrosion Mechanism of Cemented Carbide Corrosion Resistance
Electrochemical corrosion: Cemented carbide is composed of a hard phase (WC, corrosion-resistant) and a bonding phase (Co/Ni, easily corroded). It forms a microbattery in an electrolyte (such as seawater, acid solution). The bonding phase corrodes preferentially, causing the WC particles to peel off.
For example: The dissolution rate of Co in HCl is >0.1 mm/y, while that of Ni is only 0.010.05 mm/y.

Chemical corrosion: Strong acids (such as H2SO4) and strong bases (such as NaOH) directly dissolve the bonding phase, and materials with high porosity (>0.1%) accelerate corrosion.

Erosion-corrosion synergy: In fluids containing particles (such as chemical pumps), wear exposes new surfaces, accelerating electrochemical corrosion, and the corrosion rate increases by 2050%.

Corrosion resistance performance:
Excellent: The corrosion rate of WC+Ni (Ni 815%) in H_2S (>1000 ppm), seawater (pH 39), and H_2SO_4 (50%) is <0.01 mm/y.
Medium: The corrosion rate of WC+Co (Co 612%) in HCl (30%) is 0.050.1 mm/y.
Poor: Materials with porosity > 0.1% or high Co content (> 15%) have a corrosion rate > 0.2 mm/y in strong acid.

2. Factors affecting the corrosion resistance of cemented carbide

Material composition:
Bonding phase:
Ni-based: Ni (815%) is more resistant to H_2S, CO_2, and seawater corrosion than Co, and the corrosion rate is reduced by 5070% (NACE MR0175).
Co-based: Co (612%) is easily soluble in acidic environments (HCl, H_2SO_4), and the corrosion rate increases 25 times .

additive:
Cr_3C_2 (0.52 wt %): forms a Cr oxide film, increasing acid resistance by 2030%.
Mo (0.51 wt %): Improves resistance to pitting corrosion and increases Cl^- corrosion resistance by 25%.
WC grain size: Fine grains (0.52 μm) reduce the exposure of the bonding phase and increase the corrosion resistance by 1015%; coarse grains (>5 μm) increase the corrosion path.

Microstructure:
Porosity (GB/T 5169-2013):
Low porosity (<0.001%, HIP sintering): reduces the penetration of corrosive media and increases corrosion resistance by 3050%.
High porosity (>0.1%, atmosphere sintering): Porosity accelerates electrochemical corrosion, increasing the corrosion rate by 23 times .
Grain boundary: Uniform grain boundary (ball milling for 1624 hours) reduces local corrosion and increases corrosion resistance by 10%.
Residual carbon: Residual carbon <0.05% (thorough dewaxing), preventing carbide from dissolving and increasing corrosion resistance by 510%.

Sintering process:
Vacuum sintering (13501450°C, 10^{-4} 10^{-5} Pa): porosity <0.01%, uniform distribution of bonding phase, medium corrosion resistance.
HIP sintering (13501450°C, 100150 MPa): porosity <0.001%, density >99.9%, excellent corrosion resistance.
Atmosphere sintering (13001400°C, H_2/ Ar , O_2 <5 ppm): porosity <0.02%, suitable for Ni-based alloys, with slightly inferior corrosion resistance.

Dewaxing: vacuum + H2 (10 ⁻² Pa, 515 L/min), residual carbon <0.05%, corrosion resistance increased by 10%.

Surface treatment:
Polishing (Ra <0.2 μm): Reduce surface defects and increase corrosion resistance by 1520%.

coating:
Ni/Cr electroplating: Acid resistance increased by 20%, Cl^- corrosion resistance increased by 30%.
PTFE/DLC coating: Friction coefficient reduced by 20%, erosion and corrosion resistance increased by 3050%.
Passivation: An oxide film is formed, increasing pitting corrosion resistance by 25%.

Use environment:
Medium: H2SO4 (50%) corrosion rate <0.01 mm/y (Ni-based); HCl (30%) corrosion rate 0.050.1 mm/y (Co-based).
Temperature: 50300°C, the corrosion rate increases by 1020% for every 50°C increase in temperature.
Fluid erosion: Fluids containing particles (solids <20%) accelerate corrosion, increasing the rate by 2050%.

3. Evaluation method of corrosion resistance of cemented carbide

Lab Tests:
Immersion test (ASTM G31):
Procedure: The sample is immersed in a corrosive medium (such as H2SO4, HCl, NaCl) at a constant temperature (2580°C) for a period of 24720 hours.
Indicators: mass loss (mg/cm² · h), corrosion rate (mm/y).
Example: The corrosion rate of WC+10%Ni in 50% H2SO4 (80°C) is <0.01 mm/y.

Electrochemical test (ASTM G59/G61):
Procedure: Use an electrochemical workstation to measure open circuit potential (OCP), polarization curve, corrosion potential (Ecorr) and current density (Icorr).
Index: Icorr <1 μA /cm² indicates excellent corrosion resistance.
Example: WC+Ni in 3.5% NaCl, Icorr ≈ 0.5 μA / cm² , better than WC+Co (2 μA /cm²) .

Salt spray test (ASTM B117):
Procedure: Samples were exposed to 5% NaCl atomization (35°C) for 961,000 hours.
Indicators: number of surface corrosion points, weight loss rate.
Example: WC+Ni+Cr3C2 has no obvious corrosion spots after 1000 hours.
Field Test:
Environmental exposure: Carbide components (such as seals and pump bodies) are placed in actual working conditions (such as deep sea and chemical plants) and run for 6-12 months .

Indicators: surface morphology (SEM observation), dimensional change (±0.01 mm), performance degradation (such as hardness decrease <5%).
Example: WC+Ni seals operated in seawater (pH 8, 15,000 psi) for 12 months with corrosion depth <0.005 mm.

Microscopic analysis:
SEM/EDS: observe the corrosion morphology and element distribution, and determine whether the bonding phase is dissolved or WC is peeling off.
XPS: Analyze surface oxide film and evaluate corrosion resistance mechanism.
Example: WC+Ni forms a NiS protective film in H2S , and the corrosion resistance increases by 20%.

Standard evaluation:
cm² in H2S (>1000 ppm) environment .
GB/T 183762014: Porosity <0.01%, no B/C type pores (A02B00C00).
ISO 12944: C5M Corrosion rate in marine environment <0.01 mm/y.

4. Corrosion resistance performance data

Brand	Bonding phase	environment	Corrosion rate (mm/y)	Icorr (μA /cm ²)	Porosity(%)	Typical Applications
YG8	Co (8%)	HCl (30%)	0.050.1	25	<0.01	Mining drill bits
YG6X	Co (6 %) + Cr3C2	H2SO4 (50%)	0.020.05	12	<0.001	Aviation tools
YN10	Ni (10%)	Seawater (pH 8)	<0.01	0.51	<0.01	Deep sea seals
YN12+Mo	Ni (12 %) + Mo	H2S (1000 ppm)	<0.005	0.30.5	<0.001	Chemical pump body

Examples:
YG8 (vacuum sintered): mining drill bit, HCl (30%, 80°C) soaking for 720 hours, corrosion rate 0.08 mm/y, porosity <0.01%, hardness drop <5%.
YG6X (HIP sintering): aviation tools, H2SO4 (50%, 60°C) test, corrosion rate 0.03 mm/y, Icorr 1.5 μA /cm² , porosity <0.001%.
YN10 (HIP sintering): deep sea seals, seawater (15,000 psi, 12 months), corrosion depth <0.005 mm, porosity <0.001%, excellent corrosion resistance.
YN12+Mo (HIP sintering): Chemical pump body, H2S (1000 ppm, 200°C), corrosion rate <0.005 mm/y, no pitting on the surface.

5. Suggestions for optimizing corrosion resistance

Material:
Bonding phase: Ni (1015%) is preferred, and the H2S/seawater corrosion resistance increases by 5070%.
Additives: Cr3C2 (0.52 wt %) + Mo (0.51 wt %), acid resistance increased by 2030%.

WC grain size: fine grain (0.51.5 μm), reduces exposure of bonding phase, and increases corrosion resistance by 15%.

Sintering process:
HIP sintering: 1350°C, 120 MPa, 2 hours, porosity <0.001%, corrosion resistance increased by 30%.
Dewaxing: vacuum (10^{-2} Pa) + H2 (10 L/min), residual carbon <0.05%, corrosion resistance increased by 10%.
Atmosphere: H2 purity >99.999%, O2 <5 ppm, prevent oxidation, increase corrosion resistance by 10%.

Surface treatment:
Polishing (Ra <0.2 μm): Reduces the starting point of corrosion and increases corrosion resistance by 1520%.
Coating: Ni/Cr electroplating or PTFE/DLC, erosion and corrosion resistance increased by 3050%.
Passivation: Formation of Cr/Ni oxide film increases pitting corrosion resistance by 25%.

Equipment Optimization:
Temperature control: ±3°C, uniformity ±5°C, porosity deviation <±0.005%, corrosion resistance increased by 5%.
Vacuum degree: 10^{-5} Pa, complete dewaxing, corrosion resistance increased by 10%.
Molybdenum /tungsten components: pollution is reduced by 30% and corrosion resistance is increased by 5%.

Environmental adaptation:
Acidic environment: Choose YN10+Cr3C2, which is resistant to H2SO4/HCl corrosion.
Ocean/Oil and Gas: Use YN12+Mo, resistant to H2S/CO2/seawater.
Fluids containing particles: DLC coating, erosion and corrosion resistance increased by 30%.

6. Standards

GB/T 183762014: Porosity <0.01%, uniformity >95%.
GB/T 51692013: Porosity grade A02B00C00 (high performance), A04B02C00 (general).
GB/T 38502015: Density deviation <±0.1 g/ cm^3 .
GB/T 38512015: flexural strength 1.82.8 GPa .
GB/T 7997-2017 : Hardness 1400-2200 HV.
NACE MR0175: Mass loss in H2S/CO2 environment <0.1 mg/ cm^2 .
ISO 12944: Corrosion rate in C5M environment <0.01 mm/y.
ASTM G31/G59: Corrosion rate <0.01 mm/y, Icorr <1 μA / cm^2 .

7. Conclusion

The corrosion resistance of cemented carbide is determined by the bonding phase (Ni is better than

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Co), porosity (<0.001% is best), sintering process (HIP is better than vacuum/atmosphere) and surface treatment. Ni-based cemented carbide (YN10/YN12) performs well in seawater, H2S and acidic environments, with a corrosion rate of <0.01 mm/y, suitable for deep-sea seals and chemical pump bodies; Co-based alloys (YG8/YG6X) are suitable for moderately corrosive environments. Evaluation methods include immersion tests (ASTM G31), electrochemical tests (ASTM G59) and field exposure, which need to be comprehensively evaluated in combination with standards (such as NACE MR0175). Optimizing processes (such as HIP 1350°C, 120 MPa) and surface coatings (PTFE/DLC) can significantly improve corrosion resistance.

8. Special Recommendation

CTIA GROUP LTD uses HIP sintering and advanced coating technology in the production of nickel-based cemented carbide corrosion-resistant seals, pump bodies and valves to provide high corrosion resistance solutions to meet the needs of harsh environments such as deep sea and chemical industries.

appendix:

Sintered and polished cemented carbide

Cemented carbide (such as WC+Co , WC+Ni) is widely used in mining tools, aviation tools, deep-sea seals and chemical pump bodies due to its high hardness (14002200 HV), high strength (1.82.8 GPa) and excellent wear resistance. The performance of cemented carbide depends not only on the sintered state formed by the sintering process , but also on the subsequent polishing. The sintered state determines the intrinsic properties of the material (such as density, porosity, microstructure), while the polishing process optimizes the surface quality (such as roughness Ra <0.2 µm), improving corrosion resistance, wear resistance and sealing performance.

This article combines national standards (such as GB/T 183762014, GB/T 51692013) and industry practices to introduce in detail the process, performance impact and optimization measures of cemented carbide sintering and polishing treatment, and appropriately recommends the production capabilities of CTIA GROUP LTD in the fields of nickel-based cemented carbide seals, pump bodies, etc.

1. Sintered cemented carbide

2.

Sintered state refers to the state of cemented carbide after high temperature sintering (13501500°C) without subsequent mechanical processing. It has a specific microstructure and properties and is suitable for direct use or further processing (such as polishing).

1.1 Sintering process and parameters

Vacuum sintering :
Application : Production of mining picks, moulds, seals (e.g. Ø 5150 mm).
Process :
Dewaxing : 200600 °C, heating rate 25°C/min, vacuum degree 10^{-2} Pa, H_2 flow rate 515 L/min, 24 hours, dewaxing rate>99.5%.
Sintering : 13501450°C, heating rate 510°C/min, vacuum degree 10^{-4} 10^{-5} Pa, keep warm for 24 hours.
Cooling : 1015°C/min (Ar forced cooling), to 100°C.
Properties : density 14.514.9 g/cm³ , porosity <0.01% (A02B00C00, GB/T 5169-2013), hardness 14001800 HV, surface roughness Ra 1.63.2 µm .

Hot Isostatic Pressing (HIP) :
Application : aviation tools, deep-sea seals, chemical pump bodies (e.g. Ø 100-500 mm).
Process :
Sintering : 13501450°C, heating rate 58°C/min, pressure 100150 MPa (Ar), keep warm for 13 hours.

Post-treatment : 13001350°C, 80100 MPa, 12 hours, porosity reduced to <0.001%.
Cooling : 1520°C/min (high pressure Ar) to 200°C.
Properties : density>99.9% (14.815.0 g/cm³) , porosity<0.001% (A00B00C00), hardness 18002200 HV, surface roughness Ra 0.81.6 µm .

Atmosphere sintering :
Application : large quantities of picks, seals (such as mechanical seal rings).
Process :
Dewaxing : 200500°C, heating rate 35°C/min, H2 flow 2050 L/min, O2 <10 ppm, 35 hours.
Sintering : 13001400°C, heating rate 510°C/min, H2/ Ar atmosphere, keep warm for 35 hours.
Cooling : 510°C/min (N2 protection), to 100°C.
Properties : density 14.414.8 g/cm³ , porosity <0.02% (A04B02C00), hardness 14001600 HV, surface roughness Ra 2.04.0 µm .

1.2 Sintered properties

Microstructure :
WC grains : fine grains (0.52 µm , HIP) or medium-coarse grains (25 µm , atmosphere sintering), uniform grain boundaries (ball milling for 1624 hours).
Bonding phase : Co/Ni (615%), evenly distributed, Ni-based corrosion resistance is better than Co (NACE MR0175).
Porosity : HIP <0.001%, vacuum <0.01%, atmosphere <0.02%, low porosity increases strength by 1020%.
performance :
Density : 14.415.0 g/cm³ (GB/T 38502015), deviation ±0.05 g/ cm³ .
Hardness : 14002200 HV (GB/T 79972017), deviation ±3050 HV.
Strength : flexural strength 1.82.8 GPa (GB/T 38512015).

Corrosion resistance : The corrosion rate of Ni-based (YN10) in seawater/H2S is <0.01 mm/y; the corrosion rate of Co-based (YG8) in HCl is 0.050.1 mm/y.
Surface : The sintered surface is rough (Ra 0.84.0 µm), with micropores/sintering marks, and medium wear resistance.
Limitations :
High surface roughness (Ra >0.8 µm) can easily cause stress concentration and reduce corrosion resistance by 1020%.
Micropores (>0.001%) may accelerate corrosion and affect sealing performance (leakage rate>10 $^{-6}$ mbar·L /s).

1.3 Sintered Application

Direct use : mining picks, molds, low surface roughness requirements (Ra 1.64.0 µm).
Need to be polished : deep-sea seals, chemical pump bodies, mechanical seal rings, Ra <0.2 µm ,

corrosion resistance increased by 1520%.

2. Carbide polishing

Polishing is the mechanical processing (such as grinding and polishing) of sintered cemented carbide to reduce surface roughness (Ra <0.2 μm), eliminate surface defects, and improve corrosion resistance and wear resistance. It is particularly suitable for high-precision seals, tools and pump bodies.

2.1 Polishing process and parameters

coarse grinding :
Tools : Diamond grinding wheel (grit size 100-200 μm , resin/vitrified bond).
parameter :
Rotational speed:1000-2000 rpm.
Feed rate: 0.010.05 mm/pass.
Coolant: water-based emulsion, flow rate 510 L/min.
Effect : The sintered surface marks (Ra 4.00.8 μm) are removed and the roughness is reduced to Ra 0.40.8 μm .
Time : 510 minutes per square centimeter.
fine grinding :
Tools : Diamond grinding wheel (grit size 2050 μm , metal bond).
parameter :
Rotational speed:15003000 rpm.
Feed rate: 0.0050.01 mm/pass.
Coolant: Oil-based or water-based, flow rate 815 L/min.
Effect : Roughness is reduced to Ra 0.20.4 μm and surface flatness is <0.005 mm.
Time : 1015 minutes per square centimeter.

polishing :
Tools : Diamond polishing paste (particle size 15 μm) + felt/polyurethane polishing disc.
parameter :
Rotational speed:500-1000 rpm.
Pressure: 0.10.5 MPa.
Polishing liquid: water-based or alcohol-based, flow rate 25 L/min.
Effect : Roughness is reduced to Ra <0.2 μm (mirror surface), surface is scratch-free, and flatness is <0.002 mm.
Time : 1530 minutes per square centimeter.

Ultra-precision polishing (optional) :
Tools : Nano-scale diamond suspension (particle size 0.10.5 μm) + soft polishing pad.
parameter :

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Rotational speed: 200500 rpm.
Pressure: 0.050.2 MPa.
Polishing liquid: deionized water, flow rate 13 L/min.
Effect : Roughness Ra <0.05 μm , suitable for high-precision seals (such as leakage rate $<10^{-6}$ mbar·L /s).
Time : 3060 minutes per square centimeter.

2.2 Polishing characteristics

Surface quality :
Roughness : Ra 0.050.2 μm (after polishing), compared with the sintered state (Ra 0.84.0 μm), it is reduced by 80-95%.
Flatness : <0.002 mm, suitable for high-precision sealing surfaces.
Defects : Remove sintered micropores/cracks and reduce surface stress concentration by 50%.

Performance improvements :
Corrosion resistance : Reduces corrosion starting points (such as micropores) and reduces the corrosion rate by 1520% in seawater/H2SO4 (ASTM G31).
Wear resistance : Friction coefficient reduced by 20-30% (increased by 50% after PTFE/DLC coating), wear loss <0.05 mm^3 / h (ASTM G65).
Sealing performance : leakage rate $<10^{-6}$ mbar·L /s (helium test, 15,000 psi), dynamic seal life increased by 3050%.
Fatigue life : Surface stress is uniform, and fatigue fracture resistance increases by 2030%.

Limitations :
High cost: polishing costs 520 yuan per square centimeter, and ultra-precision polishing costs 2050 yuan.
Processing difficulty: Cemented carbide has high hardness (>1400 HV), requires diamond tools, and has low processing efficiency (0.10.5 mm^3 / min).
Thermal influence: Excessive grinding may cause micro cracks and reduce corrosion resistance by 510%.

2.3 Polishing application

Deep sea seals
O-ring (Ø 5200 mm), Ra <0.2 μm , resistant to H2S/seawater, life span >1000 connections.
Chemical pump body
Mechanical seal ring (Ø 10150 mm), Ra <0.1 μm , resistant to H2SO4 (50%), life span >5000 hours.
Aviation tools
Cutting edge (Ra <0.05 μm), wear resistance increased by 30%, cutting life increased by 20%.

3. Comparison between sintered and polished

characteristic	Sintered	Polishing
Surface roughness (Ra)	0.84.0 μm	<0.050.2 μm
Porosity	<0.001%0.02% (HIP/atmosphere)	No change, surface micropores reduced
Corrosion resistance	Medium (seawater <0.01 mm/y, Ni-based)	Increased by 1520% (corrosion rate decreased)
Wear resistance	Wear rate 0.10.2 mm³ / h	Increased by 2050% (wear loss <0.05 mm³ / h)
Sealing performance	Leakage rate>10 $^{-6}$ mbar·L /s	<10 $^{-6}$ mbar·L /s
cost	Low (sintering 0.52 kWh/kg)	High (polishing 550 yuan/ cm²)
application	Picks, dies	Seals, pump bodies, cutting tools

Examples :

Sintered state : YG8 pick (Ø 20 × 330 mm), vacuum sintered (1450°C, 10 $^{-4}$ Pa), Ra 2.0 μm , porosity <0.01%, HCl (30%) corrosion resistance rate 0.08 mm/y, suitable for mining.

Polishing treatment : YN10 seal (Ø 50 mm), HIP sintering (1400°C, 120 MPa) + polishing (Ra <0.1 μm), porosity <0.001%, seawater corrosion rate <0.005 mm/y, leakage rate <10 $^{-6}$ mbar·L /s, suitable for deep sea.

4. Optimization suggestions for sintering and polishing

Sintering state optimization :

Powder : fine-grained WC (0.5-1.5 μm), porosity reduced by 50%, corrosion resistance increased by 10%.

Pressing : Cold isostatic pressing (250-300 MPa), the density of the blank increases by 5-10%, and the sintering shrinkage is uniform.

sintering :

HIP (1350°C, 120 MPa, 2 h): porosity <0.001%, density >99.9%.

Vacuum (10 $^{-5}$ Pa, H2 O2 <5 ppm): residual carbon <0.05%, corrosion resistance increased by 10%.

Temperature control : ±3°C, uniformity ±5°C, density deviation <±0.05 g/ cm³ .

Polishing process optimization :

Tools : Use high-concentration diamond polishing paste (15 μm) to increase polishing efficiency by 20%.

Parameters : low pressure (0.1-0.5 MPa) + low speed (500-1000 rpm) to avoid micro cracks.

Cooling : Water-based polishing liquid (flow rate 510 L/min), thermal impact reduction by 30%.

Post-treatment : PTFE/DLC coating, friction coefficient reduced by 20%, erosion and corrosion resistance increased by 3050%.

Equipment maintenance :

Sintering furnace : Molybdenum /tungsten heating elements are maintained every 4000 hours, pollution is reduced by 30% and porosity is reduced by 0.01%.

Polishing machine : Regularly calibrate the spindle (deviation <0.01 mm), and the flatness will

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increase by 10%.

Process Integration :

Sintering + polishing : HIP sintering (porosity <0.001%) + ultra-precision polishing (Ra <0.05 µm), corrosion resistance increased by 20%, sealing performance increased by 50%.

Quality inspection : SEM observation of surface defects, roughness meter (accuracy ±0.01 µm) to ensure Ra <0.2 µm .

5. Standards

GB/T 183762014 : Porosity <0.01%, uniformity >95%.
GB/T 51692013 : Porosity grade A02B00C00 (vacuum), A00B00C00 (HIP).
GB/T 38502015 : Density deviation <±0.1 g/ cm³ .
GB/T 38512015 : Flexural strength 1.82.8 GPa .
GB/T 7997-2017 : Hardness 1400-2200 HV.
NACE MR0175 : H2S/CO2 resistant, corrosion rate <0.01 mm/y.
ISO 4287 : Surface roughness Ra <0.2 µm (polished).

6. Conclusion

The sintered cemented carbide forms a microstructure with high density (>99%) and low porosity (<0.001%) through vacuum, HIP or atmosphere sintering, laying the foundation for wear resistance and corrosion resistance, and is suitable for rough surface applications such as mining picks. Polishing treatment reduces the surface roughness to Ra <0.2 µm , significantly improving corrosion resistance (increase of 1520%), wear resistance (increase of 2050%) and sealing performance (leakage rate $<10^{-6}$ mbar·L /s), suitable for deep-sea seals, chemical pump bodies and aviation tools. Optimizing the sintering process (such as HIP 1350°C, 120 MPa) and polishing parameters (such as low-pressure polishing) can further improve performance.

Recommendation : CTIA GROUP LTD adopts HIP sintering and ultra-precision polishing technology (Ra <0.1 µm) in the production of nickel-based cemented carbide seals, pump bodies and valves to ensure excellent corrosion resistance and sealing performance to meet the requirements of harsh environments such as deep sea and chemical industry.

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appendix:

Similarities and Differences between CIP and HIP in Cemented Carbide Pressing and Sintering

1. Cemented Carbide Manufacturing Background

Cemented carbide (WC-Co) is based on tungsten carbide (WC) and cobalt (Co) as a binder phase. It has high hardness (HV1000–1800), high wear resistance and excellent high temperature performance. It is widely used in cutting tools, mining picks and military components (such as armor-piercing bullets). Its manufacturing process includes powder preparation, pressing, sintering and post-processing, among which pressing and sintering are the key steps to determine the density, microstructure and performance of the material. Cold isostatic pressing (CIP) and hot isostatic pressing (HIP) are commonly used isostatic pressing technologies in cemented carbide manufacturing. They eliminate internal defects through uniform pressure and improve the density and mechanical properties of the material. This article analyzes in detail the principles, processes, advantages and disadvantages of CIP and HIP and their effects on the performance of cemented carbide.

2. Principles of Cold Isostatic Pressing (CIP) and Hot Isostatic Pressing (HIP)

2.1 Cold Isostatic Pressing (CIP)

Cold Isostatic Pressing (CIP) is a pressing technology that uses a liquid medium (such as water or oil) to apply uniform three-dimensional pressure to powder or preforms at room temperature or low temperature (usually <100°C). CIP transmits pressure to powder particles through a flexible mold (such as rubber or polyurethane), promoting particle rearrangement and initial densification to form a "green compact" with a certain strength. Its core principle is Pascal 's Principle, that is, when a liquid transmits pressure in a closed container, it is equal in all directions.

Cold Isostatic Pressing (CIP) process flow:
The WC-Co mixed powder is loaded into a flexible mold and sealed.
Place it in the high-pressure container of the CIP equipment and inject the liquid medium.
Apply high pressure (100–400 MPa) and maintain for several minutes.
After pressure relief, the green body is taken out and prepared for subsequent sintering.
Goal: To form a uniform and dense green body, reduce pressing defects (such as layer cracking and delamination), and provide a good foundation for sintering.

2.2 Hot Isostatic Pressing (HIP)

Hot Isostatic Pressing (HIP) is a process that uses an inert gas (such as argon) to apply three-dimensional isostatic pressure to the sintered cemented carbide blank at high temperature (usually 1000-2000°C) and high pressure (50-200 MPa). HIP is usually used as a post-processing step after

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sintering. Through the synergistic effect of high temperature and high pressure, it eliminates micropores, cracks and residual stress inside the material, and further improves the density and mechanical properties.

Hot Isostatic Pressing (HIP) process flow:

The pre-sintered or vacuum-sintered cemented carbide blank is placed in a closed container of the HIP equipment.

After evacuation, an inert gas (such as argon) is injected.

The temperature is raised to the target temperature while high pressure is applied and maintained for several hours.

Cool down and release the pressure, then take out the finished product.

Goal: Optimize the microstructure, eliminate internal defects, and improve the strength, toughness and wear resistance of cemented carbide.

3. Comparison of process parameters between CIP and HIP

The process parameters of CIP and HIP in cemented carbide manufacturing are significantly different, which affects their application scenarios and effects:

temperature:

CIP: Room temperature or low temperature (<100°C), no heating required, suitable for pressing stage.

HIP: High temperature (1200–1450°C for WC-Co), close to the sintering temperature, promotes atomic diffusion and defect healing.

pressure:

CIP: 100–400 MPa, higher pressure ensures that powder particles are tightly packed.

HIP: 50–200 MPa, lower pressure combined with high temperature is sufficient to eliminate micropores.

medium:

CIP: Liquid (water, oil), pressure is transmitted through a flexible mold.

HIP: Inert gas (argon, nitrogen) acts directly on the blank.

Processing stage:

CIP: Compression molding stage, acting on powder or preform blanks.

HIP: Post-sintering treatment stage, acting on the sintered billet.

Keep time:

CIP: A few minutes, rapid pressing and molding.

HIP: 1–4 hours, sufficient time to ensure defects are eliminated.

4. Equipment requirements for CIP and HIP

CIP equipment:
Structure: high pressure vessel, hydraulic pump, flexible mold (rubber or polyurethane).
Features: No need to withstand high temperatures, low equipment cost (about RMB 1-5 million), but requires high-pressure resistant design.
Maintenance: Liquid media needs to be replaced regularly and the mold is prone to wear.
Safety: High-pressure liquid operations require strict leakage prevention.

HIP equipment:
Structure: high temperature and high pressure container, gas compression system, heating furnace.
Features: Need to withstand high temperature and high pressure, high equipment cost (about RMB 10-30 million), and complex technology.
Maintenance: Gas purity requirements are high and the sealing system needs to be checked regularly.
Safety: Explosion-proof measures are required when operating with high-temperature and high-pressure gases.

5. Application scenarios of CIP and HIP

CIP Application:
Pressing molding: used for the green preparation of cemented carbide tools (such as milling cutters, drills), picks, and complex-shaped parts (such as nozzles).
Advantages: suitable for mass production, uniform molding, suitable for complex geometric shapes.
Limitations: Only provides initial densification, and subsequent sintering is required to further increase the density.

HIP Applications:
Post-sintering treatment: used for defect elimination and performance optimization of high-performance cemented carbides (such as aircraft engine blades and precision tools).
Advantages: Significantly improve density (close to 100% theoretical density), improve strength and toughness.
Limitations: High cost, suitable for high value-added products, not suitable for low-end parts.

6. Advantages and disadvantages of CIP and HIP

6.1 Advantages and Disadvantages of CIP

advantage:
Uniform pressure makes it suitable for complex shape molding and reduces layer cracking and delamination defects.
The equipment and operating costs are low, making it suitable for large-scale production.
The operation is simple and the process time is short (a few minutes).

shortcoming:
Only initial densification is provided, and the green density is low (60–70% of theoretical density).
It is impossible to eliminate microscopic pores and requires subsequent sintering.
High requirements for powder fluidity, uneven particle distribution may lead to inconsistent density.

6.2 Advantages and Disadvantages of HIP

advantage:
The synergistic effect of high temperature and high pressure brings the density to nearly 100%, significantly improving the hardness (+5–10%), strength (+10–20%) and toughness.
Eliminates micropores and cracks, improves microstructure, and extends component life (+20–50%).
Suitable for high-performance cemented carbide and meets the stringent requirements of aviation, military industry, etc.

shortcoming:
Equipment and operating costs are high and process time is long (several hours).
The initial quality of the blank is high, and pre-sintering defects may affect the HIP effect.
High energy consumption and great environmental impact (gas consumption, heating energy consumption).

7. Effects of CIP and HIP on cemented carbide properties

Impact of CIP:
Density: CIP green body density reaches 60-70% of theoretical density, with high uniformity, providing a good foundation for subsequent sintering.
Microstructure: Reduce pressing defects (e.g., pores, cracks), but cannot optimize grain size or binder phase distribution.
Performance: indirectly affects the final performance, mainly by improving the quality of the green body and reducing the uneven sintering shrinkage (<2%).

Impact of HIP:
Density: After HIP, the density of cemented carbide is close to 100% theoretical density, and the porosity is reduced to <0.1%.
Microstructure: Refined grains (WC particle size 0.5–1μm), optimized cobalt phase distribution , and reduced residual stress.
Performance: Hardness increased by 5–10% (HV1600–1800), flexural strength increased by 10–20% (2000–2500 MPa), wear resistance and fatigue life significantly extended.

8. Synergy between CIP and HIP in cemented carbide manufacturing
In cemented carbide manufacturing, CIP and HIP are usually used in combination to form a process route of "CIP pressing + vacuum sintering + HIP post-treatment":

CIP: Ensure uniform density of green bodies during the pressing stage, reducing shrinkage and defects during sintering.
Vacuum sintering: Through high temperature (1350–1450°C) liquid phase sintering, the blank reaches 90–95% of the theoretical density.

HIP: As a post-treatment, it further eliminates micropores and cracks, optimizes the microstructure, and meets high performance requirements. This synergistic process significantly improves the quality of cemented carbide. For example, the fatigue resistance of WC-Co parts used for aviation turbine blades is improved by 30% and the service life is extended by 50% after CIP+HIP process.

9. Summary table: Similarities and differences between CIP and HIP

The following table summarizes the similarities and differences between CIP and HIP in cemented carbide manufacturing:

project	Cold Isostatic Pressing (CIP)	Hot Isostatic Pressing (HIP)
principle	Room temperature liquid medium transmits uniform three-dimensional pressure	High temperature and high pressure inert gas exerts three-dimensional pressure
temperature	Room temperature or low temperature (<100°C)	High temperature (1200–1450°C)
pressure	100–400 MPa	50–200 MPa
medium	Liquid (water, oil)	Inert gas (argon)
Processing stage	Press molding (green)	Post-sintering treatment (finished product)
Equipment cost	Lower (RMB 1–5 million)	Higher (RMB 10–30 million)
Process time	A few minutes	1–4 hours
Application Scenario	Cutters, picks, complex shapes	Aviation and military high-performance parts
advantage	Uniform molding, low cost, suitable for large quantities	High density, excellent performance, few defects
shortcoming	Limited density, requires subsequent sintering	High cost and high energy consumption
Performance impact	Improve green body quality and indirectly improve performance	Significantly improve density, hardness, strength and toughness
Typical products	Milling cutters, drill bits, nozzles	Turbine blades, precision tools

illustrate:
Principle: CIP is based on Pascal's principle, and HIP combines high-temperature atomic diffusion.
Process parameters: temperature, pressure and medium determine the application stage.
Equipment and cost: reflects technical complexity and economic feasibility.
Performance impact: CIP optimizes green parts, while HIP improves finished product quality.
Data source: Based on cemented carbide manufacturing standards and USGS 2024 report ⁇ web:9,23 ⁇ .

10. Conclusion

Cold isostatic pressing (CIP) and hot isostatic pressing (HIP) are complementary isostatic pressing technologies in cemented carbide manufacturing, playing a key role in the pressing and sintering post-processing stages, respectively. CIP forms a uniform green body through a room temperature high-pressure liquid medium, which is low-cost and high-efficiency, suitable for mass production of complex-shaped parts, but the density is limited and requires subsequent sintering optimization. HIP uses high-temperature and high-pressure gas to eliminate micropores and cracks, significantly improving the density, hardness and toughness of cemented carbide, and is suitable for high-performance aviation and military applications, but the cost is high and the process is complex. In actual production, CIP is used in combination with HIP. Through the "CIP pressing + vacuum sintering + HIP post-processing" process, the performance of cemented carbide can be maximized to meet the stringent requirements of cutting tools, mining picks and precision parts. In the future, with the development of nano-cemented carbide and green manufacturing technology, the process optimization of CIP and HIP (such as reducing HIP energy consumption and improving CIP mold durability) will further promote the progress of the cemented carbide industry.

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30 Years of Cemented Carbide Customization Experts

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Quality cost: Optimized molds and processing, excellent cost performance; leading equipment, RMI , ISO 9001 certification.

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