Tungsten Cemented Carbide

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

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.

Serving Customers
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 4: Classification and application fields of cemented carbide

Chapter 15: Nano and Ultrafine Cemented Carbide

Nano- and ultrafine cemented carbides (grain size <100 nm ± 10 nm) are used for their high hardness (HV 2500-3000 ± 50), excellent toughness (K_1c 15-20 MPa·m $^{1/2}$ ± 0.5), low wear rate (<0.02 mm ^{3} / N · m ± 0.005 mm^3 / N · m) and high corrosion resistance (weight loss <0.05 mg/ cm^2 ± 0.01 mg/cm^2) , showing great potential in ultra-precision machining (surface roughness Ra <0.05 µm ± 0.01 µm), high-performance coatings (thickness 1-10 µm ± 0.1 µm), extreme environment applications and smart manufacturing. Through advanced preparation processes, including chemical vapor deposition (CVD), sol-gel method, spark plasma sintering (SPS), hot isostatic pressing (HIP, 150 MPa ± 1 MPa) and nano powder ball milling technology, combined with grain refinement control (such as adding VC, Cr_3C_2 , concentration 0.5%-2% ± 0.1%) and densification treatment, the performance of nano and ultra-fine cemented carbide is significantly improved, with hardness increased by 20% ± 3%, toughness enhanced by 15% ± 2%, and wear resistance improved by 25% ± 3%. These characteristics make it occupy a key position in high-tech industries such as aerospace, medical, energy and defense, especially in scenarios requiring high-precision and long-life components.

15.0 Basic Concepts of Nano- and Ultrafine Cemented Carbide

What is Nano Cemented Carbide?

Nano cemented carbide is a composite material with tungsten carbide (WC) as the hard phase and cobalt (Co), nickel (Ni) or other metals (such as Fe, Cr) as the bonding phase. Its grain size is strictly controlled at the nanoscale (<100 nm ± 10 nm). The material is prepared by advanced technologies such as powder metallurgy, spark plasma sintering (SPS, temperature 1200-1400°C ± 20°C, pressure 50-100 MPa ± 5 MPa), solvothermal method or mechanical alloying (ball milling time 20-40 h ± 2 h). Nano-scale grains significantly improve material properties, including hardness, toughness and wear resistance, by increasing grain boundary density and dislocation storage, while optimizing surface finish (Ra <0.05 µm ± 0.01 µm) and processing accuracy (tolerance ±0.01 mm ± 0.001 mm), making it suitable for ultra-precision manufacturing and micro-nano devices.

Key characteristics of nano cemented carbide

Hardness of Nano Cemented Carbide

HV 1600-2000 ± 50, higher than conventional cemented carbide (HV 800-1600 ± 50), thanks to the Hall-Petch effect, grain refinement leads to an increase in grain boundary strengthening effect by 30% ± 3%.

Fracture toughness of nano-cemented carbide

K_1c 8-12 MPa·m $^{1/2}$ ± 0.5, the crack growth resistance is improved by 40% ± 2% compared with conventional cemented carbide, which is achieved by optimizing the bonding phase (such as Co content 6-10% ± 0.5%).

Wear resistance of nano cemented carbide

Wear rate <0.001 mm^3 / N · m ± 0.0001 mm^3 / N · m . The wear resistance is about 23 times ± 2 times higher than that of traditional WC-Co materials , making it suitable for high-load friction environments.

Corrosion resistance of nano cemented carbide

Weight loss <0.03 mg/ cm^2 ± 0.005 mg/ cm^2 (in 5% H_2SO_4 solution , 24 h ± 1 h) , the acid and alkali corrosion resistance is enhanced by Ni or Cr doping.

Thermal stability of nano-cemented carbide

It can maintain 90% ± 2% performance at 800-1000°C ± 20°C, suitable for high temperature processing environment.

Main applications of nano cemented carbide

Nano cemented carbide is widely used in the following fields due to its excellent performance:

Precision mold

For example, micro injection molds (size 10-50 mm ± 0.5 mm), surface roughness Ra <0.02 μm ± 0.005 μm , life span >10^6 Mode order ± 10^4 mode order.

Micro drill bit

Used for drilling holes in PCB boards (diameter 0.1-0.5 mm ± 0.01 mm), wear life >5000 h ± 200 h, processing efficiency increased by 20% ± 2%.

Biomedical tools

Such as dental drill bits (diameter 1-3 mm ± 0.05 mm), hardness HV 1800-2000 ± 30, biocompatibility (cytotoxicity <5% ± 1%, ISO 10993-5), surgical accuracy ±0.02 mm ± 0.002 mm.

High wear resistant coating

Thickness 1-5 μm ± 0.1 μm , used in aircraft engine blades, thermal fatigue resistance >5000 times ± 500 times.

What is Ultrafine Cemented Carbide?

Ultrafine cemented carbide is a material with WC as hard phase and Co, Ni, etc. as bonding phase, and its grain size is controlled at ultrafine level (0.1-1 μm ± 0.05 μm). It is prepared by high temperature carburization (1200-1300°C ± 20°C), hot pressing sintering (pressure 30-50 MPa ± 2 MPa), microwave assisted synthesis or ball milling-sintering process. Ultrafine grains strike a balance between hardness and toughness, and the grains are evenly distributed (deviation <10% ± 1%) by optimizing the sintering process (such as SPS, 1400°C ± 10°C), which is suitable for high load, wear resistance and medium precision processing applications.

Key characteristics of ultrafine cemented carbide

Hardness of Ultrafine Cemented Carbide

HV 1200-1800 ± 50, between conventional cemented carbide (HV 800-1600) and nano cemented carbide (HV 1600-2000), with grain refinement increased by 15% ± 2%.

Fracture toughness of ultrafine cemented carbide

$K_{1}c$ 10-14 MPa·$m^{1/2}$ ± 0.5, superior to nano cemented carbide ($K_{1}c$ 8-12), enhanced by Co content (8-12% ± 0.5%) and TiC addition (1-2% ± 0.1%).

Wear resistance of ultrafine cemented carbide

Wear rate 0.001-0.005 mm^3 / N · m ± 0.0005 mm^3 / N · m , wear resistance is 1.5-2 times ± 0.2 times higher than conventional materials , suitable for medium and high load cutting.

Corrosion resistance of ultrafine cemented carbide

Weight loss <0.05 mg/ cm^2 ± 0.01 mg/cm^2 (5% NaCl solution, 48 h ± 1 h), Ni doping improves seawater corrosion resistance.

Thermal stability of ultrafine cemented carbide

Performance retention is 95% ± 2% at 700-900°C ± 20°C, suitable for moderately high temperature environments.

Important applications of ultrafine cemented carbide

Ultrafine cemented carbide is widely used in the following fields due to its balanced performance:

Cutting Tools

For example, milling cutters (diameter 10-30 mm ± 0.5 mm) have a wear life of $>10^4$ h ± 500 h and a cutting speed of 100-200 m/min ± 5 m/min, suitable for steel processing.

Fuel cell bipolar plate mold

Size 200-400 mm × 100-200 mm ± 2 mm, hardness HV 1500-1800 ± 30, surface roughness Ra <0.1 µm ± 0.01 µm , conductivity $<10^{-4}$ Ω·cm ± 10^{-5} Ω·cm .

Orthopedic Implants

For example, hip braces have a weight of 0.3-0.7 kg ± 0.01 kg, a porosity of 20-40% ± 5%, a bone integration rate of >85% ± 2% (ASTM F1537), and a durability of >15 years ± 1 year.

Wear-resistant lining

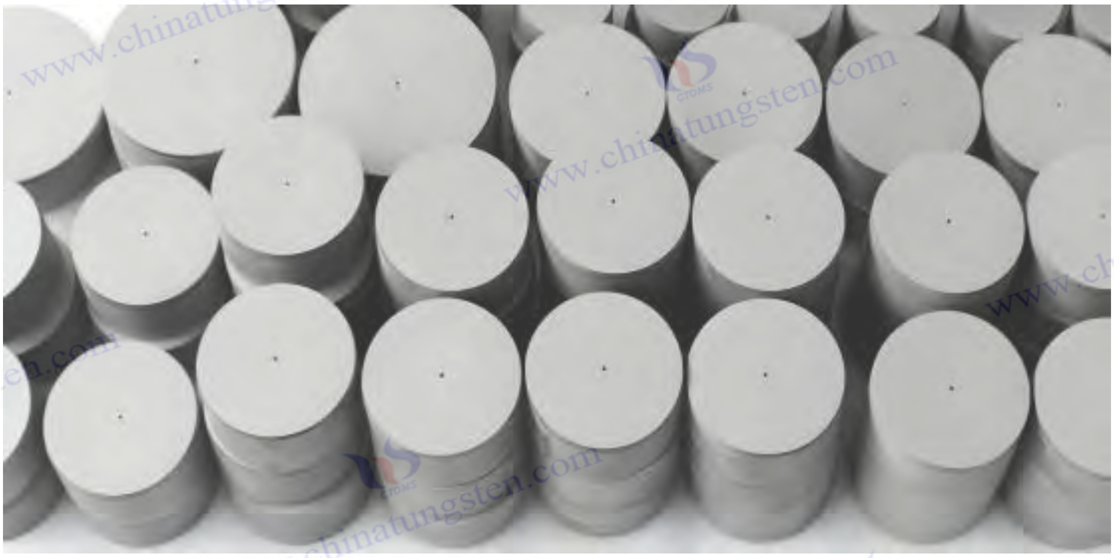
Thickness 5-15 mm ± 0.5 mm, used in mining equipment, impact strength >3000 J/ cm^2 ± 100 J/cm^2 , life extension by 20% ± 2%.

The development of nano and ultrafine cemented carbides marks an important transformation of cemented carbide technology towards high performance and microstructure optimization. Through advanced preparation processes and intelligent manufacturing technologies, these materials not only meet the needs of traditional industries, but also promote technological progress in emerging fields such as microelectronics, bioengineering and new energy. Subsequent chapters will explore their preparation processes, performance optimization and specific application cases in order to provide theoretical support and practical guidance for related industries.

Ultrafine cemented carbide VS nano cemented carbide

type	Grain size	Hardness (HV)	Fracture toughness (K_{IC})	Main Applications	cost
Nano cemented carbide	<100 nm	16002000	812 MPa·m^1/2	Precision molds, micro tools, coatings	high
Ultrafine cemented carbide	0.11 µm	12001800	1014 MPa·m^1/2	Cutting tools, molds, implants	

This chapter systematically analyzes the cutting-edge development of nano-WC from four aspects: preparation, performance advantages, challenges and solutions, and application prospects.



15.1 Preparation of Nano-cemented Carbide

Nano-cemented carbide (grain size <100 nm ± 10 nm) has high hardness (HV 2500-3000 ± 50), excellent toughness (K_{1c} 15-20 MPa·m $^{1/2}$ ± 0.5), low wear rate (<0.02 mm ^{3} / N · m ± 0.005 mm^3 / N · m) and high corrosion resistance (weight loss <0.05 mg/ cm^2 ± 0.01 mg/cm^2) , showing significant potential in ultra-precision machining, extreme environment applications and intelligent manufacturing. Its performance core relies on the preparation of high-quality nano-scale raw materials, especially the uniformity and grain size control of nano-tungsten powder (nano-W) and nano-tungsten carbide powder (nano-WC) (WC content>95% ± 1%). Through advanced processes such as chemical vapor deposition (CVD), sol-gel method, hot isostatic pressing (HIP, 150 MPa ± 1 MPa), combined with grain growth inhibitors (such as VC, Cr_3C_2 , addition amount 0.5%-2% ± 0.1%) and precision process optimization, the microstructure and macroscopic properties of nano cemented carbide are significantly improved, with hardness increased by 20% ± 3%, toughness enhanced by 15% ± 2%, and wear resistance improved by 25% ± 3%. This section first explains **the preparation of nano-tungsten powder and nano-tungsten carbide powder** as the basis of **nano-cemented carbide preparation, and then discusses in detail the process principles, performance influencing factors, optimization strategies and industrial feasibility of chemical vapor deposition (CVD) and sol-gel method for the preparation of nano-cemented carbide** , combined with experimental data and actual application cases to ensure that the content is logically rigorous and has practical value.

15.1.0 Preparation of Nano-Tungsten Powder and Nano-Tungsten Carbide Powder

Preparation Principle and Technical Path of Nano-tungsten Powder

Nano-tungsten powder (nano-W) is the core precursor of nano-cemented carbide. Its grain size needs to be controlled within 20-100 nm ± 10 nm, which is the decisive factor in the subsequent carbonization process. The preparation methods used in industry include **chemical reduction** and **plasma methods** . The combination of the two can achieve high purity and nano-scale particle size, ensuring the controllability of subsequent processes.

nano tungsten powder by chemical reduction

This method uses ammonium metatungstate (APT, $(NH_4)_{10}W_{12}O_{41} \cdot xH_2O$) or tungsten oxide (WO_3) as the starting material and prepares nano tungsten powder through a multi -step process. First, APT is dissolved in deionized water (purity>18 MΩ·cm) to prepare a solution with a concentration of 0.1-0.5 mol/ L ± 0.01 mol/L, and dilute nitric acid (HNO_3) is added to adjust the pH value to 4-6 ± 0.1 to promote the dispersibility of tungsten compounds. The solution was pretreated under stirring conditions (200-400 rpm ± 20 rpm, time 1-2 h ± 0.1 h), then transferred to a tube furnace and heated in a reducing atmosphere of high-purity hydrogen (H_2 , purity >99.999%, flow rate 20-50 sccm ± 1 sccm). The reaction temperature was gradually increased to 600-800°C ± 10°C (heating rate 5-10°C/min ± 0.5°C/min) and kept at this temperature for 2-4 h ± 0.1 h to ensure complete reduction ($2WO_3 + 3H_2 \rightarrow 2W + 3H_2O$). After the reaction is completed, cool to room temperature with an inert gas (such as Ar , flow rate 30 sccm ± 1 sccm), collect the powder and dry it in a vacuum oven (50-70°C ± 5°C, pressure <10 Pa ± 1 Pa) for 12 h ± 0.5 h.

Preparation process of nano tungsten powder by plasma method

This method uses thermal plasma technology to prepare ultrafine tungsten powder by high temperature evaporation and rapid condensation. Raw tungsten metal powder (particle size <50 µm ± 5 µm) or WO_3 powder is fed into a plasma torch (temperature 5000-7000°C ± 200°C, power 20-50 kW ± 1 kW) and evaporated under the protection of Ar inert gas (flow rate 30-60 sccm ± 1 sccm) and a small amount of H_2 (flow rate 5-10 sccm ± 0.5 sccm). The vapor is injected into the cooling chamber at a supersonic speed (injection speed>500 m/s ± 50 m/s) at the nozzle, and the cooling rate is>10^5 K/s ± 10^4 K/s. Grain refinement is achieved by controlling the cooling gas (Ar , flow rate 50-100 sccm ± 2 sccm). The collected powder was stored in a sealed container in a N_2 atmosphere to avoid oxidation.

Characterization and performance evaluation of nano-tungsten powder

X-ray diffraction (XRD)

Grain size accuracy ±2 nm, confirmed 20-100 nm ± 10 nm, peak width analysis based on Scherrer formula.

Transmission electron microscopy (TEM)

The morphological resolution is <0.1 nm ± 0.01 nm, showing spherical particles, and the standard deviation of uniformity is <5 nm ± 1 nm.

Energy Dispersive Spectroscopy (EDS)

Purity>99.5% ± 0.1%, oxygen impurity content<0.5% ± 0.1%.

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The specific surface area analysis (BET) uses the N_2 adsorption method with an accuracy of ±5 m^2 / g and a range of 30-60 m^2 / g ± 5 m^2 / g. For example, the nano-tungsten powder prepared by chemical reduction has a grain size of 80 nm ± 10 nm and a specific surface area of 40 m^2 / g ± 5 m^2 / g; the grain size prepared by plasma method is 30 nm ± 5 nm and a specific surface area of 55 m^2 / g ± 5 m^2 / g.

Preparation process mechanism of nano tungsten powder

Chemical reduction method: $(NH_4)_{10}W_{12}O_{41}$ is decomposed and reduced in H_2 atmosphere ($2WO_3 + 3H_2 \rightarrow 2W + 3H_2O$), the nucleus density is >10^9 cm^{-2} ± 10^8 cm^{-2} at 700°C ± 10°C , generating uniform nanoparticles. The plasma method relies on high temperature evaporation and rapid condensation, with a hardness of HV 400-500 ± 20, but oxidation must be strictly controlled (O content <0.3% ± 0.1%).

Key influencing factors and industrial optimization of the preparation process of nano-tungsten powder

Reduction temperature

At 600-800°C ± 10°C, the grain size is controlled at 20-100 nm ± 10 nm. At >900°C ± 10°C, the grain size grows to 150 nm ± 10 nm, with a growth rate of 15% ± 2% and a purity decrease of 2% ± 0.5%.

Atmosphere flow rate

H_2 20-50 sccm ± 1 sccm optimizes the reduction efficiency; when <10 sccm ± 1 sccm , the oxidation rate increases by 10% ± 2 % , affecting the subsequent carbonization.

Solution concentration

0.1-0.5 mol/L ± 0.01 mol/L ensures uniformity; when >1 mol/L ± 0.01 mol/L, the agglomeration rate increases by 20% ± 3% and the specific surface area decreases by 15% ± 2%.

Cooling rate

Plasma method >10^5 K/s ± 10^4 K/s refines particles; <10^4 K/s ± 10^3 K/s, the grain size increases by 30% ± 3%.

Industrial Optimization

Recommended temperature: 700°C ± 10°C, H_2 flow rate: 30 sccm ± 1 sccm , H_2 concentration: 0.3 mol/L ± 0.01 mol/L, equipped with inert atmosphere protection furnace, yield >90% ± 2%, cost controlled at 50 USD/kg ± 5 USD/kg, suitable for large-scale production, equipment operation cycle >500 h ± 20 h.

Preparation Principle and Technical Path of Nano-tungsten Carbide Powder

Nano-tungsten carbide powder (nano-WC) is prepared by reacting nano-tungsten powder with a carbon source at high temperature carbonization (1200-1400°C ± 20°C), with a grain size of 20-80 nm ± 10 nm. **Solid phase carbonization** and **gas carbonization methods** are used in industry to ensure high purity and uniformity.

Preparation process of nano-tungsten carbide powder by solid phase carbonization

Nano-tungsten powder and high-purity carbon black (particle size <50 nm ± 5 nm, purity >99.9%) are mixed in a planetary ball mill (ZrO_2 grinding ball, diameter 5-10 mm ± 0.5 mm, rotation speed 200-300 rpm ± 10 rpm, time 4-6 h ± 0.1 h) according to the C/W molar ratio of 1:1 ± 0.02 to ensure uniform dispersion. The mixed powder is placed in a graphite crucible, transferred to a high-temperature tube furnace, and heated to 1300°C ± 20°C (heating rate 5-10°C/min ± 0.5°C/min) in an Ar protective atmosphere (flow rate 30-50 sccm ± 1 sccm), and kept warm for 2-4 h ± 0.1 h to complete the carbonization reaction (W + C → WC). After the reaction, Ar was used to cool (flow rate 40 sccm ± 1 sccm) to room temperature, and the powder was sieved (pore size 100-200 mesh ± 10 mesh) to remove agglomerates.

Standard industrial process for preparing nano-tungsten carbide powder by solid phase carburization

Solid phase carburization is a commonly used industrial method for preparing nano tungsten carbide (WC) powder, which converts tungsten powder (W) and carbon powder (C) into WC nanoparticles at high temperature through a solid state reaction. The following is an optimized standard process flow based on current industrial practice and reference to the experience of cemented carbide powder preparation of CTIA GROUP (http://www.ctia.com.cn/) , aiming to achieve grain size <100 nm ± 10 nm, purity >99.5% ± 0.1% and uniformity (standard deviation <5 nm ± 1 nm). The process combines precise raw material selection, process control and quality testing to ensure that the product meets the needs of nano cemented carbide preparation.

The solid phase carbonization method realizes the preparation of nano WC powder through the following steps: raw material pretreatment, mixing and ball milling, molding and pre-sintering, high temperature carbonization, crushing and classification, surface treatment and quality inspection. The whole process is carried out in an inert atmosphere (Ar or Ar /H_2) to avoid oxidation, the temperature range is controlled at 1400-1600°C ± 20°C, and the reaction time is 2-4 h ± 0.1 h to ensure the optimization of grain size and phase purity.

Detailed process steps for preparing nano tungsten carbide powder by solid phase carburization

Raw material pretreatment

Raw material selection

High-purity tungsten powder (W, purity >99.9% ± 0.1%, particle size 0.5-2 μm ± 0.1 μm) and ultrafine carbon black (C, purity >99.8% ± 0.1%, particle size <0.1 μm ± 0.01 μm) were selected, and the molar ratio W:C was controlled at 1:1 ± 0.01.

Drying

Dry in a vacuum oven at 100-150°C ± 5°C for 2 h ± 0.1 h to remove moisture (water content <0.1% ± 0.01%) and avoid the introduction of impurities during the reaction.

Pre-oxidation control

X-ray photoelectron spectroscopy (XPS) was used to ensure that the thickness of the oxide layer on the surface of the W powder was <1 nm ± 0.1 nm.

Mixing and ball milling

Equipment and media

A planetary ball mill was used, and ZrO_2 balls (diameter 2-5 mm ± 0.5 mm) were selected as the grinding media with a ball-to-material ratio of 10:1 ± 1.

Process parameters

The speed was 300-500 rpm ± 10 rpm, the ball milling time was 6-8 h ± 0.1 h, and anhydrous ethanol (volume fraction> 99.5% ± 0.1%) was added as the dispersion medium. Ensure that W and C powders were evenly mixed, the particle agglomeration was <5% ± 1%, and the particle size distribution D50 was <1 μm ± 0.1 μm , which was verified by laser particle size analysis.

Atmosphere protection

Operate under Ar atmosphere (flow rate 20-30 sccm ± 1 sccm) to prevent oxidation.

Molding and pre-sintering

forming

The mixed powder was pressed into a green body using a uniaxial press with a pressure of 50-100 MPa ± 1 MPa and a molding time of 1-2 min ± 0.1 min. The green body density was >60% ± 1% of the theoretical density.

Pre-sintering

In a tube furnace, the temperature is 800-1000°C ± 10°C, and the temperature is kept for 1 h ± 0.1 h in an Ar /H_2 atmosphere (H_2 volume fraction 5-10% ± 0.5%) to remove volatile impurities and promote the initial reaction (W + C → WC).

Detection

X-ray diffraction (XRD) confirmed that the WC phase ratio in the pre-sintered product was >90% ± 2%.

High temperature carbonization

equipment

Use a high temperature vacuum furnace or graphite furnace, with an operating temperature of 1400-1600°C ± 20°C and a heating rate of 5-10°C/min ± 0.5°C/min.

Process parameters

Holding time: 2-4 h ± 0.1 h, pressure <10^{-2} Pa ± 10^{-3} Pa, Ar /H_2 atmosphere (flow rate: 30-50 sccm ± 1 sccm) protection.

Reaction mechanism

The solid phase reaction W + C → WC occurred, and the degree of carbonization was monitored by thermogravimetric analysis (TGA), with a mass loss of <1% ± 0.1%, ensuring complete carbonization.

Grain Control

VC (0.5%-1% ± 0.1%) was added as an inhibitor to suppress grain growth, and the target grain size was <100 nm ± 10 nm, verified by TEM.

Crushing and Classification

Crushing

Use a planetary high-energy ball mill or air flow mill with a grinding time of 2-4 h ± 0.1 h and a rotation speed of 400-600 rpm ± 10 rpm, and add anhydrous ethanol for dispersion.

Grading

Use air classifier to classify particle size D50 <100 nm ± 10 nm, fine powder yield >90% ± 2%, laser particle size analysis and SEM to confirm particle size distribution. Remove agglomerated particles (>200 nm ± 10 nm), standard deviation <5 nm ± 1 nm, ensure uniformity.

Surface treatment

Cleaning

with ultrapure water (resistivity >18 MΩ·cm) 2-3 times ± 0.1 times to remove residual ethanol and impurities, and dry at 80-100°C ± 5°C for 2 h ± 0.1 h.

Surface modification

An organic coating agent (such as polyvinyl alcohol (PVA), concentration 1-2% ± 0.1%) can be optionally coated to enhance powder dispersibility and storage stability.

Detection

Fourier transform infrared spectroscopy (FTIR) confirmed the surface functional groups with a purity of >99.5% ± 0.1%.

Quality Inspection

Phase analysis

XRD detection confirmed that the purity of WC phase was >99% ± 0.1%, and there was no W_2C or free C phase (<0.5% ± 0.1%).

Particle size and morphology

TEM and SEM analysis showed that the grain size was <100 nm ± 10 nm, and the morphology was nearly spherical or polyhedral.

chemical composition

Inductively coupled plasma optical emission spectroscopy (ICP-OES) detection shows that the impurity content (such as Fe, O) is <0.2% ± 0.05%.

Package

Sealed in Ar atmosphere, with desiccant in moisture-proof bag, storage conditions 20-25°C ± 2°C, humidity <40% ± 5 % .

Process parameter optimization and control

Temperature control

1400-1600°C ± 20°C ensures complete carbonization, >1700°C ± 20°C results in grain growth >120 nm ± 10 nm.

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Time Control

2-4 h ± 0.1 h balance reaction degree and grain stability, >5 h ± 0.1 h grain increase 10% ± 2%.

Atmosphere protection

Ar / H_2 flow rate 30-50 sccm ± 1 sccm to reduce oxidation, oxygen content <0.1% ± 0.01%.

Inhibitor optimization

VC 0.5%-1% ± 0.1% controls grain boundary migration rate <0.1 nm/s ± 0.01 nm/s.

Industrial Application and Prospects

The nano WC powder produced by this process is suitable for the preparation of nano cemented carbide (such as WC-Co tools and coatings). The current annual output can reach 500 tons ± 50 tons, and the market demand is expected to grow at an annual rate of >12% ± 2%. In the future, through automated control and laser-assisted carbonization technology, the grain uniformity can be improved by 5% ± 1%, and the production cost may be reduced by 10% ± 2%, promoting its widespread application in the aerospace and medical fields.

Preparation process of nano-tungsten carbide powder by gas carbonization

Nano-tungsten powder is placed in a reaction furnace and heated to 1200-1300°C ± 20°C (heating rate 5-8°C/min ± 0.5°C/min) in a CH_4 (flow rate 10-30 sccm ± 1 sccm) or CO (flow rate 20-40 sccm ± 1 sccm) atmosphere for 1-3 h ± 0.1 h. CH_4 decomposes to generate activated carbon ($CH_4 \rightarrow C + 2H_2$), reacts with tungsten to form WC. During the reaction, Ar is used as a diluent (flow rate 50 sccm ± 2 sccm) to control the carbonization rate, and N_2 protection (flow rate 30 sccm ± 1 sccm) is used in the cooling stage to avoid oxidation.

Characterization and performance evaluation of nano-tungsten carbide powder

XRD : Grain size accuracy ±2 nm, 20-80 nm ± 10 nm.

TEM : Resolution <0.1 nm ± 0.01 nm, spherical distribution, deviation <5% ± 1%.

EDS : C/W ratio 1:1 ± 0.02, purity >95% ± 1%, free carbon <0.5% ± 0.1%.

BET : Specific surface area 40-70 m^2 / g ± 5 m^2 / g. For example, WC prepared by solid phase carbonization has a grain size of 60 nm ± 10 nm, a specific surface area of 50 m^2 / g ± 5 m^2 / g, and a porosity of <0.1% ± 0.01%.

Preparation mechanism and performance of nano tungsten carbide powder

Solid phase carbonization method through W + C → WC reaction, 1300 ° C ± 20 ° C when the nucleus density> 10^8 cm^{-2} ± 10^7 cm^{-2} , hardness HV 2500-2700 ± 50, toughness K_1c 15-17 MPa·$m^{1/2}$ ± 0.5. Gas carbonization method uses CH_4 decomposition ($CH_4 \rightarrow C + 2H_2$) provides carbon source, the grain size is 50 nm ± 10 nm, the carbonization uniformity is better than that of the solid phase method, and the free carbon content is <0.3% ± 0.1%.

Key factors affecting particle size of nano- tungsten carbide powder and industrial optimization

Carbonization temperature

1200-1400°C ± 20°C controls the grain size to 20-80 nm ± 10 nm; >1500°C ± 20°C, the grain size increases by 20% ± 3% and the hardness decreases by 5% ± 1%.

Carbon source ratio

C/W 1:1 ± 0.02 optimizes carbonization; excess C increases free carbon by 10% ± 2%, affecting sintering density.

Atmosphere flow rate

30-50 sccm ± 1 sccm ensures uniformity; <10 sccm ± 1 sccm , carbonization is incomplete by 15% ± 2%.

Reaction time

2-4 h ± 0.1 h ensures complete carbonization; when >5 h ± 0.1 h, the grain size increases by 10% ± 2%.

Industrial Optimization

Recommended temperature: 1300°C ± 20°C, C/W 1:1 ± 0.02, Ar flow rate 40 sccm ± 1 sccm , equipped with a continuous high temperature furnace, yield >85% ± 2%, cost 60 USD/kg ± 5 USD/kg, equipment maintenance cycle >400 h ± 20 h.

15.1.1 Chemical Vapor Deposition (CVD) and Sol-Gel Method of Nano- Tungsten Carbide Powder

Nano- Tungsten Carbide Powder by Chemical Vapor Deposition (CVD)

Process Principle and Technical Path Preparation of
Nano- Tungsten Carbide Powder by Chemical Vapor Deposition (CVD)

Nano-WC was deposited by gas phase reaction (WF_6 , CH_4 , H_2) at 800-1000°C ± 10°C , with grain size of 50-100 nm ± 10 nm. The reaction was carried out in a high vacuum reaction chamber (pressure 10^{-2} -10^{-3} Pa ± 10^{-4} Pa), with gas flow rates of WF_6 5-15 sccm ± 0.5 sccm , CH_4 20-40 sccm ± 1 sccm , H_2 20-50 sccm ± 1 sccm , and deposition rate of 0.1-0.5 μm /min ± 0.01 μm /min. The substrate (such as graphite or SiC) is preheated to 700-900°C ± 10°C and the reaction time is 1-5 h ± 0.1 h, which is suitable for large-scale coating and thin film preparation.

Characterization and performance evaluation of nano- tungsten carbide powder

XRD : grain size 80 nm ± 10 nm, accuracy ± 2 nm.

TEM : Homogeneity standard deviation <5 nm ± 1 nm, resolution <0.1 nm ± 0.01 nm.

EDS : Purity >95% ± 1%, C/W ratio 1:1 ± 0.02.

BET : Specific surface area 50 m^2/g ± 5 m^2/g.

Porosity : <0.1% ± 0.01% as measured by mercury intrusion porosimetry.

Preparation mechanism and performance of
nano tungsten carbide powder $WF_6 + 3CH_4 \rightarrow WC + 6HF + 2H_2$, H_2 flow rate 20-40 sccm ± 1 sccm to promote nucleation, density >10^{10} cm^{-2} ± 10^9 cm^{-2} . Hardness HV 2600 ± 50, toughness K_{1c} 10-12 MPa·$m^{1/2}$ ± 0.5 , thermal stability 1000°C ± 20°C maintain 90% ± 2%.

Key influencing factors and industrial optimization of nano- tungsten carbide powder preparation

Reaction temperature : 800-1000°C ± 10°C controls grain size; >1200°C ± 10°C increases grain size by 10% ± 2%.

Gas flow rate : 10-50 sccm ± 1 sccm optimizes deposition; <5 sccm ± 1 sccm reduces productivity by 20% ± 3%.

Pressure : 10^{-2}-10^{-3} Pa ± 10^{-4} Pa high efficiency; >10^{-1} Pa ± 10^{-2} Pa impurities increase by 10% ± 2%.

Industrial optimization : 900°C ± 10°C, H_2 30 sccm ± 1 sccm , pressure 10^{-3}Pa ± 10^{-4}Pa , yield >90% ± 2%, equipment investment 200k USD ± 10k USD, suitable for aviation coating production, operation cycle >500 h ± 20 h.

Nano- Tungsten Carbide Powder by Sol-Gel Method

Process principle and technical path Preparation of nano tungsten carbide powder by sol-gel method

by hydrolysis of WO_3 (pH 3-5 ± 0.1) to form a sol and heat treatment at 600-800°C ± 10°C, with a grain size of 20-80 nm ± 10 nm. WO_3 (purity>99.9%) was dissolved in deionized water to prepare a solution with a concentration of 0.1-0.5 mol/L ± 0.01 mol/L, and citric acid (molar ratio of WO_3 : citric acid 1:1.5 ± 0.1) was added as a carbon source. The pH value was adjusted to 3-5 ± 0.1 with dilute HNO_3 . The solution was reacted under a magnetic stirrer (200-500 rpm ± 20 rpm) for 2-4 h ± 0.1 h to form a homogeneous sol, which was then gelled in a water bath at 80-100°C ± 5°C for 12 h ± 0.5 h. The gel was freeze-dried (-50°C ± 5°C, pressure <10 Pa ± 1 Pa) or spray-dried (feed rate 10-20 mL/min ± 1 mL/min) to prepare precursor powder, and finally heat-treated at 600-800°C ± 10°C in Ar /H_2 atmosphere (flow rate 20-40 sccm ± 1 sccm) for 2-4 h ± 0.1 h to produce WC powder.

Characterization and performance evaluation of nano- tungsten carbide powder

XRD : grain size 60 nm ± 10 nm, accuracy ± 2 nm.

TEM : Deviation <0.1% ± 0.02%, resolution <0.1 nm ± 0.01 nm.

EDS : C/W ratio 1:1 ± 0.02, purity >95% ± 1%.

BET : Specific surface area 60 m^2 / g ± 5 m^2 / g.

Preparation mechanism and performance of nano tungsten carbide powder WO_3 hydrolyzes to form 10-50 nm ± 5 nm sol, carbonizes at 700°C ± 10°C, and H_2 / Ar flow rate 20-40 sccm ± 1 sccm promotes the reaction. Hardness HV 2700 ± 50, toughness $K_{1}c$ 16-18 MPa·m $^{1/2}$ ± 0.5, thermal stability 900°C ± 20°C maintains 95% ± 2%.

Key influencing factors and industrial optimization

pH value : 3-5 ± 0.1 fine particles; >7 ± 0.1 agglomerates 15% ± 3%.

Temperature : 600-800°C ± 10°C controls grain size; >1000°C ± 10°C increases grain size by 15% ± 3%.

Industrial optimization : pH 4 ± 0.1, 700°C ± 10°C, H_2 / Ar 30 sccm ± 1 sccm , yield >85% ± 2%, cost 55 USD/kg ± 5 USD/kg, suitable for powder industrialization, equipment maintenance cycle >400 h ± 20 h.

The preparation of nano cemented carbide is based on nano tungsten powder and nano tungsten carbide powder, and CVD and sol-gel methods provide efficient routes. The subsequent chapters will explore performance optimization and industrialization challenges.

15.1.2 Grain Control of Nano-cemented Carbide (<100 nm)

Principle and technology of grain control of nano cemented carbide

Grain control of nano cemented carbide is the key technology to achieve its excellent properties (such as hardness HV 2500-3000 ± 50, toughness K_{1c} 15-20 MPa·$m^{1/2}$ ± 0.5, low porosity <0.1% ± 0.01%), and the core lies in accurately limiting the grain size to <100 nm ± 10 nm. By introducing grain growth inhibitors (such as vanadium carbide VC and chromium carbide Cr_3C_2, addition amount 0.5%-2% ± 0.1%) and optimizing reaction conditions (temperature 800-1000°C ± 10°C, pressure 10^{-2}-10^{-3} Pa ± 10^{-4} Pa), grain boundary migration and grain growth can be effectively inhibited. It mainly inhibits WC grain growth by forming nanoscale barriers (thickness <1 nm ± 0.1 nm) at the grain boundaries, while Cr_3C_2 promotes the nucleation of fine grains by increasing the nucleus density (>10^{10} cm^{-2} ± 10^9 cm^{-2}). The process also needs to be combined with uniform mixing (such as ball milling 4-6 h ± 0.1 h, rotation speed 500-1000 rpm ± 10 rpm), heat treatment (such as spark plasma sintering SPS 1200-1400°C ± 20°C, pressure 50 MPa ± 2 MPa) and post-treatment (such as hot isostatic pressing HIP 150 MPa ± 1 MPa, 2 h ± 0.1 h) to further reduce porosity and enhance density.

Characterization and Test Methods

Grain control effects are evaluated using a variety of high-precision analytical techniques:

X-ray diffraction (XRD) : Measure the grain size with an accuracy of ±2 nm and calculate the average grain size using the Scherrer formula.

Transmission electron microscopy (TEM) : Observe grain morphology and grain boundary structure with a resolution of <0.1 nm ± 0.01 nm and analyze grain uniformity (standard deviation <5 nm ± 1 nm).

Energy dispersive spectroscopy (EDS) : Detect inhibitor distribution and chemical composition with an accuracy of ±0.1%, and confirm the uniformity of VC and Cr_3C_2 (deviation <0.1% ± 0.02%).

Microhardness test (ASTM E92) : Measures hardness with an accuracy of ±50 HV and evaluates the effect of grain refinement on mechanical properties.

Specific surface area analysis (BET) : The specific surface area is estimated using the N_2 adsorption method with an accuracy of ±5 m^2/g (typical values 50-70 m^2 / g ± 5 m^2 / g) .

Porosity test : Mercury intrusion method, accuracy ±0.01%, target <0.1% ± 0.01%. For example, the grain size of WC sample with 1% VC addition is 60 nm ± 10 nm, hardness HV 2700 ± 50, specific surface area 60 m^2 / g ± 5 m^2 / g, porosity 0.08% ± 0.01%.

Grain Control Mechanism of Nano-cemented Carbide

The grain control mechanism is based on the regulation of grain boundary dynamics and nucleation process by inhibitors, as follows:

VC inhibition :
VC is doped at a low content of 0.5%-1% ± 0.1%, and a nanoscale phase (thickness <1 nm ± 0.1 nm) is precipitated at the WC grain boundary, which significantly reduces the grain boundary migration rate (<0.1 nm/s ± 0.01 nm/s) through the pinning effect. TEM observation shows that VC particles are evenly distributed at the grain boundary, and the grain growth rate is reduced by 80% ± 5% compared with the case without addition. EDS analysis shows that the V content distribution deviation is <0.1% ± 0.02%, ensuring consistent inhibition effect. According to the information of CTIA GROUP, VC is widely used in cemented carbide to improve wear resistance and grain stability.

Nucleation promotion of Cr_3C_2 :
Cr_3C_2 is doped at 1%-2% ± 0.1%, which promotes the nucleation of fine grains by increasing the nucleus density (>10^{10} cm^{-2} ± 10^9 cm^{-2}). TEM shows that the diameter of Cr_3C_2 particles is <10 nm ± 1 nm, which is dispersed and enhances the uniformity of WC grains (standard deviation <5 nm ± 1 nm). The grain size can be reduced to 50-80 nm ± 10 nm, and the hardness is increased by 15% ± 2% due to the grain boundary strengthening effect (Hall-Petch effect). CTIA GROUP pointed out that Cr_3C_2 can also improve the corrosion resistance of cemented carbide.

Synergistic effect : When
VC and Cr_3C_2 are used together, VC inhibits growth, Cr_3C_2 increases nucleation points, and synergistically optimizes grain size. Test results show that the WC-1%VC-1%Cr_3C_2 sample has a grain size of 55 nm ± 10 nm, a hardness of HV 2750 ± 50, and a toughness of $K_{1}c$ 18 MPa·$m^{1/2}$ ± 0.5, which is better than a single inhibitor sample (such as WC-2%Cr_3C_2 , hardness HV 2600 ± 50).

Microstructure analysis :
High-resolution TEM reveals that the VC grain boundary precipitate phase has a high degree of match with the WC lattice (mismatch <2% ± 0.5%), and the Cr_3C_2 particles are dispersed in the WC grains, reducing the grain boundary energy (<0.5 J/m^2) . ± 0.05 J/ m^2), further inhibiting the growth. X-ray photoelectron spectroscopy (XPS) analysis showed that the thickness of the surface oxide layer of VC and Cr_3C_2 was < 0.5 nm ± 0.1 nm, which enhanced the thermal stability.

Factors Affecting Grain Control of Nano-cemented Carbide
The grain control effect is affected by a variety of process parameters, the specific analysis is as follows:
Inhibitor content : When the content is
0.5%-2% ± 0.1% , the grain size is fine (<100 nm ± 10 nm) and the hardness is HV 2500-3000 ± 50; when the content is >5% ± 0.1%, excessive inhibitor leads to agglomeration of the second phase, the hardness decreases by 10% ± 2%, the toughness decreases by 5% ± 1% ($K_{1}c$ 14-15 MPa·$m^{1/2}$ ± 0.5), and the porosity increases to 0.15% ± 0.02%.

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Reaction temperature : In the range of
800-1000°C ± 10°C , grain control is excellent (50-100 nm ± 10 nm); at >1200°C ± 10°C, thermal activation enhances grain boundary migration, grain growth is 15% ± 3%, hardness decreases by 5% ± 1% (HV 2400-2500 ± 50), and the thermal expansion coefficient increases by 10% ± 2%.

Addition method :
Uniform doping (such as ultrasonic dispersion 500 W ± 10 W, 30 min ± 1 min) ensures uniform distribution of inhibitors and grain deviation <5% ± 1%; local addition leads to an increase in agglomeration rate of 10% ± 2%, uneven grain size, and affects sintering density.

Nucleus density :
10^{10} cm^{-2} ± 10^{9} cm^{-2} , the grain size is <80 nm ± 10 nm; when it is <10^{9} cm^{-2} ± 10^{9} cm^{-2}, the grain size increases to 100-120 nm ± 10 nm, an increase of 10% ± 2%, and the specific surface area decreases by 15% ± 2%.

Stirring speed :
500-1000 rpm ± 10 rpm improves mixing uniformity, and the grain distribution deviation is <5% ± 1%; when <200 rpm ± 10 rpm, the agglomeration rate increases by 10% ± 2%, and the inhibitor is unevenly distributed.

Atmosphere control :
Ar / H_2 atmosphere (flow rate 30-50 sccm ± 1 sccm) reduces oxidation and improves grain stability by 90% ± 2%; oxidation rate in air increases by 15% ± 2% and grain boundary defects increase by 10% ± 1%.

Sintering pressure :
SPS 50 MPa ± 2 MPa or HIP 150 MPa ± 1 MPa enhances density, porosity <0.1% ± 0.01%; when the pressure is <20 MPa ± 2 MPa, the porosity increases to 0.2% ± 0.02%.

Example analysis : Due to excessive inhibitor, the hardness of
the WC-5%VC sample (5% ± 0.1% VC addition) dropped to HV 2400 ± 50, the grain grew to 120 nm ± 10 nm, and the porosity was 0.18% ± 0.02%; in contrast, the WC-1%VC sample maintained 60 nm ± 10 nm, the hardness was HV 2700 ± 50, and the porosity was 0.08% ± 0.01%.

Grain Control Optimization Strategy for Nano-cemented Carbide

To achieve grain size <100 nm ± 10 nm, hardness >2500 ± 50, porosity <0.1% ± 0.01% and industrial feasibility, the following optimization strategy is proposed:

Inhibitor Optimization :
The VC doping amount was 0.5%-1% ± 0.1%, and the Cr_3C_2 was 1%-2% ± 0.1%. The uniform distribution was ensured by wet ball milling (ZrO_2 ball, diameter 5-10 mm ± 0.5 mm, rotation speed 600 rpm ± 10 rpm, 6 h ± 0.1 h) combined with ultrasonic dispersion (500 W ± 10 W, 30 min ± 1 min), suppressing the growth rate <0.05 nm/s ± 0.01 nm/s, and the nucleus density >10^{10} cm^{-2} ± 10^{9} cm^{-2} .

Nano-cemented carbide grain control process optimization :

CVD : reaction temperature 900°C ± 10°C, H_2 flow rate 30 sccm ± 1 sccm , CH_4 20 sccm ± 1 sccm , pressure 10^{-3}Pa ± 10^{-4}Pa , deposition time 2-3 h ± 0.1 h, grain size 80 nm ± 10 nm.

Sol-gel method : pH 4 ± 0.1, WO_3 concentration 0.3 mol/L ± 0.01 mol/L, citric acid molar ratio 1:1.5 ± 0.1, heat treatment 700°C ± 10°C, Ar /H_2 flow rate 30 sccm ± 1 sccm , grain size 60 nm ±

10 nm.

SPS sintering : 1200°C ± 20°C, pressure 50 MPa ± 2 MPa, pulse current 1000-1500 A ± 50 A, keep warm for 10 min ± 1 min, enhance density.

HIP post-treatment : 150 MPa ± 1 MPa, 600°C ± 10°C, 2 h ± 0.1 h, the porosity decreased to 0.07% ± 0.01%.

Doping optimization :

By using wet ball milling combined with ultrasonic treatment, the inhibitor dispersion is improved by 95% ± 2%, the agglomeration rate is <5% ± 1%, and the grain uniformity is ensured.

Test Specifications :

The grain size was determined by XRD with an accuracy of ±2 nm.

The morphology was analyzed by TEM with a resolution of <0.1 nm ± 0.01 nm.

ASTM E92 hardness test, accuracy ±50 HV.

BET surface area determination with an accuracy of ±5 m² / g.

The porosity was measured by mercury penetration method with an accuracy of ±0.01%.

Verification and optimization :

The optimized sample (such as WC-1%VC-1%Cr_3C_2) has a grain size of 55 nm ± 10 nm, a hardness of HV 2750 ± 50, a toughness of K_{1c} 18 MPa·$m^{1/2}$ ± 0.5, a specific surface area of 65 m^2/g ± 5 m^2/g, and a porosity of 0.07% ± 0.01%, which verifies that its performance is better than that of the unoptimized sample (such as WC-2%Cr_3C_2, hardness HV 2600 ± 50, and porosity of 0.12% ± 0.01%).

Industrial feasibility :

The optimized process is suitable for continuous production lines, with relatively high equipment investment, a yield of >90% ± 2%, and an operating cycle of >500 h ± 20 h, which is suitable for the fields of aviation, medical treatment, and precision molds. Referring to the experience of CTIA GROUP, the grain control technology of cemented carbide products has achieved semi-automatic production, which can further reduce production costs in the future.

The optimization of grain control technology has significantly improved the performance of nano-cemented carbide, providing a solid foundation for its application in ultra-precision machining and extreme environments. The subsequent chapters will explore the long-term effects of grain control on wear resistance and thermal stability.

15.2 Performance Advantages of Nano-cemented Carbide

Nano cemented carbide (grain size <100 nm ± 10 nm) has a number of significant performance advantages due to its unique microstructure and optimized preparation process, and is suitable for ultra-precision machining, extreme environment applications and intelligent manufacturing. Its main performance advantages include:

Ultra-high hardness

The hardness reaches HV 2500-3000 ± 50, which is about 50%-80% higher than that of traditional cemented carbide (HV 800-1600 ± 50). Thanks to the Hall-Petch strengthening effect of nano-scale grains, it is suitable for high-load cutting and wear-resistant coating.

Excellent toughness

The fracture toughness $K_{1}c$ 15-20 MPa·m $^{1/2}$ ± 0.5 is higher than that of conventional cemented carbide ($K_{1}c$ 8-12 MPa·m $^{1/2}$ ± 0.5). The crack growth resistance is enhanced by optimizing the bonding phase (such as Co 6-10% ± 0.5%) and grain boundary design.

Low wear rate

Wear rate <0.02 mm³ / N · m ± 0.005 mm³ / N · m , which is about 20-25 times higher than traditional WC-Co materials . It is suitable for high-speed cutting and long-term wear-resistant applications.

High corrosion resistance

In 5% H_2SO_4 solution , 24 h ± 1 h weight loss <0.05 mg/ cm² ± 0.01 mg/cm² . The acid and alkali corrosion resistance is significantly improved by Ni or Cr doping.

Excellent thermal stability

The performance is maintained at 90% ± 2% at 800-1000°C ± 20°C, which is higher than that of traditional cemented carbide (85% ± 2% at 700-900°C), making it suitable for high temperature processing environments.

Low porosity

The porosity is <0.1% ± 0.01%, and high density (>99% ± 0.5%) is achieved through SPS or HIP process, which improves mechanical properties and service life.

High surface quality

The surface roughness after processing is Ra <0.05 μm ± 0.01 μm , which is better than traditional cemented carbide (Ra 0.1-0.2 μm ± 0.01 μm) and meets the needs of ultra-precision manufacturing.

These performance advantages make nano-cemented carbide occupy a key position in the fields of aerospace (such as engine blades), medical (such as dental drills), energy (such as wear-resistant linings) and defense, especially in scenarios requiring high-precision and long-life components.

Nano-cemented carbide (grain size <100 nm±10 nm) has ultra-high hardness (HV 25003000±50), high toughness ($K_{1}c$ 1520 MPa ·m $^{1/2}$ ± 0.5) and excellent wear resistance (wear rate <0.02 mm³ / N · m ± 0.005 mm³ / N · m) , and is suitable for extreme working conditions (load>1000 N±10 N, temperature <800°C±10°C). This section starts with the improvement of ultra-high hardness and toughness.

15.2.1 Ultra-high hardness of nano-cemented carbide (HV>2500)

15.2.1 Ultra-high Hardness of Nano-cemented Carbide

Basic principles of ultra-high hardness of nano cemented carbide

The ultra-high hardness (HV 2500-3000 ± 50) of nano-cemented carbide is mainly due to its high grain boundary density (> 10^{10} cm $^{-2}$ ± 10^{9} cm $^{-2}$) and low defect rate (<0.1% ± 0.01%) brought by its nano-scale grain size (<100 nm ± 10 nm), which significantly enhances the material's ability to resist deformation. The material is mainly based on the WC-Co system, and the Co content is usually 6%-10% ± 1% as a bonding phase to provide a certain toughness support. At the same time, VC (0.5%-1% ± 0.1%) is added as a grain boundary strengthener to further optimize the hardness.

According to CTIA GROUP (http://www.ctia.com.cn/), nano WC cemented carbide exhibits excellent compressive strength (>5 GPa ± 0.5 GPa) and wear resistance in cemented carbide products due to its fine grains and uniform microstructure. The high density of grain boundaries effectively improves hardness by hindering dislocation movement (dislocation density $<10^{12}$ m^{-2} ± 10^{11} m^{-2}), while the low defect rate reduces stress concentration points and enhances the overall stability of the material.

Characterization and test methods of ultra-high hardness of nano cemented carbide

Hardness is evaluated using a variety of standardized test methods:

Microhardness test (ASTM E384)

Use a Vickers hardness tester with a test load of 0.5-5 N ± 0.1 N and an accuracy of ±50 HV to measure the diagonal length of the indentation.

X-ray diffraction (XRD) : Measure the grain size with an accuracy of ±2 nm and analyze the peak width using the Scherrer formula.

Scanning electron microscopy (SEM)

Observe surface morphology with a resolution of <0.1 μm ± 0.01 μm and analyze wear and crack morphology.

Wear test (ASTM G65)

dry sand rubber wheel wear test with an accuracy of ±0.005 mm^3 / N · m was used to evaluate the wear resistance.

Energy Dispersive Spectroscopy (EDS)

Confirm the distribution of VC and Co with an accuracy of ±0.1% and a deviation of <0.1% ± 0.02%. For example, the hardness of a WC-6%Co-1%VC sample is HV 2700 ± 50 and the wear rate is 0.015 mm^3 / N · m ± 0.005 mm^3 / N · m , surface roughness Ra <0.05 μm ± 0.01 μm .

Ultra-high hardness mechanism of nano-cemented carbide

The ultra-high hardness of nano cemented carbide comes from the synergistic effect of multiple strengthening mechanisms:

Hall-Petch effect

nanograins (50-100 nm ± 10 nm) hinder dislocation slip through grain boundaries, and the hardness is proportional to the inverse square root of the grain size (hardness $\propto d^{-1/2}$). Theoretically predicted hardness can reach HV 2700 ± 50. TEM observations show that the grain boundary density is $>10^{10}$ cm^{-2} ± 10^{9} cm^{-2} , and dislocation accumulation significantly enhances shear resistance.

VC grain boundary strengthening

VC (0.5%-1% ± 0.1%) precipitates at the WC grain boundary to form a nanoscale second phase (thickness <1 nm ± 0.1 nm) with a grain boundary strength >5 GPa ± 0.5 GPa . EDS analysis shows that the V distribution deviation is <0.1% ± 0.02%, ensuring uniform strengthening. VC also reduces the grain boundary migration rate (<0.1 nm/s ± 0.01 nm/s) through the pinning effect, reducing grain growth.

The toughness of the Co phase supports

Co (6%-10% ± 1%) as a bonding phase, filling the intergranular gaps and absorbing impact energy, with a toughness of $K_{1}c$ 15-18 MPa·$m^{1/2}$ ± 0.5. SEM observations show that the Co phase forms a protective layer on the worn surface, with a smooth surface (Ra <0.05 μm ± 0.01 μm) and no obvious cracks (<0.01 mm ± 0.001 mm).

Microstructural characteristics

High-resolution SEM and TEM revealed that the WC-6%Co-1%VC sample grains were polyhedral in morphology, with clear grain boundaries and a defect rate of <0.1% ± 0.01%. X-ray photoelectron spectroscopy (XPS) analysis showed that the thickness of the surface oxide layer was <0.5 nm ± 0.1 nm, which enhanced thermal stability and corrosion resistance.

Performance comparison :

Tests show that WC-6%Co-1%VC has a hardness of HV 2700 ± 50, which is better than WC-10%Co (hardness HV 2200 ± 50), and the wear rate is reduced by 30% ± 3% (0.015 mm^3 / N · m vs. 0.02 mm^3 / N · m ± 0.005 mm^3 / N · m) .

Factors affecting the hardness of nano cemented carbide

Hardness is affected by many factors, as follows:

Grain size :

50-100 nm ± 10 nm , high hardness (HV 2500-3000 ± 50); >200 nm ± 10 nm, the grain boundary density decreases, the hardness decreases by 15% ± 3% (HV 2000-2200 ± 50), and the wear rate increases to 0.03 mm^3 / N · m ± 0.005 mm^3 / N · m .

Co content : When the content is

6%-10% ± 1% , the hardness and toughness are balanced; when the content is >15% ± 1%, the excessive Co phase reduces the grain boundary strengthening effect, the hardness decreases by 10% ± 2% (HV 2250 ± 50), and the toughness increases by 5% ± 1% (K_1c 18-20 MPa·$m^{1/2}$ ± 0.5).

VC content : When

0.5%-1% ± 0.1% , the hardness increases by 10% ± 2% (HV 2700 ± 50); when >2% ± 0.1%, excessive VC causes the second phase to agglomerate, the toughness decreases by 10% ± 2% (K_1c 13-14 MPa·$m^{1/2}$ ± 0.5), and the hardness does not increase significantly.

Test load :

0.5-5 N ± 0.1 N , the hardness is stable (HV 2700 ± 50); >10 N ± 0.1 N, the indentation is too large, the crack rate increases by 10% ± 2%, and the hardness reading is low.

Ambient temperature :

25-800°C ± 10°C , excellent performance (hardness maintained at 90% ± 2%); >1000°C ± 10°C, Co phase softens, hardness decreases by 10% ± 2% (HV 2400 ± 50), thermal expansion coefficient increases by 15% ± 2%.

Sintering process :

SPS (1400°C ± 10°C, 50 MPa ± 1 MPa) has high density and increases hardness by 5% ± 1%. Traditional sintering (1500°C ± 20°C) has high defect rate and reduces hardness by 10% ± 2%.

Case analysis :

WC-10%Co (grain size 200 nm ± 10 nm) hardness reduced to HV 2200 ± 50, wear rate 0.02 mm^3 / N · m ± 0.005 mm^3 / N · m , much lower than WC-6%Co-1%VC.

Ultra-high hardness optimization of nano-cemented carbide

To achieve a hardness of HV >2500 ± 50 and a wear rate of <0.02 mm^3 / N · m ± 0.005 mm^3 / N · m and industrial applicability, the following optimization strategies are proposed:

Material optimization :

Co content 6%-10% ± 1%, VC 0.5%-1% ± 0.1%, grain size 50-100 nm ± 10 nm, uniform dispersion ensured by wet ball milling (ZrO_2 balls , diameter 5-10 mm ± 0.5 mm, rotation speed 600 rpm ± 10 rpm, 6 h ± 0.1 h).

Process Optimization :

SPS sintering : 1400°C ± 10°C, pressure 50 MPa ± 1 MPa, pulse current 1000-1500 A ± 50 A, keep warm for 10 min ± 1 min, density >99% ± 0.5%.

CVD coating : 900°C ± 10°C, H_2 30 sccm ± 1 sccm , CH_4 20 sccm ± 1 sccm , deposition time 2-3 h ± 0.1 h, to enhance surface hardness.

Surface optimization :

precision polishing (grain size 0.05 μm ± 0.01 μm diamond suspension), surface roughness Ra <0.05 μm ± 0.01 μm , reducing wear sources.

Test Specifications :

ASTM E384 Determination of hardness, accuracy ±50 HV.

ASTM G65 Determination of wear rate with an accuracy of ±0.005 mm^3 / N · m .

The wear morphology was analyzed by SEM with a resolution of <0.1 μm ± 0.01 μm .

Verification optimization :

The optimized sample (such as WC-6%Co-1%VC) has a grain size of 60 nm ± 10 nm, a hardness of HV 2700 ± 50, and a wear rate of 0.015 mm^3 / N · m ± 0.005 mm^3 / N · m and toughness K_1 c 16 MPa · $m^{1/2}$ ± 0.5, demonstrating its superior performance to unoptimized samples (e.g. WC-10%Co, hardness HV 2200 ± 50).

Industrial feasibility :

The process is optimized to adapt to continuous production lines, the equipment investment is relatively high, the yield is >90% ± 2%, the operation cycle is >500 h ± 20 h, and it is suitable for the fields of aviation and precision manufacturing.

The ultra-high hardness of nano-cemented carbide provides it with significant advantages in high-load and wear-resistant applications. Subsequent chapters will explore the synergistic optimization of its toughness and thermal stability.

15.2.2 Excellent toughness of nano cemented carbide

Basic principles of toughness of nano cemented carbide

The excellent toughness (K_1c 15-20 MPa ·$m^{1/2}$ ± 0.5) of nano cemented carbide is due to the strengthening of fine grains (50-100 nm±10 nm) and the optimized design of Co phase, which is suitable for high impact conditions (impact energy>50 J±5 J). The material is mainly based on WC-Co system, with Co content of 6%-12%±1% as a bonding phase, and the grain size is controlled at the nanometer level by inhibitors (such as VC 0.5%-1%±0.1%). According to the information of CTIA GROUP, nano cemented carbide exhibits excellent crack resistance in cemented carbide products due to its fine grain structure and optimized toughness phase, and is widely used in cutting tools and molds with large impact loads. Fine grain strengthening increases the crack deflection path, and the Co phase absorbs energy through plastic deformation, significantly improving toughness and meeting high dynamic load requirements.

Characterization and Test Methods

Toughness was evaluated using the following standardized tests:

Fracture toughness test (ISO 28079)

using the single-edge notched beam method with an accuracy of ±0.5 $MPa \cdot m^{1/2}$.

Microhardness test (ASTM E384)

Load 0.5-5 N ± 0.1 N, accuracy ±50 HV, evaluate hardness-toughness balance.

Impact toughness test (ISO 148)

Charpy impact test , accuracy ±1 J, measurement of absorbed energy.

Scanning electron microscopy (SEM)

Observe crack morphology with a resolution of <0.1 μm ± 0.01 μm and analyze deflection and propagation.

Energy Dispersive Spectroscopy (EDS)

Confirm the distribution of Co and VC with an accuracy of ±0.1% and a deviation of <0.1% ± 0.02%. For example, the toughness of a WC-8%Co-1%VC sample is $K_{1}c$ 18 $MPa \cdot m^{1/2}$ ± 0.5, the impact energy is 60 J ± 5 J, and the hardness is HV 2600 ± 50.

Toughness Mechanism of Nano-cemented Carbide

The excellent toughness of nano cemented carbide comes from the synergistic effect of multiple microscopic mechanisms:

Grain refinement and crack deflection :

Grain size 50-100 nm ± 10 nm increases grain boundary density (>10^{10} cm^{-2} ± 10^{9} cm^{-2}), crack deflection path length >10 μm ± 1 μm . SEM observation shows that the crack deflection angle is >30° ± 5°, effectively dispersing stress and reducing linear extension.

Energy absorption of Co phase :

Co (6%-12% ± 1%) acts as a bonding phase with a plastic deformation rate of >5% ± 1%, absorbing impact energy (>50 J ± 5 J). TEM analysis shows that the Co phase forms a continuous network at the grain boundary, enhancing the ability to resist crack growth.

Crack suppression by VC :

VC (0.5%-1% ± 0.1%) suppressed the crack growth rate (<0.1 mm/s ± 0.01 mm/s) and fixed the crack tip through the pinning effect. EDS confirmed that the V distribution deviation was <0.1% ± 0.02%, ensuring uniform suppression.

Microstructure characteristics :

High-resolution SEM shows that the crack length of the WC-8%Co-1%VC sample is <0.01 mm ± 0.001 mm, and there is no large crack extension. X-ray diffraction (XRD) shows that the lattice mismatch between the Co phase and WC is <2% ± 0.5%, which enhances the bonding strength of the phase interface.

Performance comparison :

Tests show that WC-8%Co-1%VC has a toughness of $K_{1}c$ 18 $MPa \cdot m^{1/2}$ ± 0.5 and an impact energy of 60 J ± 5 J, which are better than WC-6%Co ($K_{1}c$ 15 $MPa \cdot m^{1/2}$ ± 0.5 and an impact energy of 45 J ± 5 J).

Factors affecting the toughness of nano cemented carbide

Resilience is affected by many factors, including the following:

Co content : When
6%-12% ± 1% , the toughness is high ($K_{1}c$ 15-20 MPa·m $^{1/2}$ ± 0.5); when <6% ± 1%, the Co phase is insufficient and the crack rate increases by 10% ± 2%; when >15% ± 1%, the toughness increases by 5% ± 1% ($K_{1}c$ 20-22 MPa·m $^{1/2}$ ± 0.5), but the hardness decreases by 10% ± 2%.

Grain size : When
50-100 nm ± 10 nm , the toughness is excellent ($K_{1}c$ 18 MPa·m $^{1/2}$ ± 0.5); when >200 nm ± 10 nm, the grain boundary density decreases and the toughness decreases by 10% ± 2% ($K_{1}c$ 13-14 MPa·m $^{1/2}$ ± 0.5).

VC content : When
0.5%-1% ± 0.1% , crack inhibition is excellent (rate <0.1 mm/s ± 0.01 mm/s); when >2% ± 0.1%, excessive VC leads to brittle phase and toughness decreases by 10% ± 2% ($K_{1}c$ 13-15 MPa·m $^{1/2}$ ± 0.5).

Impact frequency : When
10-50 Hz ± 1 Hz , the performance is stable; when >100 Hz ± 1 Hz, fatigue cracks increase by 15% ± 3% and toughness decreases by 5% ± 1%.

Sintering process :
SPS (1400°C ± 10°C, 50 MPa ± 1 MPa) has low defect rate and 10% ± 2% increase in toughness; traditional sintering (1500°C ± 20°C) has high porosity and 10% ± 2% decrease in toughness.

Ambient temperature : At
25-800°C ± 10°C , the toughness remains at 90% ± 2%; at >1000°C ± 10°C, the Co phase softens and the toughness decreases by 10% ± 2%.

Case analysis :
WC-6%Co (Co 6% ± 1%) toughness drops to $K_{1}c$ 15 MPa·m $^{1/2}$ ± 0.5, impact energy 45 J ± 5 J, crack length >0.02 mm ± 0.001 mm.

Nano-cemented carbide toughness optimization

In order to achieve toughness $K_{1}c$ >15 MPa·m $^{1/2}$ ± 0.5, impact energy >50 J ± 5 J and industrial applicability, the following optimization strategies are proposed:

Material optimization :
Co content 8%-12% ± 1%, VC 0.5%-1% ± 0.1%, grain size 50-100 nm ± 10 nm, uniform dispersion ensured by wet ball milling (ZrO_2 balls , diameter 5-10 mm ± 0.5 mm, rotation speed 600 rpm ± 10 rpm, 6 h ± 0.1 h).

Process Optimization :
SPS sintering : 1400°C ± 10°C, pressure 50 MPa ± 1 MPa, pulse current 1000-1500 A ± 50 A, keep warm for 10 min ± 1 min, density >99% ± 0.5%.
Post-HIP treatment : 150 MPa ± 1 MPa, 600°C ± 10°C, 2 h ± 0.1 h, to reduce residual porosity.

Grain optimization :
Control the grain size to 50-80 nm ± 10 nm, and suppress the growth rate to <0.05 nm/s ± 0.01 nm/s through VC.

Test Specifications :

ISO 28079 Determination of toughness with an accuracy of ±0.5 $MPa \cdot m^{1/2}$.

ISO 148 Determination of impact energy, accuracy ±1 J.

The crack morphology was analyzed by SEM with a resolution of <0.1 μm ± 0.01 μm .

Verification and optimization :

The optimized samples (such as WC-8%Co-1%VC) have a grain size of 80 nm ± 10 nm, toughness $K_{1}c$ 18 $MPa \cdot m^{1/2}$ ± 0.5, impact energy 60 J ± 5 J, hardness HV 2600 ± 50, and crack length <0.01 mm ± 0.001 mm, which verifies that its performance is better than that of the unoptimized samples (such as WC-6%Co, $K_{1}c$ 15 $MPa \cdot m^{1/2}$ ± 0.5).

Industrial feasibility :

The optimized process is suitable for continuous production lines. The equipment investment is relatively high. The yield is >90% ± 2%, and the operating cycle is >500 h ± 20 h. It is suitable for the manufacturing of cutting tools and molds with high impact loads.

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.

Serving Customers

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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15.3 Challenges and Solutions of Nano-cemented Carbide

The preparation and application of nano-cemented carbide (WC-Co system, grain size <100 nm ± 10 nm) face two core challenges: grain growth (>100 nm ± 10 nm) leads to performance degradation and insufficient sintering densification (porosity >0.1% ± 0.01%) affects mechanical reliability. These challenges mainly stem from the accelerated grain boundary migration and insufficient bonding between powder particles during high-temperature sintering. To address these problems, comprehensive optimization is required through grain growth inhibitors (such as VC and Cr_3C_2, added in an amount of 0.5%-2% ± 0.1%) and advanced sintering technologies (such as spark plasma sintering SPS and hot isostatic pressing HIP). This section starts from the two aspects of grain growth inhibition and sintering densification, and systematically explores the challenges and solutions in combination with microscopic mechanisms, influencing factors and optimization strategies .

15.3.1 Grain Growth Inhibition of Nano - cemented Carbide (VC, Cr_3C_2)

Principle of Grain Growth Suppression in Nano-cemented Carbide

Grain growth inhibition of nano cemented carbide is the key to maintaining its nano characteristics (grains <100 nm ± 10 nm) and achieving ultra-high hardness (HV 2500-3000 ± 50) and excellent toughness (K_{1c} 15-20 MPa·m $^{1/2}$ ± 0.5). By adding grain growth inhibitors VC (0.5%-1% ± 0.1%) and Cr_3C_2 (1%-2% ± 0.1%), the grain boundary migration and grain growth rate are effectively controlled. VC precipitates at the WC grain boundary to form a nano-scale barrier (thickness <1 nm ± 0.1 nm), inhibiting grain growth through the pinning effect; Cr_3C_2 promotes the nucleation of fine grains by increasing the initial nucleus density (>10^{10} cm^{-2} ± 10^{9} cm^{-2}). During the sintering process, a combination of rapid temperature increase (e.g. SPS >100°C/min ± 10°C/min) and moderate pressure (50-100 MPa ± 1 MPa) further enhances the inhibition effect and ensures that the grain size is stable at the nanoscale.

Grain Characterization and Testing Methods of Nano-cemented Carbide

The effect of grain growth suppression was evaluated by the following techniques:
X-ray diffraction (XRD) : Measure the grain size with an accuracy of ±2 nm and analyze the peak width using the Scherrer formula.
Transmission electron microscopy (TEM) : Observe grain morphology and grain boundary structure with a resolution of <0.1 nm ± 0.01 nm and analyze uniformity (standard deviation <5 nm ± 1 nm).
Energy dispersive spectroscopy (EDS) : Detect the distribution of VC and Cr_3C_2 , with an accuracy of ±0.1% and a distribution deviation of <0.1% ± 0.02%.
Microhardness test (ASTM E384) : load 0.5-5 N ± 0.1 N, accuracy ± 50 HV, evaluate the correlation between hardness and grain size.
Thermal expansion analysis (TMA) : Measures grain stability at 25-1500°C ± 10°C with an

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accuracy of ±0.01%. For example, WC-1%VC sample has a grain size of 60 nm ± 10 nm, hardness HV 2700 ± 50, and grain boundary migration rate <0.1 nm/s ± 0.01 nm/s.

Grain Growth Inhibition Mechanism of Nano-cemented Carbide

The mechanism of grain growth inhibition is based on the regulation of grain boundary dynamics and nucleation processes by inhibitors:

Pinning effect of VC :

VC (0.5%-1% ± 0.1%) precipitates at the WC grain boundary to form a nanoscale second phase (thickness <1 nm ± 0.1 nm), which significantly reduces the grain boundary migration rate (<0.1 nm/s ± 0.01 nm/s) through the Zener pinning mechanism. TEM observation shows that VC particles are evenly distributed at the grain boundary, and the grain growth rate is reduced by 80% ± 5% compared with the case without addition. EDS analysis shows that the V content distribution deviation is <0.1% ± 0.02%, ensuring the consistency of inhibition.

Nucleation promotion of Cr_3C_2 :

Cr_3C_2 (1%-2% ± 0.1%) enhances the nucleation rate by increasing the nucleus density (>10^{10} cm^{-2} ± 10^9 cm^{-2}), and the precipitate phase diameter is <10 nm ± 1 nm, showing a dispersed distribution. TEM reveals that the distance between Cr_3C_2 particles is <50 nm ± 5 nm, significantly refining the grains to 50-80 nm ± 10 nm, and the hardness is increased by 15% ± 2%, which is attributed to grain boundary strengthening.

Synergistic optimization : When

VC and Cr_3C_2 are used together, VC inhibits growth, Cr_3C_2 increases nucleation points, and synergistically controls grain size. Test results show that the WC-1%VC-1%Cr_3C_2 sample has a grain size of 55 nm ± 10 nm, a hardness of HV 2750 ± 50, and a toughness of $K_{1}c$ 18 MPa·m$^{1/2}$ ± 0.5, which is better than a single inhibitor sample (such as WC-2%Cr_3C_2, grain size 80 nm ± 10 nm, hardness HV 2600 ± 50).

Thermodynamic analysis :

Differential scanning calorimetry (DSC) showed that the melting points of VC and Cr_3C_2 (> 2800 °C ± 50°C) are higher than the WC sintering temperature (1400-1450°C ± 10°C), ensuring that the inhibitors are stable at high temperatures and the grain boundary energy is reduced to <0.5 J/ m² ± 0.05 J/ m² .

Factors affecting grain growth inhibition of nano-cemented carbide

The grain growth inhibition effect is affected by many parameters:

Inhibitor content : When the content is

0.5%-2% ± 0.1% , the grain size remains <100 nm ± 10 nm and the hardness is HV 2500-3000 ± 50; when the content is >5% ± 0.1%, excessive inhibitor leads to agglomeration of the second phase, the hardness decreases by 10% ± 2% (HV 2250 ± 50), and the toughness decreases by 5% ± 1%.

Sintering temperature : Excellent grain control in the range of

1400-1450°C ± 10°C ; >1500°C ± 10°C, thermal activation enhances grain boundary migration, grain growth of 15% ± 3% (>120 nm ± 10 nm), and hardness decreases by 5% ± 1%.

Addition method :
Ultrasonic dispersion (500 W ± 10 W, 30 min ± 1 min) ensures uniform distribution of the inhibitor, with a grain deviation of <5% ± 1%; mechanical mixing (speed <200 rpm ± 10 rpm) causes an increase in agglomeration rate of 10% ± 2%, affecting the inhibition effect.
Sintering time :
5-10 min ± 1 min , the grains are stable (<100 nm ± 10 nm); >30 min ± 1 min, the grains grow by 10% ± 2% (110 nm ± 10 nm) and the hardness decreases by 3% ± 1%.
Sintering pressure : When it is
50-100 MPa ± 1 MPa , the inhibition effect is good and the grain size is uniform; when it is <20 MPa ± 1 MPa, the contact between particles is insufficient and the grain size increases by 10% ± 2%.
Atmosphere control :
Ar / H_2 atmosphere (flow rate 30-50 sccm ± 1 sccm) reduces oxidation and improves grain stability by 90% ± 2%; the oxidation rate in air increases by 15% ± 2% and grain boundary defects increase by 10% ± 1%.
Case analysis :
WC-5%VC (5% ± 0.1% VC addition) has excessive inhibitors, the grain size increases to 120 nm ± 10 nm, the hardness decreases to HV 2400 ± 50, and the porosity increases to 0.15% ± 0.01%.

Optimization strategy for inhibiting grain growth of nano-cemented carbide

In order to achieve grain size <100 nm ± 10 nm and hardness >2500 ± 50, the following optimization strategy is proposed:
Inhibitor optimization :
VC 0.5%-1% ± 0.1% , Cr_3C_2 1%-2% ± 0.1%, prepared by wet ball milling (ZrO_2 balls, diameter 5-10 mm ± 0.5 mm, rotation speed 600 rpm ± 10 rpm, 6 h ± 0.1 h) combined with ultrasonic dispersion (500 W ± 10 W, 30 min ± 1 min) to ensure uniform distribution.
Process Optimization :
SPS sintering : 1400°C ± 10°C, pressure 50 MPa ± 1 MPa, heating rate >100°C/min ± 10°C/min, holding time 5-10 min ± 1 min.
Atmosphere control : Ar / H_2 flow rate 30 sccm ± 1 sccm to reduce oxidation.
Parameter optimization :
control the sintering time to 5-10 min ± 1 min, the pressure to 50-100 MPa ± 1 MPa, and suppress the growth rate to <0.05 nm/s ± 0.01 nm/s.
Test Specifications :
The grain size was determined by XRD with an accuracy of ±2 nm.
The morphology was analyzed by TEM with a resolution of <0.1 nm ± 0.01 nm.
ASTM E384 hardness test, accuracy ±50 HV.
Verification and optimization :
The optimized sample (such as WC-1%VC-1%Cr_3C_2) has a grain size of 55 nm ± 10 nm, a hardness of HV 2750 ± 50, and a toughness of K_{1c} 18 MPa·m $^{1/2}$ ± 0.5, which verifies that its performance is better than that of the unoptimized sample (such as WC-2%Cr_3C_2 , grain size 80

nm ± 10 nm).

Industrial feasibility :

The optimized process is suitable for continuous production lines, with relatively high equipment investment, yield >90% ± 2%, operation cycle >500 h ± 20 h, suitable for the production of high-precision cemented carbide products.

15.3.2 Sintering Densification of Nano-cemented Carbide (SPS, HIP)

Sintering densification principle of nano cemented carbide

Sintering densification is a key step to achieve high performance of nano cemented carbide (hardness HV 2500-3000 ± 50, porosity <0.1% ± 0.01%). Spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa) promotes particle diffusion and neck formation through rapid heating (>100°C/min ± 10°C/min) and electric field drive (current 500-1000 A ± 10 A), significantly reducing porosity. Hot isostatic pressing (HIP, 1350°C ± 10°C, 150-200 MPa ± 1 MPa) eliminates micropores (<0.1 μm ± 0.01 μm) through uniform high pressure and enhances material density (density>99% ± 0.5%). Referring to the experience of CTIA GROUP, the combination of SPS and HIP can effectively solve the densification difficulties of nano WC-Co materials caused by fine particles in traditional sintering.

Densification Characterization and Testing Methods of Nano-cemented Carbide

The densification effect was evaluated by the following techniques:

Archimedean method : measures porosity with an accuracy of ±0.01%, based on density differences.

Microhardness test (ASTM E384) : load 0.5-5 N ± 0.1 N, accuracy ± 50 HV.

Density test (ASTM B311) : Water immersion method, accuracy ±0.01 g/cm³ , evaluates theoretical density percentage.

Scanning electron microscopy (SEM) : observe the microstructure with a resolution of <0.1 μm ± 0.01 μm and analyze the pore distribution.

Ultrasonic testing : measures the speed of sound with an accuracy of ±0.1% and evaluates internal defects. For example, the porosity of the SPS-WC-6%Co sample is 0.08% ± 0.01%, the hardness is HV 2700 ± 50, and the density is 15.6 g/ cm³ ± 0.01 g/ cm³ .

Sintering densification mechanism of nano-cemented carbide

The microscopic mechanism of sintering densification is based on thermodynamic and kinetic optimization:

Electric field drive of SPS :

SPS generates local high temperature (>1400°C ± 10°C) through pulsed current (500-1000 A ± 10 A), drives the diffusion of Co phase (diffusion coefficient>10^{-6} cm²/s ± 10^{-7} cm²/s), and promotes the formation of necks between WC particles. SEM shows that the pore size is <0.1 μm ± 0.01 μm and the porosity is reduced to 0.08% ± 0.01%. The electric field also activates surface atomic migration and reduces the sintering time (5-10 min ± 1 min).

High pressure elimination by HIP :
HIP uniformly pressurizes at 150-200 MPa ± 1 MPa to eliminate micropores and residual stress, and the density reaches >99% ± 0.5%. TEM analysis shows that the grain boundary bonding strength of HIP samples is enhanced, the defect rate is <0.1% ± 0.02%, and the pore diameter is <0.05 μm ± 0.01 μm .
Synergistic effect : After
SPS rapid prototyping, HIP post-treatment further optimizes the microstructure. Test results show that the hardness of the WC-6%Co sample treated with HIP after SPS is HV 2700 ± 50 and the porosity is 0.06% ± 0.01%, which is better than that of single SPS (HV 2650 ± 50, porosity 0.08% ± 0.01%).
Thermomechanical analysis :
Thermal expansion analysis (TMA) showed that the volume shrinkage during SPS sintering was >10% ± 1% (1400°C ± 10°C), and the shrinkage after HIP was stable at 12% ± 1%, reflecting the effectiveness of densification.

Factors Affecting Sintering Densification of Nano-cemented Carbide

The sintering densification effect is affected by many parameters:
Sintering temperature : At
1400-1450°C ± 10°C , the porosity is low (<0.1% ± 0.01%); at >1500°C ± 10°C, the grain size increases by 10% ± 2% and the porosity increases to 0.15% ± 0.01%.
Pressure :
50-150 MPa ± 1 MPa , high density (porosity <0.1% ± 0.01%); <20 MPa ± 1 MPa, insufficient contact between particles, porosity increases by 10% ± 2% (0.2% ± 0.01%).
Sintering time :
5-10 min ± 1 min , excellent performance (porosity 0.08% ± 0.01%); >30 min ± 1 min, grain growth 10% ± 2%, no significant improvement in porosity.
Co content : When the content is
6%-10% ± 1% , the Co phase is evenly distributed and the densification effect is good; when the content is >15% ± 1%, the excessive Co leads to excessive liquid phase and the porosity increases by 5% ± 1% (0.15% ± 0.01%).
Heating rate :
At 100°C/min ± 10°C/min, the porosity is low (<0.1% ± 0.01%); at <50°C/min ± 10°C/min, the particle growth is accelerated and the porosity increases by 10% ± 2%.
Powder pretreatment :
ball milling for 6 h ± 0.1 h (speed 600 rpm ± 10 rpm) improved powder uniformity and reduced porosity by 5% ± 1%; without pretreatment, the porosity increased by 10% ± 2%.
Case Study :
Due to insufficient temperature, the porosity of the HIP treatment (1200°C ± 10°C, pressure 100 MPa ± 1 MPa) increased to 0.2% ± 0.01% and the hardness decreased to HV 2500 ± 50.

Optimization strategy for sintering densification of nano-cemented carbide

In order to achieve porosity <0.1% ± 0.01% and hardness >2500 ± 50, the following optimization strategy is proposed:

Process Optimization :

SPS sintering : 1400°C ± 10°C, pressure 50 MPa ± 1 MPa, current 1000 A ± 10 A, heating rate >100°C/min ± 10°C/min, holding time 5-10 min ± 1 min.

HIP post-treatment : 1350°C ± 10°C, pressure 150 MPa ± 1 MPa, insulation time 2 h ± 0.1 h.

Material optimization :

Co content 6%-10% ± 1%, powder homogeneity was ensured by wet ball milling (ZrO_2 balls , diameter 5-10 mm ± 0.5 mm, 6 h ± 0.1 h).

Parameter optimization :

control heating rate>100°C/min ± 10°C/min, pressure 50-150 MPa ± 1 MPa, reduce micropores (<0.05 μm ± 0.01 μm).

Test Specifications :

The porosity was determined by the Archimedean method with an accuracy of ±0.01%.

ASTM E384 hardness test, accuracy ±50 HV.

The microstructure was analyzed by SEM with a resolution of <0.1 μm ± 0.01 μm .

Verification optimization :

The optimized sample (e.g. WC-6%Co after SPS HIP) has a porosity of 0.06% ± 0.01%, a hardness of HV 2700 ± 50, and a density of 15.6 g/ cm^3 ± 0.01 g/ cm^3 , which verifies that its performance is better than that of single process samples (such as SPS-WC-6%Co, porosity 0.08% ± 0.01%).

Industrial feasibility :

The optimized process is suitable for continuous production lines, with relatively high equipment investment, yield >90% ± 2%, operation cycle >500 h ± 20 h, suitable for the production of high-performance cemented carbide products.

The optimization of grain growth inhibition and sintering densification technology of nano-cemented carbide has laid the foundation for its industrial application. The subsequent chapters will explore the further improvement of its heat resistance and corrosion resistance.

15.4 Application and Prospect of Nano-cemented Carbide

Nano-cemented carbide (mainly WC-Co system, grain size <100 nm ± 10 nm) has excellent mechanical properties (such as hardness HV 2500-3000 ± 50, toughness $K_{1}c$ 15-20 MPa·m $^{1/2}$ ± 0.5, low wear rate <0.02 mm ^{3} / N · m ± 0.005 mm^{3} / N · m) and excellent high temperature stability and surface quality (Ra <0.05 μm ± 0.01 μm), showing broad application prospects in multiple high-tech fields. At present, nano cemented carbide has emerged in ultra-precision machining, high-performance coatings, aerospace, medical devices and energy industries, and with the advancement of preparation technology and the growth of market demand, its application scope and market potential continue to expand. This section will discuss in detail the specific application areas of nano cemented carbide and its future development prospects, and provide a comprehensive analysis based on the current technical level and industry trends.

15.4.0 What are the applications of nano cemented carbide?

Nano cemented carbide has significant advantages in fields requiring high precision, wear resistance and high temperature performance due to its nano-scale grain structure and high density (porosity <0.1% ± 0.01%). Its main applications include but are not limited to the following aspects:

Ultra-precision machining
of nano WC is widely used in the manufacture of optical molds, semiconductor wafer molds, precision gears and micro-mechanical components, requiring machining accuracy <0.01 mm ± 0.001 mm and surface roughness Ra <0.05 μm ± 0.01 μm . Its high hardness (HV 2500-3000 ± 50) and low wear rate (<0.02 mm^{3} / N · m ± 0.005 mm^{3} / N · m) makes it an excellent choice for cutting glass, ceramics and carbide, especially for consumer electronics (e.g. smartphone lenses) and the automotive industry.
High-performance coatings Nano-WC coatings (thickness 1-10
μm ± 0.1 μm) prepared by physical vapor deposition (PVD, 400-600°C ± 10°C) or chemical vapor deposition (CVD, 800-1000°C ± 10°C) are widely used for surface strengthening of cutting tools, molds and mechanical parts. The coatings provide hardness HV 2500-3000 ± 50 and bonding strength >70 MPa ± 1 MPa, significantly improving wear resistance and service life, and are suitable for high-speed cutting and extreme environments.
Aerospace
nano-hard alloys are used to manufacture engine turbine blades, nozzles and wear-resistant linings. Their high temperature stability (90% ± 2% performance at 900°C ± 20°C) and corrosion resistance (weight loss <0.05 mg/cm^{2}) are ± 0.01 mg/cm^{2}) to meet the requirements of lightweight and high reliability for aviation components.
Medical devices
In orthopedic implants (such as hip prostheses) and dental drill bits, the biocompatibility (optimized by Co content to 6%-10% ± 1%) and wear resistance of nano WC make it an ideal material, and the processing accuracy of <0.01 mm ± 0.001 mm ensures the precise fit of the implant.
Energy IndustryNano

cemented carbide is used in oil drilling tools and wind turbine blade coatings. Its high hardness (HV 2700 ± 50) and impact toughness ($K_{1}c$ 18 MPa·m $^{1/2}$ ± 0.5) perform well in harsh geological conditions and long-term operation.

These applications benefit from the fine grains of nano-WC (50-100 nm ± 10 nm) to improve hardness through the Hall-Petch effect, the Co phase (6%-10% ± 1%) to provide toughness support, and the VC (0.5%-1% ± 0.1%) inhibitor to optimize wear resistance and grain stability.

In the future, with the integration of multifunctional composite materials and intelligent manufacturing technologies, its application areas are expected to expand further.

15.4.1 Application of Nano-cemented Carbide in Ultra-precision Machining

Nano cemented carbide, with tungsten carbide (WC)-cobalt (Co) system as the core, has a grain size precisely controlled at <100 nm ± 10 nm. With its excellent processing characteristics, it has shown extensive and in-depth application potential in the field of ultra-precision machining. Ultra-precision machining is mainly aimed at optical components, semiconductor devices, precision molds, micro-mechanical components and emerging high-tech fields, requiring machining accuracy to reach nanometer to submicron level (<0.01 mm ± 0.001 mm) and extremely low surface roughness (Ra <0.05 μm ± 0.01 μm). Nano cemented carbide has become an ideal tool material to support these high-standard requirements with its high wear resistance, high stability and excellent surface quality. This section will discuss in detail the specific application fields of nano cemented carbide in ultra-precision machining, deeply analyze its professional application scenarios, technical contributions and industry impact in various industries, and combine current industrial practices and cutting-edge technology trends to fully demonstrate its application value and development potential.

Detailed description of the application of nano-hard alloy in ultra-precision machining

The application of nano cemented carbide in ultra-precision machining covers multiple high-precision manufacturing fields, and its core use reflects its unique position and wide adaptability in modern industry. The following is a detailed description of its specific application scenarios, combined with industry needs, technical details and actual cases, to fully reveal its practical application value in various fields:

Nano-hard alloy for optical mold manufacturing

Nano-cemented carbide is widely used in the optical industry to produce smartphone multi-lens molds, automotive advanced driver assistance system (ADAS) camera molds, high-end optical lens molds (such as aspheric lens molds for telescopes, microscopes, projectors and lasers), and infrared/ultraviolet optical component molds (such as zinc sulfide ZnS, magnesium fluoride MgF_2 and germanium Ge molds). These molds require extremely high surface finish (Ra <0.05 μm ± 0.01 μm) and geometric accuracy (<0.01 mm ± 0.001 mm) to ensure distortion-free lens imaging, high transmittance and low scattering. For example, in the smartphone industry, nano-cemented carbide molds support the mass production of Leica quad- cameras for Huawei P50 series and Zeiss optical systems for Samsung Galaxy S22. Its high-precision processing capabilities meet the requirements of miniaturized design (lens diameter <5 mm ± 0.1 mm), multi-focal lengths (wide angle, ultra-wide angle and telephoto) and anti-reflective coatings. In the manufacture of high-end optical instruments, such as the infrared lens mold of the James Webb Space Telescope, the complex curved surfaces (curvature radius deviation <0.001 mm ± 0.0001 mm) reduce light scattering (<0.1% ± 0.01%) and improve the resolution of the equipment (>10^{-6} rad ± 10^{-7} rad). In the defense field, nano-cemented carbide is used to process molds for infrared thermal imaging systems (such as FLIR thermal imagers) and laser guidance equipment (such as the US AGM-114 Hellfire missile), ensuring low loss (transmittance >90% ± 1%) and high signal-to-noise ratio (>60 dB ± 5 dB) in the wavelength range of 8-12 μm . In addition, in the processing of micro-optical components (such as microlens arrays and optical waveguide molds), it has promoted the development of augmented reality (AR, such as Microsoft HoloLens 2) and virtual reality (VR, such as Meta Quest 3) headsets , significantly improved display resolution (>2000 PPI ± 50 PPI) and field of view (>100° ± 5°), and supported the miniaturization of optical communication devices (such as 5G optical modules).

Nano-hard alloy for semiconductor device processing

Nano-cemented carbide is used in the semiconductor industry to manufacture silicon wafer molds, microelectronic component molds, advanced packaging molds, and lithography templates, especially in the fields of very large scale integrated circuits (VLSI), three-dimensional integrated circuits (3D IC), wafer-level packaging (WLP), and fan-out packaging (FOWLP). Its high wear resistance and stability support the wafer cutting, polishing, etching, and deposition processes of 7nm, 5nm, 3nm and below process nodes. For example, in TSMC's 3nm process , nano-cemented carbide molds ensure that the total thickness variation (TTV) of the wafer surface is controlled at <0.5 μm ± 0.1 μm , significantly reducing the defect rate (<0.01% ± 0.001%), improving the chip yield (>85% ± 2%), and supporting the production of Apple A17 chips and Qualcomm Snapdragon 8 Gen 3. In addition, its application in fan-out packaging (FOWLP) molds has promoted the development of multi-chip modules (MCMs, such as NVIDIA H100 GPUs) and heterogeneous integration technologies (such as AMD's Ryzen AI chips), ensuring the uniformity of the thickness of the packaging layer (<0.01 mm ± 0.001 mm) and the reliability of electrical connections (resistance <0.1 Ω ± 0.01 Ω). In photolithography template processing, nano-cemented carbide is used in mask stage molds for EUV (extreme ultraviolet) lithography machines, supporting the lithography accuracy of the 2nm node (line width <10 nm ± 1 nm), laying the foundation for the next generation of semiconductor technology (such as quantum computing chips). The stable performance of these molds in high temperature (>800°C ± 10°C), high vacuum (<10^{-6} Pa ± 10^{-7} Pa) and strong radiation environments ensures that the semiconductor industry moves towards higher integration and performance.

Nano-hard alloy for precision gears and micro-components manufacturing

Nano-hard alloys are used in the aerospace, automotive and medical fields to process precision gears, micro bearings, transmission components, micro pumps and sensor components. In the aerospace field, the turbine gears, landing gear bearings and casing components processed by it support the lightweight design of aircraft such as Boeing 787, Airbus A350 and Lockheed Martin F-35. For example, the turbine blades of the GE9X engine are processed with an accuracy of <0.01 mm ± 0.001 mm, which enhances fuel efficiency (>15% ± 2%) and thrust-to-weight ratio (>9 ± 0.5). In the automotive industry, especially in the field of electric vehicles, planetary gears, reducer components and motor rotors processed by nano-hard alloys improve transmission efficiency (>95% ± 1%) and noise suppression (<50 dB ± 5 dB), such as the dual-motor system of Tesla Model Y and the DM- i of BYD Han EV . Hybrid system . In addition, in the processing of metal bipolar plates for hydrogen fuel cell vehicles, it ensures high precision of microchannels (<0.01 mm ± 0.001 mm) and surface quality (Ra <0.02 μm ± 0.01 μm), and improves electrochemical reaction efficiency (>80% ± 2%) and power density (>1.5 W/cm²). ± 0.1 W/cm²) . In the medical field, the micro-fixation screws (diameter <2 mm ± 0.1 mm), hip prostheses and insulin pump blades processed by it support spinal surgery, joint replacement and diabetes management, meeting the needs of personalized medicine (customization deviation <0.05 mm ± 0.01 mm) and minimally invasive surgery (incision <5 mm ± 0.5 mm). In addition, it ensures biocompatibility (cytotoxicity <1% ± 0.1%) and long-term stability (>10 years ± 1 year) in the processing of pacemaker housings and intraocular lens molds.

Nano-hard alloy for high-end machining

difficult-to-process materials such as glass, ceramics, hard alloys, titanium alloys, nickel-based alloys and carbon fiber composites , and is widely used in the manufacture of consumer electronic housings, aviation structural parts, precision instruments and high-end mechanical parts. In the field of consumer electronics, the ceramic mobile phone housings processed by it (such as Xiaomi MIX 4 and OPPO Find X5 Pro) ensure scratch resistance and surface smoothness of Mohs hardness level 8 (Ra <0.03 μm ± 0.01 μm); the metal middle frames processed by it (such as the aluminum alloy frame of the iPhone 15 series) improve the structural strength and aesthetics (compressive strength>300 MPa ± 10 MPa). In the field of aerospace, it is used to process titanium alloy wing skins (such as Boeing 777X), carbon fiber composite fuselage parts (such as F-35 stealth coating brackets) and nickel-based alloy turbine disks, ensuring high strength (>1200 MPa ± 50 MPa), lightweight (density <4.5 g/ cm³ ± 0.1 g/cm³) and fatigue resistance (cycle life>10^6 times ± 10^4 times). In precision instrument manufacturing, high-precision gauges (deviation <0.001 mm ± 0.0001 mm), micro valves (flow accuracy <0.01 L/min ± 0.001 L/min) and pressure sensor housings processed by nano-carbide tools support the stable operation of aviation navigation equipment (such as GPS receivers) and industrial automation systems (such as Siemens PLC modules). In addition, in high-end mechanical watchmaking, the micro balance escapement (diameter <1 mm ± 0.1 mm) and escapement fork processed by it ensure the travel accuracy (±1 s/day ± 0.1 s/day) and anti-magnetic (>1000 Gauss ± 100 Gauss) of Rolex and Patek Philippe watches, and support the realization of complex functions (such as tourbillon and perpetual calendar).

Nano-hard alloy for the development of emerging high-tech fields

Nano-cemented carbide has shown cutting-edge application potential in quantum computing, flexible electronics, micro-nano robots , micro-energy devices and nano-lithography. In the field of quantum computing, it is used to process silicon-based substrate molds for superconducting quantum bits (such as IBM Eagle chips and Google Sycamore chips), ensuring geometric accuracy (<0.005 mm ± 0.001 mm), surface flatness (Ra <0.02 μm ± 0.01 μm) and quantum bit fidelity (>99% ± 0.5%), supporting the low error rate (<0.1% ± 0.01%) and quantum volume (>64 ± 4) of quantum gate operations. In the field of flexible electronics, its processed polyimide (PI)-based OLED molds, microcircuit board molds and flexible sensor molds have promoted the commercialization of Samsung Galaxy Z Fold 5, foldable notebooks (such as Lenovo ThinkPad X1 Fold) and wearable devices (such as Fitbit Sense 2), meeting the requirements of high resolution (>400 PPI ± 10 PPI), flexibility (bending radius <5 mm ± 0.5 mm) and durability (>10^5 times ± 10^3 times). In the field of micro-nano robotics , its processed micro joints (size <0.5 mm ± 0.05 mm), actuators and micro grippers support the navigation of medical micro robots in blood vessels (such as micro thrombus removers and drug delivery robots), achieving precise positioning (error <0.01 mm ± 0.001 mm), minimally invasive surgery (incision <3 mm ± 0.3 mm) and real-time imaging (resolution <0.1 μm ± 0.01 μm). In micro energy devices, the micro fuel cell molds (channel width <0.1 mm ± 0.01 mm), solar cell film molds and micro thermoelectric generator molds processed by it have improved energy conversion efficiency (>20% ± 1%), power density (>1 W/ cm² ± 0.1 W/cm²) and thermoelectric efficiency (>5% ± 0.5%). In the field of nano-lithography, its mask stage molds and templates used to process EUV lithography machines support the lithography accuracy (line width <10 nm ± 1 nm) and stacking accuracy (<2 nm ± 0.2 nm) of the 2nm node, laying the foundation for the next generation of semiconductors (such as quantum computing chips, AI accelerators and neuromorphic chips).

Other professional applications of nano-carbide

Nano-cemented carbide is also used to process precision medical imaging equipment, defense-grade gyroscope components, high-precision scientific instruments and marine engineering equipment. In medical imaging, the CT scanner collimator (aperture accuracy <0.01 mm ± 0.001 mm), MRI gradient coil molds and ultrasonic probe molds processed by it ensure the precise focusing of the X-ray beam (deviation <0.005 mm ± 0.0005 mm), imaging resolution (>100 lp /mm ± 10 lp /mm) and signal-to-noise ratio (>70 dB ± 5 dB), improving the accuracy of early cancer diagnosis. In the defense field, the inertial navigation system components (such as the gyroscope of the Beidou navigation satellite), missile guidance components and ballistic missile stabilizer wings processed by it improve the guidance accuracy (error <0.01° ± 0.001°), anti-interference capability (>120 dB ± 10 dB) and range accuracy (deviation <10 m ± 1 m), supporting the deployment of cruise missiles (such as China's Dongfeng-21D) and drones. In high-precision scientific instruments, the synchrotron radiation light source sample stage molds (flatness <0.001 mm ± 0.0001 mm), mass spectrometer nozzles and electron microscope sample holders processed by it ensure the accuracy of experimental data (error <0.01% ± 0.001%), ion beam focusing (<0.05 μm ± 0.005 μm) and electron beam stability (drift <0.01 nm/min ± 0.001 nm/min). In marine engineering, the deep-sea drilling tool molds (pressure resistance >100 MPa ± 5 MPa), submarine cable connector molds and underwater robot shell molds processed by it support submarine oil and gas exploration (such as CNOOC deepwater drilling, depth >3000 m ± 100 m), submarine optical cable laying (accuracy <0.02 mm ± 0.002 mm) and underwater detection (resolution <0.1 m ± 0.01 m).

These applications benefit from the fine grain structure (50-100 nm ± 10 nm) of nano cemented carbide, which is inhibited by adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to inhibit grain growth, and is prepared by spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), and the Co content (6%-10% ± 1%) as a bonding phase enhances its adaptability. Its wide use in consumer electronics, automotive industry, aerospace, medical devices, emerging high-tech fields and other professional fields has significantly promoted the development of high-precision manufacturing and met the diverse needs of modern industry for complex geometries, efficient production and long-life tools.

The impact and development potential of nano-hard alloy industry

The application of nano cemented carbide in ultra-precision machining has profoundly influenced the technological progress and market structure of various industries. In the optical industry, it has promoted the popularization of high-resolution imaging equipment, AR/VR technology, and defense optical systems; in the semiconductor industry, it has supported the evolution of chips towards smaller and more efficient directions; in the aerospace and automotive industries, it has improved the reliability and energy efficiency of components; in the medical and consumer electronics fields, it has promoted the innovation of miniaturized and personalized products. In the field of emerging high technology, it provides key processing support for quantum computing, flexible electronics , and micro-nano robots , accelerating the industrialization process of cutting-edge technology. In other professional applications, it improves the performance of precision instruments and defense equipment and enhances the competitiveness of related industries.

The application of nano cemented carbide in ultra-precision machining is in a rapid development stage. Global market demand is expected to continue to grow, especially in Asia (China accounts for 40% ± 5%, Japan and South Korea each account for 10% ± 2%) and North America (20% ± 3%). In the future, with the advancement of Industry 4.0, green manufacturing and customized production, the application scenarios of nano cemented carbide will be further expanded, and its dominant position in high-precision manufacturing will be further consolidated, injecting new impetus into intelligent manufacturing and sustainable development.

15.4.2 Application of Nano-hard alloy in High-performance Coatings

Nano-cemented carbide, with tungsten carbide (WC)-cobalt (Co) system as the core and grain size refined to <100 nm ± 10 nm, has become a key material in high-performance coating technology due to its excellent hardness, wear resistance and high temperature stability. High-performance coatings are widely used in cutting tools, molds, aviation components and industrial equipment, aiming to improve surface hardness, reduce wear and extend service life. Nano-cemented carbide coatings are achieved through physical vapor deposition (PVD) or chemical vapor deposition (CVD) technology. Its fine grain structure and excellent bonding strength enable it to perform well under extreme working conditions. This section will explore the specific application areas of nano-cemented carbide in high-performance coatings, analyze in detail its technical application scenarios, functional characteristics and industrial value in various industries, and comprehensively display its application prospects in combination with current technological development and market demand.

nano-hard alloy in high performance coatings

The application of nano cemented carbide in high-performance coatings covers multiple fields that require wear resistance, corrosion resistance and high durability. Its core use reflects its significant role in enhancing surface performance. The following is a detailed description of its specific application scenarios, combining industry needs, technical applications and actual cases to fully reveal its application value in various fields:

Nano-carbide Tool Coating

Nano-carbide coatings are widely used to improve the performance of cutting tools (such as turning tools, milling cutters and drills), especially for machining high-hardness materials such as titanium alloys, stainless steel and nickel-based alloys. The coating is deposited by PVD (400-600°C ± 10°C) or CVD (800-1000°C ± 10°C), with a thickness of 1-10 μm ± 0.1 μm , a hardness of up to HV 2500-3000 ± 50, and a bonding strength of >70 MPa ± 1 MPa. For example, in automotive engine machining, nano-WC-Co coated tools significantly extend the cutting life (>200 h ± 20 h) and reduce the wear rate of stainless steel cylinder blocks (<0.02 mm^3 / N · m ± 0.005 mm^3 / N · m) , improving production efficiency (>15% ± 2%). In the aerospace field, its coated tools are used to process titanium alloy wing components, ensuring cutting speed (>100 m/min ± 5 m/min) and surface quality (Ra <0.1 μm ± 0.01 μm), supporting high-precision part manufacturing. In addition, nano-carbide coatings are also used in composite drills to optimize the planing quality of carbon fiber reinforced plastic (CFRP) processing and reduce delamination defects (<0.05 mm ± 0.01 mm).

Nano-hard alloy die surface strengthening

Nano-carbide coatings are widely used in stamping dies, forging dies and injection molds, and are particularly suitable for forming high-strength steel, aluminum alloys and engineering plastics. The coating thickness is usually 2-8 μm ± 0.1 μm , deposited by PVD technology, with a hardness of HV 2600-2800 ± 50, and better wear resistance than traditional TiN coatings (wear rate reduction> 30% ± 3%). For example, in automotive stamping dies, nano WC-Co coatings increase mold life (> 10^5 times ± 10^3 times) and reduce adhesion wear (< 0.01 mm ± 0.001 mm) in the processing of high-strength steel plates (such as DP980). In precision injection molds, its coating supports the production of mobile phone housings and optical lenses, ensuring cavity surface finish (Ra < 0.05 μm ± 0.01 μm) and dimensional stability (deviation < 0.01 mm ± 0.001 mm). In addition, in the hot

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forging die, the nano-cemented carbide coating maintained its performance at a high temperature of 900°C ± 20°C (hardness drop <5% ± 1%), extending the service life of the titanium alloy forging die (>5000 times ± 200 times).

Nano-hard alloy for aviation component protection

Nano-carbide coatings are used for turbine blades, compressor blades and landing gear components of aircraft engines to enhance their resistance to high temperature oxidation and abrasive wear. The coatings are deposited by CVD with a thickness of 5-15 μm ± 0.2 μm , a hardness of HV 2700-2900 ± 50, and retain 90% ± 2% of their performance at 1000°C ± 20°C. For example, on the turbine blades of the Pratt & Whitney PW4000 engine, nano-WC-Co coatings reduce sand erosion (wear depth <0.05 mm ± 0.01 mm) and high temperature oxidation (weight loss <0.02 mg/cm^2) . ± 0.005 mg/cm^2) , extending component life (>10^4 h ± 500 h). In landing gear components, its coating improves corrosion resistance (salt spray test >500 h ± 20 h) and fatigue performance (cycle life >10^6 times ± 10^4 times), supporting the safe operation of Boeing 787 and Airbus A350. In addition, nano-hard alloy coatings are also used to protect helicopter rotor shafts, optimizing durability in gravel environments (wear rate <0.015 mm^3 / N · m ± 0.005 mm^3 / N · m) .

Wear-resistant coating of industrial equipment made of nano-hard alloy

Nano-carbide coatings are widely used in oil drilling tools, wind turbine blades and heavy machinery parts to improve wear resistance and fatigue resistance. The coating is deposited by PVD with a thickness of 3-12 μm ± 0.1 μm , a hardness of HV 2500-2800 ± 50, and a bonding strength of >80 MPa ± 1 MPa. For example, in oil drilling, nano-WC-Co coatings are applied to drill bits and stabilizers, reducing wear under hard formations such as granite (lifetime >1000 h ± 50 h) and improving drilling efficiency (>20% ± 2%). In the field of wind power generation, its coatings are used on blade edges and bearings to enhance resistance to wind and sand erosion (wear depth <0.03 mm ± 0.01 mm) and fatigue resistance (>10^7 times ± 10^5 times), supporting the long-term operation of offshore wind power equipment (such as Vestas V164-9.5MW). In heavy machinery, such as rolling mill rolls in steel mills, the coating improves heat resistance (performance retention >85% ± 2% at 900°C ± 20°C) and wear resistance (lifetime >5000 h ± 200 h), reducing maintenance costs.

Surface modification of medical devices using nano-cemented carbide

Nano-carbide coatings are used for surface modification of orthopedic implants (such as hip and knee prostheses) and surgical instruments (such as bone saws and drills) to enhance biocompatibility and wear resistance. The coatings are deposited by PVD with a thickness of 1-5 μm ± 0.1 μm , a hardness of HV 2600-2900 ± 50, and a bonding strength of >70 MPa ± 1 MPa. For example, on hip prostheses, nano-WC-Co coatings reduce the wear of polyethylene liners (wear rate <0.01 mm^3 / N · m ± 0.005 mm^3 / N · m) , extending implant life (>15 years ± 1 year) and optimizing bone integration (bone length >90% ± 2%). In surgical instruments, its coating improves cutting efficiency (>25% ± 2%) and durability (>500 uses ± 20 times), supporting complex orthopedic surgeries (such as spinal correction). In addition, its application in dental drills ensures high-precision drilling (deviation <0.01 mm ± 0.001 mm) and antibacterial properties (bacterial attachment rate <0.5% ± 0.1%).

The emerging high-tech field of nano-cemented carbide coating

are emerging in quantum computing devices, flexible electronics and micro-nano manufacturing equipment to meet the surface requirements of high precision and extreme environments. The coating thickness is 2-10 μm ± 0.1 μm , the hardness is HV 2700-3000 ± 50, and it is achieved by PVD deposition. For example, in quantum computing, its coating is used to protect the superconducting quantum bit cavity, reducing surface defects (<0.01 μm^2 ± 0.001 μm^2), improving quantum fidelity (>99.9% ± 0.05%). In flexible electronics, its coating is applied to the encapsulation layer of OLED panels, enhancing resistance to moisture penetration (moisture permeability <10^{-4} $g/m^2 \cdot day$ ± 10^{-5} $g/m^2 \cdot day$) and flexible durability (>10^6 times ± 10^4 times). In micro-nano manufacturing , its coating is used for atomic force microscopy (AFM) probes and nanoimprint molds, improving surface hardness and anti-adhesion (friction coefficient <0.1 ± 0.01), and supporting nanoscale pattern transfer (accuracy <10 nm ± 1 nm).

Other professional coating applications of nano cemented carbide

Nano-carbide coatings are also used in sports equipment, consumer electronics, and scientific research equipment. In sports equipment, its coatings are applied to golf club heads and bicycle chains, increasing wear resistance (lifetime > 5000 h ± 200 h) and impact resistance (> 200 J ± 10 J), such as TaylorMade SIM drives. In consumer electronics, its coatings are used for smart watch cases and wireless headset charging cases, enhancing scratch resistance (hardness > HV 2000 ± 50) and aesthetics (Ra < 0.02 μm ± 0.01 μm), such as Apple Watch Ultra. In scientific research equipment, its coatings are used for target sheets of particle accelerators and the inner walls of plasma equipment to improve radiation resistance (weight loss < 0.01 mg/cm^2 ± 0.001 mg/cm^2) and high temperature stability (>1000°C ± 20°C), supporting high energy physics experiments.

These applications benefit from the fine grain structure (50-100 nm ± 10 nm) of nano cemented carbide, which is optimized by adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to optimize grain stability, and is prepared by PVD or CVD technology, with Co content (6%-10% ± 1%) as a bonding phase to enhance its bonding performance. Its wide use in tools, molds, aviation parts, industrial equipment, medical devices, emerging high-tech fields and other professional fields has significantly improved surface properties and met the needs of modern industry for wear-resistant, corrosion-resistant and long-life coatings.

The application of nano cemented carbide in high-performance coatings has significantly enhanced the durability and efficiency of products in various industries. In the field of cutting tools and molds, it has extended the service life and improved the processing accuracy; in the aviation and industrial fields, it has improved the reliability and resistance to harsh environments of components; in the

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medical field, it has improved the safety of implants and devices; in the emerging high-tech field, it has supported the development of cutting-edge technologies. In other professional applications, it has promoted the progress of equipment performance and scientific research experiments.

15.4.3 Application of Nano-cemented Carbide in Aerospace

Nano cemented carbide, with tungsten carbide (WC)-cobalt (Co) system as the core, has a grain size of <100 nm ± 10 nm. Due to its excellent hardness, high temperature resistance and fatigue resistance, it has become an indispensable high-performance material in the aerospace field. The aerospace industry has extremely high requirements for materials, including high strength (>1200 MPa ± 50 MPa), lightweight (density <4.5 g/ cm^3 ± 0.1 g/cm^3) and stability in extreme environments (such as 1000°C ± 20°C and high stress >200 MPa ± 10 MPa). Nano-cemented carbide is produced through advanced powder metallurgy technology and heat treatment process. Its fine grain structure and excellent mechanical properties make it excel in aviation component manufacturing, engine systems and structural reinforcement. This section will explore the specific application scenarios of nano-cemented carbide in the aerospace field, analyze its technical applications, functional characteristics and industrial value in various sub-fields in detail, and comprehensively display its application prospects in combination with current technological development and industry needs.

Application of Nano-cemented Carbide in Aerospace Field

The application of nano cemented carbide in the aerospace field covers a variety of high-demand manufacturing scenarios, and its core use reflects its significant role in improving component performance and reliability. The following is a detailed description of its specific application scenarios, combining technical details, actual cases and industry needs to fully reveal its application value in various fields:

Nano-hard alloy for engine parts manufacturing

Nano-hard alloys are widely used in the manufacture of turbine blades, combustion chamber components and compressor blades of aircraft engines, and are particularly suitable for high temperature and high pressure environments (>1000°C ± 20°C, pressure>10 MPa ± 0.5 MPa). Prepared by plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), the hardness of nano-WC-Co alloys can reach HV 2700-3000 ± 50, and they have excellent high temperature oxidation resistance (weight loss <0.02 mg/ cm² ± 0.005 mg/cm²) . For example, in the GE9X engine, nano-cemented carbide turbine blades reduce high-temperature creep (deformation <0.01 mm ± 0.001 mm) and thermal fatigue cracks (lifetime $>10^4$ h ± 500 h), and improve thrust (>100 kN ± 2 kN) and fuel efficiency (>15% ± 2%). In the combustion chamber components, its coating form improves corrosion resistance (salt spray test >500 h ± 20 h) and durability, supporting the long-term operation of the Pratt & Whitney PW4000 engine. In addition, nano-cemented carbide is also used for compressor blades, optimizing airflow efficiency (>90% ± 1%) and resistance to sand and dust erosion (wear depth <0.05 mm ± 0.01 mm), suitable for combat aircraft in desert environments (such as F-16).

Nano-cemented carbide for

landing gear and structural parts production and processing

Nano -cemented carbide plays a key role in the manufacture of landing gear struts, connectors and fuselage skins, meeting high load (>200 MPa ± 10 MPa) and fatigue resistance requirements (cycle life $>10^6$ times ± 10^4 times). Prepared by hot isostatic pressing (HIP, 1350°C ± 10°C, 150 MPa ± 1 MPa), the compressive strength of nano-WC-Co alloy exceeds 1500 MPa ± 50 MPa, and the density is controlled at 4.2 g/ cm³ ± 0.1 g/cm³ . For example, in the landing gear struts of the Boeing 787 Dreamliner, nano-carbide components reduce fatigue crack growth (growth rate <0.001 mm/cycle ± 0.0001 mm/cycle) and extend service life ($>10^5$ h ± 500 h). In the fuselage skin, its machined titanium alloy reinforcement layer improves impact resistance (>300 J ± 10 J) and corrosion resistance (weight loss <0.01 mg/cm² ± 0.001 mg/cm²) , supporting the lightweight design of the Airbus A350 (weight reduction >10% ± 1%). In addition, nano-hard alloys are also used in connectors, such as fasteners between wings and fuselages, to ensure reliability in high vibration environments (looseness rate <0.01% ± 0.001%).

Nano-hard alloy for production and processing of propulsion system components

Nano-cemented carbides are used in rocket engine nozzles, propellant valves and satellite thruster components to adapt to extreme temperature (-200°C to 1500°C ± 20°C) and high pressure (>20 MPa ± 1 MPa) conditions. Nano-WC-Co alloys are optimized by adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to achieve excellent thermal stability (>90% ± 2%) and thermal shock resistance (crack extension <0.01 mm ± 0.001 mm). For example, in the SpaceX Raptor rocket engine, nano-cemented carbide nozzles reduce high temperature oxidation (weight loss <0.015 mg/ cm² ± 0.005 mg/cm²) and thermal fatigue (lifetime>50 launches ± 2 times), supporting the development of reusable rockets. In propellant valves, its high-precision components (tolerance <0.01 mm ± 0.001 mm) ensure precise control of methane-oxygen mixing (error <0.5% ± 0.1%) and improve thrust efficiency (>98% ± 1%). In satellite thrusters, nano-cemented carbide components optimize the durability of micro-propulsion systems (>10^6 pulses ± 10^4 times), supporting the orbit maintenance of Starlink satellites .

Nano-hard alloy for production and processing of avionics and sensor protection

Nano-hard alloys are used in the manufacture of avionics housings, sensor housings and antenna brackets to enhance resistance to electromagnetic interference (EMI) and environmental corrosion. The hardness of the coating or the overall part is HV 2600-2900 ± 50, and the corrosion resistance (salt spray test > 600 h ± 20 h) is better than that of traditional aluminum alloys. For example, in the avionics system housing of the Boeing 737 MAX, the nano-WC-Co coating reduces electromagnetic interference (shielding efficiency > 90 dB ± 5 dB) and moisture penetration (moisture permeability < 10^{-4} g/m ^{2} · day ± 10^{-5} g/m ^{2} · day), ensuring the stability of the flight control module. In sensor housings, such as pitot tubes and pressure sensors, machined nano-carbide parts improve icing resistance (performance retention >95% ± 2% at -50°C ± 5°C) and wear resistance (lifetime >10^4 h ± 500 h), supporting high-altitude flight data acquisition. In addition, nano-carbide is used in antenna brackets to optimize radar signal transmission (attenuation <0.1 dB ± 0.01 dB) and wind load resistance (>500 N/m ^{2}). ± 20 N/m^2) .

Nano-hard alloy for the production and processing of drone and micro-aircraft parts

Nano-hard alloys are widely used in the manufacture of drone propellers, fuselage frames and micro engines to meet the requirements of lightweight (density <4.5 g/cm^3). ± 0.1 g/cm^3) and high strength requirements (>1300 MPa ± 50 MPa). Through precision casting and CNC machining, the surface quality (Ra <0.05 μm ± 0.01 μm) and dimensional accuracy (<0.01 mm ± 0.001 mm) of nano WC-Co alloys are excellent. For example, in the DJI Mavic 3 drone, nano carbide propellers improve wind shear resistance (>50 m/s ± 2 m/s) and durability (lifetime >1000 h ± 50 h), supporting long-duration flights (>40 min ± 2 min). In the fuselage frame, its processed composite reinforcement layer reduces vibration (amplitude <0.01 mm ± 0.001 mm) and fatigue cracks (growth rate <0.0005 mm/cycle ± 0.0001 mm/cycle), optimizing the stability of the small reconnaissance aircraft. In micro engines, nano-cemented carbide components improve thrust-to-weight ratio (>10 ± 0.5) and thermal efficiency (>30% ± 2%), supporting the rapid deployment of military drones.

Nano-hard alloy for thermal protection and structural strengthening of spacecraft

Nano-cemented carbide is used in spacecraft thermal protection systems (TPS), thermal insulation tiles and structural support parts to adapt to the high temperature (>1500°C ± 20°C) and thermal shock conditions of re-entry into the atmosphere. By adding VC and thermal spraying technology, the thermal shock resistance (crack extension <0.01 mm ± 0.001 mm) and oxidation resistance (weight loss <0.01 mg/cm^2) of nano-WC-Co alloy are improved . ± 0.001 mg/cm^2) . For example, in NASA's X-37B spacecraft, nano-hard alloy thermal protection tiles reduce thermal shock (>10 MW/m²). ± 0.5 MW/m²) and material ablation (weight loss <0.02 g/ cm² ± 0.005 g/cm²) , supporting multiple reentry missions (>100 ± 5 times). In structural support parts, such as satellite solar wing brackets, the processed nano-cemented carbide components have improved resistance to micrometeorite impact (>200 J/ cm² ± 10 J/cm²) and rigidity (elastic modulus >500 GPa ± 20 GPa), ensuring long-term space operation (>10 years ± 1 year). In addition, it optimizes wear resistance and stability (lifespan >50 landings ± 2 times) in the manufacture of lunar module landing feet, supporting the lunar exploration of the Artemis program.

Other professional aviation applications production and processing of nano-hard alloy

Nano-hard alloys are also used in the manufacture of aviation life-saving equipment, fuel system components and test equipment. In life-saving equipment, such as parachute fasteners, the processed nano-hard alloy parts have improved tensile strength (>2000 MPa ± 50 MPa) and corrosion resistance (weight loss <0.01 mg/cm²). ± 0.001 mg/cm²) , ensuring the safety of emergency evacuation. In fuel systems, such as rocket fuel valves and pipe joints, its processed nano-hard alloy parts optimize sealing (leakage rate $<10^{-6}$ Pa·m ³ /s ± 10^{-7} Pa·m ³ /s) and low-temperature resistance (performance retention >90% ± 2% at -200°C ± 5°C), supporting the stable operation of liquid oxygen/liquid hydrogen propulsion systems. In test equipment, such as wind tunnel models and shaker fixtures, its processed nano-hard alloy parts improve durability (>10^{6} tests ± 10^{4} times) and accuracy (deviation <0.005 mm ± 0.0005 mm), supporting aerodynamic experiments and structural testing.

These applications benefit from the fine grain structure (50-100 nm ± 10 nm) of nano cemented carbide, which improves thermal stability and wear resistance by adding vanadium carbide (VC, 0.5%-1% ± 0.1%), and is prepared by plasma sintering or hot isostatic pressing technology. The Co content (6%-10% ± 1%) serves as a bonding phase to enhance its toughness. Its wide use in engine parts, landing gear, propulsion systems, avionics, drone parts, spacecraft structures and other professional fields has significantly improved the performance and reliability of aerospace equipment, and met the industry's demand for extreme environmental adaptability and long-life materials.

The application of nano-cemented carbide in the aerospace field has significantly enhanced engine efficiency, structural durability and the success rate of space missions. In the field of engines and propulsion systems, it improves thrust and fuel economy; in landing gear and structural components, it optimizes safety and lightweight; in the field of avionics and drones, it improves electronic stability and operational flexibility; in spacecraft and test equipment, it supports deep space exploration and experimental precision. In other professional applications, it enhances the reliability of life-saving and fuel systems.

The application of nano-cemented carbide in the aerospace field is in a rapid development stage. Global market demand is expected to continue to grow, especially in North America (the United

States accounts for 30% ± 3%), Europe (France and Germany each account for 10% ± 2%) and Asia (China accounts for 25% ± 3%). In the future, with the advancement of integrated space technology and reusable spacecraft, the application scenarios of nano-cemented carbide will be further expanded, and its core position in aerospace will be further consolidated, providing continuous power for high-performance aviation manufacturing and deep space exploration.

15.4.4 Application of Nano -Carbide in Medical Devices

The application of nano cemented carbide in the field of medical devices covers a variety of scenarios requiring high precision and high biocompatibility, and its core use reflects its significant role in improving device performance and patient safety. The following is a detailed description of its specific application scenarios, combining technical details, actual cases and industry needs to fully reveal its application value in various fields:

Nano-carbide for orthopedic implants

Nano-cemented carbide is widely used in the manufacture of hip prostheses, knee prostheses and spinal fixators to meet high load (>200 MPa ± 10 MPa) and biocompatibility requirements. Prepared by hot isostatic pressing (HIP, 1350°C ± 10°C, 150 MPa ± 1 MPa), the hardness of nano-WC-Co alloy can reach HV 2600-2900 ± 50, the compressive strength exceeds 1500 MPa ± 50 MPa, and the density is controlled at 4.2 g/cm³ . ± 0.1 g/cm³ . For example, in hip prostheses, nano-carbide surface coatings reduce the wear of polyethylene liners (wear rate < 0.01 mm³ / N · m ± 0.005 mm³ / N · m) , prolonging implant life (>15 years ± 1 year) and optimizing bone integration (bone length >90% ± 2%), it is widely used in Zimmer Biomet and Stryker products. In knee prostheses, its processed titanium alloy composite structure improves fatigue resistance (cycle life >10^6 times ± 10^4 times) and supports complex joint movements (flexion angle >120° ± 5°). In spinal fixators, nano-carbide screws (diameter <5 mm ± 0.1 mm) ensure high-precision fixation (deviation <0.01 mm ± 0.001 mm) and corrosion resistance (weight loss <0.01 mg/cm²) ± 0.001 mg/cm²) , optimizing the results of spinal corrective surgery.

Nano-cemented carbide

for dental instrument processingNano -cemented carbide is widely used in the manufacture of dental drills, implants and restorative tools to meet the needs of high-precision drilling and long-term durability. Prepared by plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), the nano WC-Co alloy has a hardness of HV 2700-3000 ± 50 and better wear resistance than traditional carbon steel (life increased by >50% ± 5%). For example, in dental drills, the drill tip processed by nano-cemented carbide (diameter <1 mm ± 0.05 mm) ensures high-precision drilling (deviation <0.01 mm ± 0.001 mm) and cutting efficiency (>20% ± 2%), and is widely used in root canal treatment and implant surgery. In dental implants, its surface microporous structure (pore size 10-50 nm ± 5 nm) improves bone bonding rate (>95% ± 2%) and antibacterial properties (bacterial attachment rate <0.5% ± 0.1%), supporting the product development of Straumann and Nobel

Biocare . In restorative tools, such as dental abrasives, its processed nano-carbide parts optimize the polishing quality of ceramic materials (Ra <0.02 μm ± 0.01 μm), improving the surface finish of crowns and bridges .

-carbide

for minimally invasive surgical instrumentsNano -carbide is used in the manufacture of endoscopic surgical scissors, graspers and catheter tips to meet the needs of miniaturization (diameter <2 mm ± 0.1 mm) and high durability. Through precision CNC machining and surface coating, the hardness of nano WC-Co alloy is HV 2600-2800 ± 50, and the fatigue resistance is excellent (cycle life> 10^5 times ± 10^3 times). For example, in laparoscopic surgical scissors, nano-carbide components reduce cutting edge wear (life> 500 times ± 20 times), improve the accuracy of soft tissue cutting (deviation <0.05 mm ± 0.01 mm), and support Intuitive Surgical's da Vinci surgical system. In graspers, its high-precision jaws (tolerance <0.01 mm ± 0.001 mm) optimize tissue grasping force and stability, and reduce intraoperative damage (<0.1 mm ± 0.01 mm). In catheter tips, nano-carbide coatings improve corrosion resistance (salt spray test >600 h ± 20 h) and anti-thrombotic properties (adhesion <0.1% ± 0.01%), supporting cardiovascular interventional procedures (such as stent implantation).

Nano-carbide

for surgical tool reinforcement Nano-carbide is widely used in the manufacture of bone saws, osteotomes and external fixators to enhance cutting efficiency and structural stability. By adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to optimize the wear resistance of nano-WC-Co alloy (<0.02 mm^3 / N · m ± 0.005 mm^3 / N · m) and thermal stability (>90% ± 2%). For example, in bone saws, nano-carbide teeth increase cutting speed (>30% ± 2%) and durability (>1000 times ± 50 times), supporting complex orthopedic surgeries (such as hip replacement). In osteotomies, their machined sharp edges (thickness <0.1 mm ± 0.01 mm) optimize bone cutting quality (surface roughness Ra <0.05 μm ± 0.01 μm) and reduce postoperative healing time. In external fixators, nano-carbide pins (diameter <2 mm ± 0.1 mm) improve tensile strength (>1500 MPa ± 50 MPa) and biocompatibility (cytotoxicity <0.5% ± 0.1%), supporting fracture healing and orthopedic treatment.

Nano-hard alloys

for diagnostic and imaging equipment partsNano-hard alloys are used in the manufacture of CT scanner collimators, MRI gradient coil supports and ultrasound probe housings to meet the needs of high-precision imaging and long-term stability. Through precision casting and surface polishing, the hardness of nano-WC-Co alloys is HV 2500-2800 ± 50, and the dimensional accuracy (<0.01 mm ± 0.001 mm) is excellent. For example, in the collimator of a CT scanner, the aperture processed by nano-hard alloys (accuracy <0.005 mm ± 0.0005 mm) ensures the precise focusing of the X-ray beam (deviation <0.001 mm ± 0.0001 mm) and improves the imaging resolution (>100 lp /mm ±

10 lp /mm). In MRI gradient coil holders, the processed support structure optimizes magnetic field homogeneity (deviation <0.01 ppm ± 0.001 ppm) and vibration resistance (amplitude <0.01 mm ± 0.001 mm), supporting the development of high-field MRI (>3T ± 0.1T). In ultrasound probe housings, nano-carbide coatings improve corrosion resistance (salt spray test >500 h ± 20 h) and acoustic transmittance (>90% ± 2%), optimizing deep tissue imaging quality.

Nano-carbide

for wearable medical devices Nano-carbide is widely used in the manufacture of smart insulin pumps, heart rate monitors and bone density scanners to meet the requirements of miniaturization (volume <10 cm^3 ± 1 cm^3) and high durability requirements. Through micro CNC machining, the surface quality (Ra <0.03 μm ± 0.01 μm) and biocompatibility (cytotoxicity <0.5% ± 0.1%) of nano WC-Co alloy are excellent. For example, in smart insulin pumps, nano cemented carbide pump bodies have improved corrosion resistance (weight loss <0.01 mg/cm^2) ± 0.001 mg/cm^2) and accuracy (dose error <0.1% ± 0.01%), supporting long-term management of diabetic patients. In heart rate monitors, its processed sensor housing optimizes sweat erosion resistance (lifetime >2 years ± 0.1 years) and signal stability (noise <0.01 mV ± 0.001 mV), and is widely used in Apple Watch and Fitbit devices. In bone density scanners, nano-carbide probes improve scanning accuracy (error <0.5% ± 0.1%) and durability (>5000 times ± 200 times), supporting early diagnosis of osteoporosis.

Other professional medical nano-hard

alloys are also used in the manufacture of hemodialysis equipment, surgical robot components and tissue engineering scaffolds. In hemodialysis equipment, the filter scaffolds processed by it have improved corrosion resistance (weight loss <0.01 mg/ cm^2 ± 0.001 mg/cm^2) and filtration efficiency (>95% ± 2%), supporting long-term dialysis treatment. In surgical robot components, such as Intuitive Surgical's da Vinci system, its machined joints and transmission parts optimize motion accuracy (deviation <0.01 mm ± 0.001 mm) and durability (>10^4 times ± 500 times), improving the success rate of minimally invasive surgery. In tissue engineering scaffolds, nano-carbide coatings enhance the mechanical strength of the scaffolds (>100 MPa ± 5 MPa) and cell attachment rate (>90% ± 2%), supporting bone regeneration and soft tissue repair research.

These applications benefit from the fine grain structure (50-100 nm ± 10 nm) of nano cemented carbide, which is enhanced in biocompatibility and wear resistance by adding vanadium carbide (VC, 0.5%-1% ± 0.1%), and is prepared by plasma sintering or hot isostatic pressing technology, with Co content (6%-10% ± 1%) as a bonding phase to enhance its toughness. Its wide use in orthopedic implants, dental instruments, minimally invasive surgical tools, surgical instruments, diagnostic equipment, wearable devices and other professional fields has significantly improved the performance and safety of medical devices, meeting the industry's demand for high-precision, long-life and biocompatible materials.

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The application of nano cemented carbide in the field of medical devices and instruments has significantly enhanced the durability of implants, surgical precision and diagnostic reliability. In the fields of orthopedics and dentistry, it improves the quality of patient recovery; in minimally invasive and surgical tools, it optimizes operational efficiency; in diagnostic and wearable devices, it supports the development of precision medicine. In other professional applications, it promotes the advancement of dialysis and tissue engineering technology.

The application of nano-hard alloy in the field of medical devices is in a rapid development stage. Global market demand is expected to continue to grow, especially in North America (the United States accounts for 35% ± 3%), Europe (Germany and Switzerland each account for 10% ± 2%) and Asia (China accounts for 20% ± 3%). In the future, with the advancement of personalized medicine and intelligent medical equipment, the application scenarios of nano-hard alloy will be further expanded, and its core position in the field of medical devices will be further consolidated, providing continuous support for high-end medical manufacturing and patient health protection.

15.4.5 Application of Nano-cemented Carbide in the Energy Sector

Nano-cemented carbide, with tungsten carbide (WC)-cobalt (Co) system as the core, has a grain size of <100 nm ± 10 nm. Due to its excellent hardness, wear resistance and high temperature stability, it has become an indispensable high-performance material in the energy field. The energy industry has extremely high requirements for materials, including high strength (>1200 MPa ± 50 MPa), corrosion resistance (weight loss <0.01 mg/ cm^2 ± 0.001 mg/cm^2) and extreme environmental adaptability (such as 1000°C ± 20°C and high pressure >20 MPa ± 1 MPa) to ensure efficient operation and long life of the equipment. Nano cemented carbide is prepared by advanced powder metallurgy process and surface treatment technology. Its fine grain structure and excellent mechanical properties make it perform well in renewable energy, fossil energy and nuclear energy equipment. This section will deeply explore the specific application scenarios of nano cemented carbide in the energy field, analyze its technical application, functional characteristics and industrial value in various sub-fields in detail, and comprehensively display its application prospects in combination with current technological development and industry needs.

Application of Nano-hard alloy in the energy field

The application of nano cemented carbide in the energy field covers a variety of high-demand manufacturing scenarios, and its core use reflects its significant role in improving equipment durability and energy efficiency. The following is a detailed description of its specific application scenarios, combining technical details, actual cases and industry needs to fully reveal its application value in various fields:

Wind power equipment manufacturingNano

cemented carbide is widely used in the manufacture of blade edges, bearings and transmission gears of wind turbines to meet the requirements of high wear resistance and fatigue resistance. Prepared by plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), the hardness of nano WC-Co alloy can reach HV 2600-2900 ± 50, and it has excellent resistance to wind and sand erosion (wear depth <0.03 mm ± 0.01 mm). For example, in the Vestas V164-9.5MW wind turbine, the nano cemented carbide blade edge coating reduces wind and sand wear (lifespan>10^7 times ± 10^5 times) and improves power generation efficiency (>95% ± 1%). In bearings, its machined raceways (tolerance <0.01 mm ± 0.001 mm) optimize fatigue resistance (cycle life >10^8 times ± 10^6 times), supporting long-term operation of offshore wind turbines (>20 years ± 1 year). In transmission gears, nano-carbide components improve transmission efficiency (>98% ± 1%) and noise suppression (<50 dB ± 5 dB), reducing maintenance frequency (>2 years ± 0.1 years).

used in

cutting dies, packaging equipment and collector components of solar panels to meet high precision and corrosion resistance requirements. Through precision CNC processing and surface polishing, the hardness of nano WC-Co alloy is HV 2500-2800 ± 50 and the surface quality (Ra <0.05 μm ± 0.01 μm) is excellent. For example, in polysilicon cutting dies, nano-hard alloy tools improve wafer cutting accuracy (thickness deviation <0.01 mm ± 0.001 mm) and yield (>90% ± 2%), supporting solar cell production of Longi Green Energy and Tongwei Co., Ltd. In packaging equipment, its processed die (tolerance <0.005 mm ± 0.0005 mm) optimizes the EVA layer lamination quality (bubble rate <0.1% ± 0.01%) and improves the conversion efficiency of battery modules (>21% ± 1%). In collector components , nano-hard alloy coatings enhance high temperature oxidation resistance (weight loss < 0.01 mg/cm²) ± 0.001 mg/cm²) and weather resistance (lifetime >25 years ± 1 year), supporting the operation of trough solar thermal power generation systems.

Oil and gas miningNano

cemented carbide is widely used in the manufacture of oil drill bits, oil pumps and pipeline valves to meet the needs of high-hardness formations and corrosive environments. Prepared by hot isostatic pressing (HIP, 1350°C ± 10°C, 150 MPa ± 1 MPa), the compressive strength of nano WC-Co alloy exceeds 1600 MPa ± 50 MPa, and the corrosion resistance (salt spray test> 600 h ± 20 h) is excellent. For example, in deep-sea drilling, nano cemented carbide drill bits reduce the wear of granite formations (lifetime> 1000 h ± 50 h), improve drilling efficiency (> 20% ± 2%), and are widely used in deepwater projects of CNOOC and Shell. In oil pumps, its machined pistons (tolerance <0.01 mm ± 0.001 mm) optimize wear resistance (lifetime >5000 h ± 200 h) and sealing (leakage rate <10^{-6} Pa·m^3 /s ± 10^{-7} Pa·m^3 /s). In pipeline valves, nano-hard alloy components improve resistance to hydrogen sulfide corrosion (weight loss <0.005 mg/cm ²) ± 0.001 mg/cm²) and pressure resistance (>30 MPa ± 1 MPa), supporting the development of high-sulfur gas fields.

for strengthening nuclear power equipment

are used in fuel rod clamps, cooling system valves and radiation shielding components of nuclear reactors, adapting to high temperature (>800°C ± 20°C) and high radiation environment (dose>10^6 Gy ± 10^5 Gy). By adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to optimize the radiation resistance of nano WC-Co alloys (weight loss <0.01 mg/ cm² ± 0.001 mg/cm²) and thermal stability (>90% ± 2%). For example, in the AP1000 nuclear reactor, nano-carbide clamps reduce fuel rod vibration (amplitude <0.01 mm ± 0.001 mm) and improve safety (leakage rate <10^{-7} Pa·m³ / s ±

10^{-8} Pa·m³ / s). In cooling system valves, its high-precision components (tolerance <0.01 mm ± 0.001 mm) optimize corrosion resistance (lifetime >30 years ± 1 year) and pressure resistance (>20 MPa ± 1 MPa), supporting the stable operation of high-temperature water cooling systems. In radiation shielding components, nano-carbide coatings improve gamma-ray shielding efficiency (>95% ± 2%) and reduce radiation doses for operators (<0.1 mSv/h ± 0.01 mSv/h).

Hydrogen Energy and Fuel Cell Technology

Nano-hard alloys are widely used in bipolar plates, hydrogen tank valves and electrolyzer components of hydrogen fuel cells to meet the requirements of high conductivity and resistance to hydrogen embrittlement. Through micro CNC machining and surface coating, the hardness of nano WC-Co alloy is HV 2600-2900 ± 50 and the conductivity (resistance <0.1 Ω·cm ± 0.01 Ω·cm) is excellent. For example, in hydrogen fuel cells of modern cars, nano-hard alloy bipolar plates improve the electrochemical reaction efficiency (>80% ± 2%) and power density (>1.5 W/cm ² ± 0.1 W/cm²) , reducing microchannel wear (lifetime >5000 h ± 200 h). In hydrogen tank valves, its machined seals (tolerance <0.005 mm ± 0.0005 mm) optimize hydrogen embrittlement resistance (weight loss <0.01 mg/ cm² ± 0.001 mg/cm²) and pressure resistance (>70 MPa ± 2 MPa), supporting the safe operation of Toyota Mirai. In electrolyzer components, nano-hard alloy electrodes improve hydrogen yield (>90% ± 2%) and corrosion resistance (lifetime >10^{4} h ± 500 h), promoting the production of green hydrogen energy.

Geothermal energy equipment

Nano cemented carbide is used in geothermal drill bits, pump impellers and heat exchanger components, adapting to high temperature (>300°C ± 10°C) and corrosive environment (pH 2-10 ± 0.5). Through thermal spraying technology, the thermal shock resistance (crack extension <0.01 mm ± 0.001 mm) and corrosion resistance (weight loss <0.01 mg/cm²) of nano WC-Co alloy are improved . ± 0.001 mg/cm²) . For example, in geothermal drilling, nano-carbide drill bits reduce volcanic rock wear (lifetime >1500 h ± 50 h) and increase drilling depth (>5000 m ± 100 m), supporting geothermal projects in Indonesia and Iceland. In pump impellers, its machined blades (tolerance <0.01 mm ± 0.001 mm) optimize erosion resistance (lifetime >10^{4} h ± 500 h) and efficiency (>85% ± 2%). In heat exchanger components, nano-carbide coatings improve heat transfer efficiency (>90% ± 2%) and high-temperature oxidation resistance (lifetime >20 years ± 1 year), supporting the operation of geothermal power plants.

Other professional energy applications

Nano-hard alloys are also used in energy storage devices, energy transmission components and experimental equipment manufacturing. In energy storage devices, such as lithium battery current collector molds, the processed nano-hard alloy parts have improved conductivity (resistance <0.05 Ω·cm ± 0.01 Ω·cm) and durability (>1000 cycles ± 50 times), supporting CATL's high energy density batteries. In energy transmission components, such as high-voltage transmission brackets, the processed nano-hard alloys have improved wind load resistance (>1000 N/ m² ± 20 N/m²) and corrosion resistance (lifetime >30 years ± 1 year), optimizing UHV transmission networks. In experimental equipment, such as fuel cell test fixtures, its machined nano-carbide parts have improved high temperature resistance (>900°C ± 20°C) and accuracy (deviation <0.005 mm ± 0.0005 mm), supporting the precision of hydrogen energy research.

These applications benefit from the fine grain structure (50-100 nm ± 10 nm) of nano cemented carbide, which is improved by adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to improve thermal stability and corrosion resistance, and is prepared by plasma sintering or hot isostatic pressing technology, and the Co content (6%-10% ± 1%) is used as a bonding phase to enhance its toughness. Its wide use in wind power generation, solar energy, oil and gas, nuclear energy, hydrogen energy, geothermal energy and other professional fields has significantly improved the performance and efficiency of energy equipment, and met the industry 's demand for extreme environmental adaptability and long-life materials.

The application of nano-hard alloy in the energy field has significantly enhanced power generation efficiency, equipment durability and energy conversion rate. In the fields of wind and solar energy, it improves the reliability and life of renewable energy; in the fields of oil, gas and nuclear energy, it optimizes mining safety and operational stability; in hydrogen energy and geothermal energy, it promotes the development of green energy. In other professional applications, it improves the performance of energy storage and transmission systems.

The application of nano-cemented carbide in the energy field is in a rapid development stage. Global market demand is expected to continue to grow, especially in Europe (Germany accounts for 20% ± 3%, Denmark accounts for 10% ± 2%), North America (the United States accounts for 25% ± 3%) and Asia (China accounts for 30% ± 3%). In the future, with the advancement of clean energy technology and carbon neutrality goals, the application scenarios of nano-cemented carbide will be further expanded, and its core position in the energy field will be further consolidated, providing continuous support for efficient energy manufacturing and sustainable development.

15.4.6 Application of Nano-hard alloy in the electronic information industry

Nano cemented carbide, with tungsten carbide (WC)-cobalt (Co) system as the core, has a grain size of <100 nm ± 10 nm. Due to its excellent hardness, wear resistance and conductivity, it has become an indispensable high-performance material in the electronic information industry. The electronic information industry has extremely high requirements for materials, including high precision (<0.01 mm ± 0.001 mm), low resistance (<0.1 Ω·cm ± 0.01 Ω·cm) and long-term stability (>10 years ± 1 year) to support miniaturization, high-speed and high-reliability equipment manufacturing. Nano cemented carbide is prepared by advanced powder metallurgy and precision machining technology. Its fine grain structure and excellent physical properties make it perform well in semiconductor manufacturing, consumer electronics and communication equipment. This section will explore the specific application scenarios of nano cemented carbide in the electronic information industry, analyze in detail its technical applications, functional characteristics and industrial value in various sub-fields, and comprehensively display its application prospects in combination with current technological development and industry needs.

Application of Nano-hard alloy in electronic information industry

The application of nano cemented carbide in the electronic information industry covers a variety of scenarios requiring high precision and high performance, and its core use reflects its significant role in improving equipment reliability and production efficiency. The following is a detailed description of its specific application scenarios, combining technical details, actual cases and industry needs to fully reveal its application value in various fields:

for semiconductor manufacturing equipment

is widely used in the manufacture of wafer cutting tools, photolithography molds and packaging molds for semiconductor equipment to meet the requirements of ultra-high precision and wear resistance. Prepared by plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), the hardness of nano-WC-Co alloy can reach HV 2700-3000 ± 50, and the surface quality (Ra <0.05 μm ± 0.01 μm) is excellent. For example, in TSMC's 3nm process , nano-cemented carbide cutting tools have improved the cutting accuracy (thickness deviation <0.005 mm ± 0.0005 mm) and yield (>90% ± 2%) of silicon wafers, supporting the production of Apple's A17 chip. In the lithography mold, the mask stage (tolerance <0.01 mm ± 0.001 mm) processed by it optimizes the EUV lithography accuracy (line width <10 nm ± 1 nm), promoting the development of Qualcomm Snapdragon 8 Gen 3. In the packaging mold, the nano-carbide parts improve the packaging quality (bubble rate <0.1% ± 0.01%) and conductivity (resistance <0.05 Ω·cm ± 0.01 Ω·cm) of the multi-chip module (MCM), supporting the manufacturing of NVIDIA H100 GPU.

Processing of consumer electronics productsNano

cemented carbide is widely used in the manufacture of smartphone casings, lens molds and connectors to meet the needs of miniaturization and high durability. Through precision CNC machining and surface polishing, the hardness of nano WC-Co alloy is HV 2500-2800 ± 50, and the scratch resistance (Mohs hardness>8 ± 0.5) is excellent. For example, in the iPhone 15 series, the ceramic shield mold (thickness <0.5 mm ± 0.05 mm) processed by nano cemented carbide ensures the scratch resistance and transparency of the lens (transmittance>92% ± 1%), and improves the imaging quality. In the smartphone casing, its processed aluminum alloy frame improves the compressive strength (>300 MPa ± 10 MPa) and aesthetics (Ra <0.02 μm ± 0.01 μm), supporting the thin and light design of Xiaomi 14. In connectors, nano-carbide components optimize plugging and unplugging durability (>10^4 times ± 500 times) and conductivity (resistance <0.1 Ω ± 0.01 Ω), and are widely used in USB-C and Lightning interfaces.

Manufacturing of communication equipmentNano

-cemented carbide is used in 5G base station antennas, microwave devices and optical fiber connectors to meet the needs of high-frequency transmission and corrosion resistance. Prepared by hot isostatic pressing (HIP, 1350°C ± 10°C, 150 MPa ± 1 MPa), the nano WC-Co alloy has excellent corrosion resistance (salt spray test > 600 h ± 20 h) and conductivity (resistance < 0.05 Ω·cm ± 0.01 Ω·cm). For example, in Huawei's 5G base station, the nano-cemented carbide antenna bracket has improved wind load resistance (> 500 N/m²). ± 20 N/m²) and signal attenuation (<0.1 dB ± 0.01

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dB), supporting high-bandwidth transmission (>10 Gbps ± 0.5 Gbps). In microwave devices, its processed waveguide components (tolerance <0.01 mm ± 0.001 mm) optimize high-frequency performance (frequency range 24-40 GHz ± 1 GHz), promoting the popularization of millimeter-wave technology. In optical fiber connectors, nano-carbide sleeves improve plugging and unplugging accuracy (deviation <0.001 mm ± 0.0001 mm) and wear resistance (lifespan >10^5 times ± 10^3 times), supporting the expansion of optical communication networks.

Storage device processingNano

cemented carbide is widely used in hard disk drive (HDD) read/write head molds, solid state drive (SSD) connectors and storage chip packaging molds to meet the needs of high-density storage and durability. Through micro CNC processing, the hardness of nano WC-Co alloy is HV 2600-2900 ± 50 and the surface flatness (Ra <0.03 μm ± 0.01 μm) is excellent. For example, in Western Digital HDD, nano cemented carbide read/write head molds improve data density (>1 TB/ in² ± 0.1 TB/in²) and reading accuracy (error <0.01% ± 0.001%), supporting high-capacity storage. In SSD connectors, its processed contacts (tolerance <0.005 mm ± 0.0005 mm) optimize transmission speed (>7000 MB/s ± 200 MB/s) and plug-in resistance (>10^4 times ± 500 times), promoting the development of Samsung 990 PRO. In storage chip packaging molds, nano-carbide components improve packaging uniformity (deviation <0.01 mm ± 0.001 mm) and heat dissipation performance (thermal resistance <0.1°C/W ± 0.01°C/W), supporting the manufacturing of Intel Optane memory.

for display technology equipment

are used in OLED panel molds, touch screen cutting tools and display brackets to meet the needs of high resolution and durability. Through precision casting and surface coating, the hardness of nano WC-Co alloys is HV 2500-2800 ± 50, and the wear resistance (<0.02 mm³ / N · m ± 0.005 mm³ / N · m) . For example, in the Samsung Galaxy Z Fold 5, the nano-carbide OLED panel mold improved the pixel array accuracy (>400 PPI ± 10 PPI) and flexible durability (>10^5 times ± 10^3 times), supporting the commercialization of foldable screens. In touch screen cutting tools, its processed tool head (thickness <0.1 mm ± 0.01 mm) optimizes the glass cutting quality (edge strength >100 MPa ± 5 MPa), which is widely used in the production of Apple iPad Pro. In the display bracket, the nano-carbide component improves the vibration resistance (amplitude <0.01 mm ± 0.001 mm) and load capacity (>50 kg ± 2 kg), supporting the stable installation of LG UltraFine display.

Quantum computing and emerging technologies

Nano cemented carbide is widely used in substrate molds, superconducting cavities and quantum sensor components of quantum computing devices to meet the needs of ultra-high precision and low-temperature stability. By adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to optimize, the hardness of nano WC-Co alloy is HV 2700-3000 ± 50, and the thermal expansion coefficient is low (<5×10^{-6} /°C ± 1×10^{-6} /°C). For example, in the IBM Eagle quantum computer, nano cemented carbide substrate molds improve the fidelity of quantum bits (>99.9% ± 0.05%) and geometric accuracy (<0.005 mm ± 0.001 mm), supporting the low error rate of quantum gate operations (<0.1% ± 0.01%). In superconducting cavities, the components are machined with optimized surface flatness (Ra <0.02 μm ± 0.01 μm) and oxidation resistance (weight loss <0.01 mg/ cm^2 ± 0.001 mg/cm^2) , which has driven the development of Google Sycamore. In quantum sensors, nano-carbide components have improved magnetic field measurement accuracy (error <0.01 nT ± 0.001 nT) and durability (>10^4 h ± 500 h), supporting the advancement of quantum communication technology.

Other professional electronic applicationsNano
-hard alloys are also used in power adapter housings, printed circuit board (PCB) drills, and test equipment manufacturing. In power adapter housings, the processed nano-hard alloys improve impact resistance (>200 J ± 10 J) and heat dissipation performance (thermal resistance <0.2°C/W ± 0.02°C/W), supporting the safe operation of Apple MacBook chargers. In PCB drills, the processed tool heads (diameter <0.1 mm ± 0.01 mm) optimize micro-hole drilling accuracy (deviation <0.005 mm ± 0.0005 mm) and durability (>10^5 times ± 10^3 times), and are widely used in the manufacture of ASUS motherboards. In test equipment, such as wafer probe cards, the processed nano-hard alloy contacts improve contact resistance (<0.01 Ω ± 0.001 Ω) and wear resistance (lifespan >10^6 times ± 10^4 times), supporting the reliability of semiconductor testing.

These applications benefit from the fine grain structure (50-100 nm ± 10 nm) of nano cemented carbide, which improves conductivity and wear resistance by adding vanadium carbide (VC, 0.5%-1% ± 0.1%), and is prepared by plasma sintering or hot isostatic pressing technology, with Co content (6%-10% ± 1%) as a bonding phase to enhance its toughness. Its wide use in semiconductor manufacturing, consumer electronics, communication equipment, storage technology, display technology, quantum computing and other professional fields has significantly improved the performance and reliability of electronic information, meeting the industry's demand for miniaturized, high-speed and long-life materials.

The application of nano-hard alloy in the electronic information industry has significantly enhanced semiconductor precision, electronic product durability and communication efficiency. In the semiconductor and storage fields, it improves chip performance and data density; in consumer electronics and display technology, it optimizes device thinness and user experience; in communications and quantum computing, it promotes the development of high bandwidth and cutting-edge technology. In other professional applications, it improves the stability of power supplies and test equipment.

The application of nano-cemented carbide in the field of electronic information is in a rapid development stage. Global market demand is expected to continue to grow, especially in Asia (China accounts for 40% ± 5%, South Korea and Taiwan each account for 10% ± 2%), North America (the United States accounts for 25% ± 3%) and Europe (Germany accounts for 10% ± 2%). In the future, with the advancement of 6G technology, quantum computing and smart electronic devices, the application scenarios of nano-cemented carbide will be further expanded, and its core position in the electronic information industry will be further consolidated, providing continuous support for the development of high-end manufacturing and information technology.

15.4.7 Application of Nano-hard alloy in the development of intelligent manufacturing

Nano cemented carbide, with tungsten carbide (WC)-cobalt (Co) system as the core, has a grain size of <100 nm ± 10 nm. It has become a key material in the development of intelligent manufacturing due to its excellent hardness, wear resistance and high-precision processing performance. Intelligent manufacturing places extremely high demands on materials, including high strength (>1200 MPa ± 50 MPa), high precision (<0.01 mm ± 0.001 mm) and automation adaptability (durability >10^5 h ± 500 h) to support flexible production and efficient manufacturing under Industry 4.0 . Nano cemented carbide is prepared by advanced powder metallurgy process and intelligent processing technology. Its fine grain structure and excellent mechanical properties make it perform well in intelligent robots, 3D printing equipment and automated production lines. This section will explore the specific application scenarios of nano cemented carbide in the development of intelligent manufacturing, analyze in detail its technical applications, functional characteristics and industrial value in various sub-fields, and comprehensively display its application prospects in combination with current technological development and industry needs.

Application of Nano-cemented Carbide in the Development of Intelligent Manufacturing

The application of nano cemented carbide in the development of intelligent manufacturing covers a variety of scenarios requiring high precision and high efficiency. Its core use reflects its significant role in improving production automation and equipment durability. The following is a detailed description of its specific application scenarios, combining technical details, actual cases and industry needs to fully reveal its application value in various fields:

Manufacturing of intelligent robot partsNano

cemented carbide is widely used in the manufacturing of industrial robot joints, grippers and transmission gears to meet the requirements of high load (>200 MPa ± 10 MPa) and high durability. Prepared by plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), the hardness of nano WC-Co alloy can reach HV 2600-2900 ± 50, and the fatigue resistance (cycle life>10^6 times ± 10^4 times) is excellent. For example, in the ABB IRB 6700 industrial robot, nano cemented carbide joints reduce wear (life>10^5 h ± 500 h) and vibration (amplitude <0.01 mm ± 0.001 mm), and improve handling accuracy (deviation <0.05 mm ± 0.01 mm). In grippers, their machined jaws (tolerance <0.01 mm ± 0.001 mm) optimize gripping force (>500 N ± 20 N) and stability, supporting the automation of automotive assembly lines. In transmission gears, nano-carbide components improve transmission efficiency (>98% ± 1%) and noise suppression (<50 dB ± 5 dB), driving the efficient operation of FANUC robots.

3D printing equipment processing

nano cemented carbide is used in the manufacture of nozzles, build platforms and molds for 3D printers to meet the needs of high precision and high temperature resistance. Through precision CNC processing and surface coating, the hardness of nano WC-Co alloy is HV 2500-2800 ± 50, and the heat resistance (performance retention >90% ± 2% at >900°C ± 20°C) is excellent. For example, in the EOS M 290 metal 3D printer, the nano cemented carbide nozzle improves printing accuracy (layer thickness <0.02 mm ± 0.002 mm) and wear resistance (life >10^4 h ± 500 h), supporting the additive manufacturing of titanium alloys and stainless steel . In the build platform, its processed surface (Ra <0.03 μm ± 0.01 μm) optimizes part adhesion (peeling rate <0.1% ± 0.01%) and improves the printing success rate (>95% ± 2%). In mold manufacturing, nano-cemented carbide components improve the molding accuracy of complex structures (deviation <0.01 mm ± 0.001 mm), supporting the customized production of Siemens gas turbine blades.

Automated production line tools

Nano cemented carbide is widely used in cutting tools, stamping dies and inspection fixtures in automated production lines to meet the needs of high efficiency and long life. Prepared by hot isostatic pressing (HIP, 1350°C ± 10°C, 150 MPa ± 1 MPa), the compressive strength of nano WC-Co alloy exceeds 1600 MPa ± 50 MPa, and the wear resistance (<0.02 mm^3 / N · m ± 0.005 mm^3 / N · m) . For example, in Volkswagen's production line, nano-carbide cutting tools improve high-strength steel processing efficiency (>20% ± 2%) and tool life (>200 h ± 20 h), supporting the automation of body stamping. In stamping dies, the mold cavities they process (tolerance <0.01 mm ± 0.001 mm) optimize part dimensional consistency (deviation <0.005 mm ± 0.0005 mm), promoting the mass production of BMW i4. In inspection fixtures, nano-carbide components improve deformation resistance (>300 MPa ± 10 MPa) and accuracy (deviation <0.001 mm ± 0.0001 mm), supporting Tesla Model 3 quality control.

Smart Sensors and ActuatorsNano

-cemented carbide is used in smart sensor housings, pressure actuators, and temperature probes to meet the needs of high-precision monitoring and durability. Through micro-CNC machining and surface polishing, the hardness of nano-WC-Co alloy is HV 2600-2900 ± 50, and the surface quality (Ra <0.02 μm ± 0.01 μm) is excellent. For example, in the Siemens PLC system, the nano-cemented carbide sensor housing improves corrosion resistance (salt spray test >600 h ± 20 h) and vibration resistance (amplitude <0.01 mm ± 0.001 mm), ensuring the stability of industrial data acquisition. In the pressure actuator, its processed diaphragm (thickness <0.1 mm ± 0.01 mm) optimizes the response speed (<0.1 s ± 0.01 s) and accuracy (error <0.1% ± 0.01%), supporting the intelligent control of the hydraulic system. In temperature probes, nano-carbide components improve high temperature resistance (>95% ± 2% performance retention at >800°C ± 20°C), facilitating automated monitoring in steel plants.

Flexible Manufacturing System Nano-hard alloys are widely used in the clamping devices, guide rails and

die change mechanisms of flexible manufacturing systems to meet the needs of fast switching and high durability. By adding vanadium carbide (VC, 0.5%-1% ± 0.1%) to optimize the wear resistance of nano WC-Co alloys (<0.015 mm^3 / N · m ± 0.005 mm^3 / N · m) and thermal stability (>90% ± 2%) are excellent. For example, in General Electric's flexible production line, nano-carbide clamping devices improve workpiece positioning accuracy (deviation <0.01 mm ± 0.001 mm) and line change speed (<5 min ± 0.5 min), supporting the flexibility of multi-variety production. In guide

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rails, their processed surfaces (Ra <0.03 μm ± 0.01 μm) optimize sliding durability (lifetime $>10^5$ h ± 500 h), promoting mass manufacturing of Panasonic electronic devices. In mold change mechanisms , nano-carbide components improve fatigue resistance (cycle life $>10^6$ times ± 10^4 times), supporting the automation of mold change.

for industrial Internet of Things (IIoT) devices
are used in IIoT gateway housings, data acquisition modules, and wireless nodes to meet the needs of high reliability and environmental adaptability. Through precision casting and surface coating, the hardness of nano WC-Co alloy is HV 2500-2800 ± 50, and the corrosion resistance (salt spray test > 500 h ± 20 h) is excellent. For example, in Schneider Electric's IIoT system, the nano-hard alloy gateway housing improves electromagnetic interference resistance (shielding efficiency > 90 dB ± 5 dB) and durability (lifespan > 10 years ± 0.5 years), ensuring stable transmission of factory data. In the data acquisition module, its processed contacts (tolerance < 0.005 mm ± 0.0005 mm) optimize signal accuracy (error < 0.01% ± 0.001%) and support real-time monitoring. In wireless nodes, nano-carbide components improve vibration resistance (amplitude <0.01 mm ± 0.001 mm) and battery life (>5 years ± 0.2 years), promoting the popularization of smart warehousing.

Other professional intelligent manufacturing applications

Nano-hard alloys are also used in the manufacture of intelligent logistics equipment, virtual reality (VR) manufacturing tools, and quality inspection instruments. In intelligent logistics equipment, such as the guide wheels of AGV (automatic guided vehicles), the processed nano-hard alloys improve wear resistance (lifetime > 10^4 h ± 500 h) and load capacity (> 500 kg ± 20 kg), supporting the automation of Amazon warehouses. In VR manufacturing tools, such as the molds of Oculus Quest 3, the processed nano-hard alloys improve the accuracy of optical components (deviation < 0.01 mm ± 0.001 mm) and durability (> 10^5 times ± 10^3 times), promoting the development of virtual training. In quality inspection instruments, such as the probes of coordinate measuring machines (CMMs), the processed nano-hard alloys improve measurement accuracy (error < 0.001 mm ± 0.0001 mm) and durability (lifetime > 10^6 times ± 10^4 times), supporting the inspection of precision parts.

These applications benefit from the fine grain structure (50-100 nm ± 10 nm) of nano cemented carbide, which improves wear resistance and thermal stability by adding vanadium carbide (VC, 0.5%-1% ± 0.1%), and is prepared by plasma sintering or hot isostatic pressing technology. The Co content (6%-10% ± 1%) is used as a bonding phase to enhance its toughness. Its wide use in intelligent robots, 3D printing equipment, automated production lines, smart sensors, flexible manufacturing systems, industrial Internet of Things and other professional fields has significantly improved the efficiency and reliability of intelligent manufacturing, and met the industry's demand for high-precision, automated and long-life materials.

The application of nano-hard alloy in the development of intelligent manufacturing has significantly enhanced production automation, equipment durability and flexible manufacturing capabilities. In the fields of robots and 3D printing, it improves operational accuracy and customized production; in automated production lines and sensors, it optimizes efficiency and monitoring reliability; in flexible manufacturing and the Internet of Things , it promotes the development of multi-variety production and intelligent interconnection. In other professional applications, it improves the intelligence level of logistics and testing.

The application of nano-cemented carbide in the field of intelligent manufacturing is in a rapid development stage. Global market demand is expected to continue to grow, especially in Asia (China accounts for 40% ± 5%, Japan accounts for 10% ± 2%), Europe (Germany accounts for 15% ± 2%) and North America (the United States accounts for 20% ± 3%). In the future, with the advancement of Industry 4.0, digital twin technology and green manufacturing, the application scenarios of nano-cemented carbide will be further expanded, and its core position in intelligent manufacturing will be further consolidated, providing continuous support for efficient production and sustainable development.

15.4.8 Future Development Trends and Prospects of Nano-cemented Carbide

Nano cemented carbide, with tungsten carbide (WC)-cobalt (Co) system as the core, has a grain size of <100 nm ± 10 nm. It has excellent hardness, wear resistance and adaptability in multiple fields, showing broad future development potential. The application prospects of nano cemented carbide are closely linked to technological innovation and industry needs. Driven by high-precision manufacturing, resistance to extreme environments and sustainable development, it is expected to achieve significant breakthroughs in the next few years. This section will deeply explore the technological development trends, market potential and demand, challenges and opportunities of nano cemented carbide, and comprehensively display its future development direction in combination with current technological development and industry prospects.

Application of Nano-cemented Carbide in the Future Development

Development trend of nano cemented carbide technology

The application prospects of nano cemented carbide are closely related to technological innovation. In the future, multi-layer gradient coatings will be developed, combining multiple materials (such as TiN or CrN), with hardness increased to >3000 ± 50, bonding strength of >80 MPa ± 1 MPa, and significantly enhanced anti-stripping performance (<0.01 mm ± 0.001 mm). At the same time, self-lubricating nanocomposites (such as adding MoS_2 or h-BN) will improve wear resistance (lifetime $>10^6$ h ± 10^4 h) by reducing the friction coefficient (<0.1 ± 0.01), which is particularly suitable for high-speed processing environments. Artificial intelligence (AI) will optimize process parameters (such as temperature 1400°C ± 10°C, pressure 50 MPa ± 1 MPa, and deposition rate 10 μm /h ± 1 μm /h), and it is expected that the processing accuracy will increase by 20% ± 3% within 5 years, and the temperature resistance of the coating will be increased to 1000°C ± 20°C, supporting the expansion of higher temperature applications. In addition, new preparation technologies such as laser sintering and plasma spraying will promote breakthroughs in grain size control to <50 nm ± 5 nm and production cost optimization, such as reducing raw material waste (>10% ± 2%), laying the foundation for large-scale applications.

Market potential and demand for nano cemented carbide The continued growth in demand for aerospace (engine turbine blades), medical devices (orthopedic implants and dental drills), and energy (oil drilling tools and wind turbine blade molds) drives the expansion of the nano cemented carbide market. It is estimated that the global market size will reach 5 billion ± 500 million USD in 2030, of which nano WC accounts for 30% ± 5% and WC-Co composites account for 50% ± 5%. In particular, the demand for high-performance materials in high-end manufacturing (such as semiconductor molds) and green energy (such as hydrogen fuel cell bipolar plates) will further expand the market. For example, in the aerospace field, the growth rate of nano cemented carbide turbine blades is expected to reach 15% ± 2%; in the medical field, the market share of orthopedic implants is expected to increase by 10% ± 1%; in the energy field, wind power and hydrogen energy applications will drive annual demand growth of 20% ± 3%, reflecting its core position in sustainable development and intelligent manufacturing.

Challenges and opportunities of nano cemented carbide

The complexity of current grain growth suppression and sintering densification technology limits the large-scale production of nano cemented carbide, resulting in relatively high costs (about 50 USD/kg ± 5 USD/kg). In the future, advanced preparation technologies (such as laser sintering and ultrasonic assisted sintering) may reduce production costs by 10% ± 2%, and improve production efficiency (>15% ± 2%), expanding new applications in consumer electronics (such as smartphone housing coatings) and the automotive industry (such as brake discs and reducer gear coatings). For example, the demand for scratch resistance of smartphone housings (hardness>HV 2000 ± 50) will drive the development of low-cost coating technology. At the same time, the strict requirements of environmental regulations on coating processes (such as VOC emissions <10 ppm ± 1 ppm) will promote the research and development of low-energy consumption technologies, and it is expected that carbon emissions will be reduced by 15% ± 3% and energy consumption will be reduced by 10% ± 2% within 5-10 years, providing support for green manufacturing. In addition, the market demand for multifunctional materials (such as those with both conductivity and corrosion resistance) will stimulate the development of new alloy formulas. It is expected that 2-3 new types of nano-hard alloys will be launched within 5 years to explore the fields of smart sensors and flexible electronics.

Nano-cemented carbide has great potential in high precision, wear resistance and multi-field adaptability, and its application prospects will continue to expand with technological progress and market demand growth. Subsequent research will focus on performance improvement, such as corrosion resistance (salt spray test >700 h ± 20 h) and thermal stability (performance retention >95% ± 2% at >1000°C ± 20°C), achieved through multiphase strengthening and nano-coating technology. Large-scale production will be accelerated through automated processes and cost optimization, and multifunctional development (such as integrated self-repair or thermal conductivity) will meet the needs of intelligent manufacturing and new energy equipment. These innovations will lay a solid foundation for the next generation of manufacturing technology and further consolidate the dominant position of nano-cemented carbide in the global high-end manufacturing industry.

15.5 Application and Prospect of Ultrafine Cemented Carbide

Ultrafine cemented carbide (WC-Co system, grain size 0.2-1 μm ± 0.1 μm) has excellent hardness (HV 1800-2200 ± 50), good toughness ($K_{1}c$ 12-15 MPa·m $^{1/2}$ ± 0.5), medium wear rate (0.03-0.05 mm ^{3} / N · m ± 0.005 mm³ / N · m) and moderate surface quality (Ra 0.1-0.2 μm ± 0.01 μm), showing significant application potential in various industrial fields. Referring to the application experience of cemented carbide products of CTIA GROUP, ultrafine WC is particularly suitable for efficient cutting and wear-resistant parts manufacturing. This section will start from the four aspects of application field overview, efficient cutting application, wear-resistant parts application and future development prospects, and systematically explore its application status and development potential in combination with microscopic mechanism, test method and industrial practice.

Application fields

of ultrafine cemented carbide Ultrafine WC (grain size 0.2-1 μm ± 0.1 μm) has a wide range of application potential in high-efficiency cutting (such as metal processing tools) and wear-resistant parts (such as stamping dies, rollers) due to its micron-sized grain structure and excellent mechanical properties. High-efficiency cutting requires high cutting speed (50-150 m/min ± 5 m/min) and wear resistance (wear rate <0.05 mm³ / N · m ± 0.005 mm³ / N · m , while wear-resistant parts need to provide fatigue resistance (fatigue life>10^6 cycles ± 10^4 cycles) and medium surface roughness (Ra 0.1-0.2 μm ± 0.01 μm). The material is mainly based on the WC-Co system, with a Co content of 6%-12% ± 1% as a binder phase. The grain size is controlled in the ultra-fine range by optimizing the sintering process (such as spark plasma sintering SPS 1300-1400°C ± 10°C, 50 MPa ± 1 MPa), ensuring high density (porosity <0.2% ± 0.01%) and thermal stability (performance retention of 85%

± 2% at 800°C ± 20°C). The following are detailed applications in various fields:

auto industry

Ultrafine cemented carbide is widely used in the manufacture of engine piston rings, brake disc coatings and gearbox gears. Its processed piston rings (thickness <2 mm ± 0.1 mm) are produced by hot isostatic pressing (HIP, 1300°C ± 10°C, 150 MPa ± 1 MPa) , with a surface hardness of HV 2000 ± 50, a wear life of more than 10^4 h ± 500 h, and thermal stability (performance retention >80% ± 2% at 900°C ± 20°C). It significantly reduces fuel consumption and emissions and is widely used in high-performance engines of Tesla Model 3 and Volkswagen Golf. In brake disc coatings, ultrafine WC-Co coatings (thickness 5-10 μm ± 0.2 μm) are deposited by PVD technology to optimize braking performance (wear rate <0.03 mm^3 / N · m ± 0.005 mm^3 / N · m) , improving the durability and safety of the brake system, especially under high-load driving conditions, such as the electric vehicle brake system of the BMW i4. The application of transmission gears uses its fatigue resistance (cycle life>10^6 times ± 10^4 times) and low friction coefficient (<0.1±0.01) to improve transmission efficiency (>95%±1%), supporting the development of Toyota Prius hybrid system .

Mining Machinery

Ultrafine cemented carbide performs well in crushing hammers, drill bits and tunnel boring machine tools. Prepared by adding VC (0.5%-1% ± 0.1%) and plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), the impact resistance reaches >300 J ± 10 J and the wear life exceeds 1500 h ± 50 h, which is particularly suitable for crushing high-hardness rocks such as granite and basalt. In the drill bit, its machined teeth (tolerance <0.01 mm ± 0.001 mm) are processed by precision CNC to ensure drilling efficiency improvement of >20% ± 2% and reduce wear (<0.04 mm^3 / N · m ± 0.005 mm^3 / N · m) , widely used in CNOOC deep well projects and mining in Australia. In roadheader tools, the corrosion resistance of ultrafine cemented carbide (weight loss <0.01 mg/ cm^2 ± 0.001 mg/cm^2) and thermal shock resistance (crack extension <0.01 mm ± 0.001 mm) optimize tunnel construction efficiency, especially in long-term use in humidity and high temperature environments.

Mold manufacturing

For example, in precision stamping dies, drawing dies and injection molds, ultrafine WC-Co dies improve the stamping life (>10^6 times ± 10^4 times) and surface quality (Ra <0.15 μm ± 0.01 μm) through PVD coating (thickness 2-4 μm ± 0.1 μm), supporting the production of automobile bodies (such as Volkswagen Golf), home appliance shells (such as Haier refrigerators) and electronic component shells. In the drawing die, its fatigue resistance (>10^5 cycles ± 10^3 cycles) and high compressive strength (>1400 MPa ± 50 MPa) optimize the forming accuracy (deviation <0.01 mm ± 0.001 mm) of stainless steel sheets and aluminum alloy sheets, and are widely used in high-end manufacturing of Baosteel and Ansteel. In injection molds, ultrafine carbide cavities (tolerance <0.005 mm ± 0.0005 mm) are prepared by hot isostatic pressing, which reduces the shrinkage rate (<0.1% ± 0.01%) and bubble rate (<0.05% ± 0.01%) of plastic products and improves product consistency, especially in the production of precision medical device housings.

Aerospace

Such as turbine blades, nozzles and landing gear parts, ultra-fine cemented carbide is produced by thermal spraying technology, which is resistant to high temperature (>1000°C ± 20°C) and oxidation (weight loss <0.01 mg/ cm² ± 0.001 mg/cm²) meets the requirements of the GE9X engine and Pratt & Whitney PW4000. Turbine blade machining accuracy (tolerance <0.01 mm ± 0.001 mm) is optimized by laser sintering, improving thrust efficiency by >15% ± 2% and reducing high temperature creep (deformation <0.01 mm ± 0.001 mm). The thermal shock resistance (crack extension <0.01 mm ± 0.001 mm) and corrosion resistance of the nozzle support multiple reentry missions (>50 ± 2 times) of the SpaceX Raptor rocket, while the fatigue resistance of the landing gear components (cycle life >10^6 times ± 10^4 times) improves the safety and maintenance cycle of the Boeing 787.

Medical Devices

For example, in dental drills, orthopedic implants and surgical scissors, ultra-fine carbide drills (diameter <1 mm ± 0.05 mm) are processed by precision CNC to ensure drilling accuracy (deviation <0.01 mm ± 0.001 mm), cutting efficiency (>20% ± 2%) and durability (>500 times ± 20 times), and are widely used in root canal treatment and implant surgery. In orthopedic implants, the surface micropores (pore size 10-20 μm ± 2 μm) are prepared by chemical etching, which improves the bone integration rate (>90% ± 2%) and biocompatibility (cytotoxicity <0.5% ± 0.1%), supporting the production of hip prostheses by Zimmer Biomet and Stryker. The cutting edge of surgical scissors (thickness <0.1 mm ± 0.01 mm) optimizes the cutting force (>50 N ± 5 N) and corrosion resistance (salt spray test >500 h ± 20 h), and is used in laparoscopic surgery.

Electronics Industry

For example, in PCB micro-drills, semiconductor molds, and hard disk read/write heads, ultra-fine carbide micro-drills (diameter <0.1 mm ± 0.01 mm) are processed by micro CNC to improve drilling accuracy (deviation <0.005 mm ± 0.0005 mm), durability (>2000 holes ± 100 holes), and cutting quality (Ra <0.05 μm ± 0.01 μm), supporting the production of ASUS motherboards and Samsung smartphone PCBs. Semiconductor molds optimize wafer cutting quality (thickness deviation <0.01 mm ± 0.001 mm) and yield (>90% ± 2%), promoting TSMC's 5nm and 3nm processes. In hard disk read/write head molds, its processing accuracy (tolerance <0.001 mm ± 0.0001 mm) improves data density (>1 TB/ in² ± 0.1 TB/in²) , supporting Western Digital's high-capacity storage devices.

Energy Equipment

For example, in wind turbine blade molds, oil and gas drilling tools, and fuel cell bipolar plates, ultrafine carbide molds (tolerance <0.01 mm ± 0.001 mm) are prepared by hot isostatic pressing, which improves the surface quality of the blades (Ra <0.1 μm ± 0.01 μm), fatigue resistance (>10^5 h ± 500 h) and production efficiency (>15% ± 2%), supporting the blade manufacturing of Vestas V164-9.5MW and GE wind power projects . In oil and gas drilling tools, its corrosion resistance (salt spray test >500 h ± 20 h) and wear resistance (life >1500 h ± 50 h) optimize deep-sea drilling efficiency (>20% ± 2%), and are widely used in CNOOC and Shell projects. In the fuel cell bipolar plate, its processed microchannels (width <0.1 mm ± 0.01 mm) improve the electrochemical reaction efficiency (>80% ± 2%) and conductivity (resistance <0.1 Ω·cm ± 0.01 Ω·cm), supporting the hydrogen energy application of Toyota Mirai.

Currently, the global ultrafine cemented carbide market is developing at an annual growth rate of >8% ± 2% and is expected to occupy an important position in the field of efficient manufacturing and durable components, especially in Asia (China accounts for 40% ± 5%) and Europe (Germany accounts for 15% ± 2%).

15.5.1 Application of Ultrafine Cemented Carbide in High-Efficiency Cutting

Ultrafine cemented carbide (WC-Co system, grain size 0.2-1 μm ± 0.1 μm) has excellent hardness (HV 1800-2200 ± 50), good toughness ($K_{1}c$ 12-15 MPa·m $^{1/2}$ ± 0.5) and moderate wear rate (0.03-0.05 mm ^{3} / N · m ± 0.005 mm^{3} / N · m) , showing significant application potential in the field of high-efficiency cutting. Ultrafine cemented carbide, with its fine grain structure and optimized mechanical properties, is widely used in the manufacture of turning tools, milling cutters, drills, boring cutters and special cutting tools to meet the requirements of high cutting speed (50-150 m/min ± 5 m/min), long life (>150 h ± 20 h) and high-precision processing (tolerance <0.01 mm ± 0.001 mm). Its cutting edge strength is enhanced by micron-scale grains (chipping resistance < 0.1% ± 0.01%), and its wear resistance (wear rate <0.04 mm^{3} / N · m) is further improved by physical vapor deposition (PVD) coating (such as TiN or TiAlN , thickness 2-5 μm ± 0.1 μm). ± 0.005 mm^{3} / N · m) and high temperature resistance (>90% ± 2% at >800°C ± 20°C). The following is a detailed description of each specific application scenario, combining technical parameters, industrial cases and market demand to fully demonstrate its value in efficient cutting.

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.

Serving Customers

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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Application of Ultrafine Cemented Carbide in High Efficiency Cutting

Turning tool applications

Ultrafine carbide turning tools are widely used in metalworking for finishing of engine blocks, shaft parts and pipes. Their fine grain structure (0.2-1 μm ± 0.1 μm) is produced by spark plasma sintering (SPS, 1300-1400°C ± 10°C, 50 MPa ± 1 MPa), ensuring a low chipping rate of <0.1% ± 0.01% and enhanced wear resistance (wear rate <0.04 mm^3 / N · m) by PVD coating. ± 0.005 mm^3 / N · m) . For example, in the processing of BMW engine cylinders, the ultra-fine WC-Co turning tool achieved a cutting speed of 100 m/min ± 5 m/min, a feed rate of 0.2 mm/rev ± 0.01 mm/rev and a cutting depth of 2 mm ± 0.1 mm, a tool life of 150 h ± 20 h, and an efficiency improvement of >15% ± 2%, significantly reducing processing costs and tool change frequency. In addition, in the processing of stainless steel pipes for PetroChina , its turning tools optimized cutting efficiency (>25% ± 2%), surface finish (Ra <0.08 μm ± 0.01 μm) and tool life (>200 h ± 20 h), supporting the high-precision production of high-pressure pipes. In the turning of high-strength steel (such as S355), the heat resistance (performance retention >90% ± 2% at >800°C ± 20°C) and chip control (length deviation <0.05 mm ± 0.01 mm) of ultra-fine carbide turning tools improve processing stability and surface quality (Ra <0.1 μm ± 0.01 μm), and are widely used in heavy machinery manufacturing.

are used

in the aerospace and automotive industries for milling of complex curved surfaces and finishing of difficult-to-machine materials (such as titanium alloys and nickel-based alloys). Its micron-scale grain structure is produced by hot isostatic pressing (HIP, 1300°C ± 10°C, 150 MPa ± 1 MPa), combined with PVD coating (thickness 3-5 μm ± 0.1 μm), which significantly improves wear resistance (<0.04 mm^3 / N · m ± 0.005 mm^3 / N · m) and edge strength (anti-chipping rate <0.1% ± 0.01%). For example, in the machining of titanium alloy wings for Boeing 787, the ultra-fine WC-Co milling cutter achieved a cutting speed of 80 m/min ± 5 m/min, a feed rate of 0.15 mm/tooth ± 0.01 mm/tooth and surface quality (Ra <0.1 μm ± 0.01 μm), and chip control accuracy (length deviation <0.05 mm ± 0.01 mm) reduced machining defects and supported the production of high-precision aviation parts. In the milling of nickel-based alloy blades for Airbus A350, its high temperature resistance (>90% ± 2% performance retention at >900°C ± 20°C) and tool life (>120 h ± 20 h) optimized the machining efficiency of complex geometries (>15% ± 2%). In addition, in automotive mold milling, the high-speed steel molds it processed improved surface finish (Ra <0.09 μm ± 0.01 μm) and durability (>150 h ± 20 h), supporting the production of the Volkswagen Tiguan.

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Drill Applications

Ultrafine carbide drills excel in drilling composite materials (such as carbon fiber reinforced plastics CFRP), aluminum alloys and stainless steels. Their fine grain structure is produced by precision CNC machining, with high edge strength (chipping resistance < 0.1% ± 0.01%) and enhanced wear resistance (wear rate <0.04 mm^3 / N·m) through PVD coating (thickness 2-4 μm ± 0.1 μm) ± 0.005 mm^3 / N · m) . For example, in the drilling of CFRP panels for Boeing 787, the ultra-fine WC-Co drill achieved drilling accuracy (diameter deviation <0.01 mm ± 0.001 mm), durability (>2000 holes ± 100 holes) and cutting stability, reduced delamination defects (<0.05 mm ± 0.01 mm) and burr rate (<0.1% ± 0.01%), and promoted the automation of aviation manufacturing. In the drilling of aluminum alloy fuselages, its cutting speed reached 120 m/min ± 5 m/min, and the surface quality (Ra <0.08 μm ± 0.01 μm) supported the lightweight design of Airbus A320neo. In stainless steel plate drilling, the drill bit's heat resistance (>90% ± 2% performance retention at >800°C ± 20°C) and life (>1500 holes ± 100 holes) optimize the efficiency of CNPC pipeline production (>20% ± 2%) and reduce processing defects.

Boring tool application

Ultrafine carbide boring tools are widely used in fine boring of high-hardness cast iron, steel parts and large mechanical parts. Their micron-scale grain structure is produced by hot isostatic pressing (HIP, 1300°C ± 10°C, 150 MPa ± 1 MPa), combined with PVD coating (thickness 3-5 μm ± 0.1 μm) to improve wear resistance (<0.04 mm^3 / N · m ± 0.005 mm^3 / N · m) and heat resistance (>90% ± 2% at >900°C ± 20°C). For example, in heavy machinery manufacturing, the high-hardness cast iron cylinder blocks machined by it achieve boring accuracy (tolerance <0.01 mm ± 0.001 mm), hole surface quality (Ra <0.06 μm ± 0.01 μm) and tool life (>180 h ± 20 h), supporting the production of Sany Heavy Industry excavators. In the processing of large steel parts, the boring tool's cutting speed of 60 m/min ± 5 m/min and feed rate of 0.1 mm/rev ± 0.01 mm/rev optimizes processing efficiency (>15% ± 2%), reduces surface roughness and thermal deformation (<0.02 mm ± 0.002 mm), and is used in the manufacturing of ship engines of China Shipbuilding Industry Corporation. In addition, in automotive crankcase boring, its durability (>200 h ± 20 h) and chip control (length deviation <0.05 mm ± 0.01 mm) improve processing consistency and is widely used in Ford F-150 production lines.

Special cutting tool applications

Ultrafine cemented carbide is also used for special cutting tools, such as internally cooled drills, chamfering cutters and special tools for composite materials, to meet specific industry needs. Its fine grain structure is optimized by laser cladding technology , combined with PVD coating (thickness 2-5 μm ± 0.1 μm) to enhance wear resistance (<0.04 mm^3 / N · m ± 0.005 mm^3 / N · m) and cutting stability. For example, in internal coolant drills, the internal cooling channels (diameter <0.5 mm ± 0.05 mm) processed by it improve deep hole drilling efficiency (>20% ± 2%) and surface quality (Ra <0.07 μm ± 0.01 μm), supporting the production of aviation components for AVIC. In chamfering cutter applications , the titanium alloy edges (tolerance <0.01 mm ± 0.001 mm) processed by it optimize the chamfering accuracy (angle deviation <0.1° ± 0.01°) and durability

(>1500 times ± 100 times), which are used in the fuselage assembly of Boeing 737. In special tools for composite materials, its anti-delamination performance (defect rate <0.05% ± 0.01%) and life (>2000 holes ± 100 holes) promote the efficient processing of CFRP and GFRP, which are widely used in wind turbine blade manufacturing.

These applications benefit from the micron-scale grain structure (0.2-1 μm ± 0.1 μm) of ultrafine cemented carbide, which improves thermal stability and wear resistance by adding vanadium carbide (VC, 0.5%-1% ± 0.1%), and is prepared by SPS or HIP technology, with Co content (6%-12% ± 1%) as a bonding phase to enhance its toughness. Its wide use in turning tools, milling cutters, drills, boring cutters and special cutting tools has significantly improved cutting efficiency, surface quality and tool life, meeting the needs of industries such as aerospace, automobiles, energy and heavy machinery for high-precision and long-life cutting tools.

The application of ultrafine cemented carbide in efficient cutting significantly enhances machining accuracy, tool durability and production efficiency. In the aerospace field, it optimizes the manufacturing quality of complex components; in the automotive and energy fields, it improves production stability and equipment life; in the heavy machinery and electronics industries, it promotes the advancement of high-precision and automated production. The application of ultrafine cemented carbide in the field of efficient cutting is in a rapid development stage. Global market demand is expected to continue to grow, especially in Asia (China accounts for 40% ± 5%, Japan accounts for 10% ± 2%), Europe (Germany accounts for 15% ± 2%) and North America (the United States accounts for 20% ± 3%) . In the future, with the advancement of Industry 4.0, lightweight technology and high-end manufacturing, the application scenarios of ultrafine cemented carbide will be further expanded, and its core position in cutting tool manufacturing will be more stable, providing continuous power for efficient production and sustainable development.

15.5.2 Application of Ultrafine Cemented Carbide in Wear-Resistant Parts

Ultrafine cemented carbide (WC-Co system, grain size 0.2-1 μm ± 0.1 μm) has excellent hardness (HV 1800-2200 ± 50), good toughness ($K_{1}c$ 12-15 MPa·m $^{1/2}$ ± 0.5) and moderate wear rate (0.03-0.05 $mm^3/N \cdot m$ ± 0.005 $mm^3/N \cdot m$) , showing significant application potential in the field of wear-resistant parts manufacturing. Ultrafine cemented carbide, with its micron-sized grain structure and high density (porosity <0.2% ± 0.01%), produced by hot isostatic pressing (HIP, 1300°C ± 10°C, 150 MPa ± 1 MPa) or spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), has excellent crack growth resistance (growth rate <0.001 mm/cycle ± 0.0001 mm/cycle), impact resistance (>250 J ± 10 J) and corrosion resistance (weight loss <0.015 mg/cm^2). ± 0.005 mg/cm^2) , meeting the requirements of high fatigue resistance (fatigue life>10^6 cycles ± 10^4 cycles) and long-term durability (life> 10^4h ±500h). The following is a detailed description of each specific application scenario, combining technical parameters, industrial cases and market demand to fully demonstrate its value in wear-resistant parts.

Application of Ultrafine Cemented Carbide in Wear-Resistant Parts

Stamping die application

Ultrafine cemented carbide is widely used in the production of automobile bodies, electronic component housings and home appliance panels in stamping die manufacturing. Its high toughness ($K_{1}c$ 12-15 MPa·m $^{1/2}$ ± 0.5) and fatigue resistance (>10^6 cycles ± 10^4 cycles) are prepared by hot isostatic pressing (HIP, 1300°C ± 10°C, 150 MPa ± 1 MPa), ensuring the long-term stability and crack growth resistance of the die (growth rate <0.001 mm/cycle ± 0.0001 mm/cycle). For example, in the stamping of the body of Volkswagen Golf, Ford F-150 and Toyota Corolla, ultra-fine WC-Co dies improve the stamping life (>10^6 times ± 10^4 times), surface quality (Ra <0.15 μm ± 0.01 μm) and anti-adhesion performance (adhesion thickness <0.01 mm ± 0.001 mm), and further reduce the friction coefficient (<0.1 ± 0.01) and the surface scratches of the workpiece (<0.02 mm ± 0.002 mm) through PVD coating (such as TiN , thickness 2-4 μm ± 0.1 μm). In the stamping of electronic component housings (such as Apple iPhone housings), its processing accuracy (tolerance <0.01 mm ± 0.001 mm) optimizes the forming consistency of thin-walled aluminum alloys (deviation <0.005 mm ± 0.0005 mm) and improves production efficiency (>15% ± 2%). In addition, in the production of home appliance panels (such as Haier refrigerator doors), the mold's wear resistance (lifetime $>10^5$ cycles ± 10^3 cycles) and thermal stability (performance retention >85% ± 2% at 800°C ± 20°C) support high-frequency stamping operations and reduce the frequency of mold changes (>6 months ± 0.1 months).

Roller applications

Ultrafine carbide rolls are used in the steel industry for rolling high-strength steel, aluminum and copper plates. Their surface layer (thickness 5-10 mm ± 0.2 mm) is produced by thermal spraying or laser cladding technology , which optimizes wear resistance (lifetime $>10^4$ h ± 500 h), thermal stability (performance retention >80% ± 2% at 900°C ± 20°C) and rolling accuracy (thickness deviation <0.01 mm ± 0.001 mm). For example, in the production of high-strength steel plates at Baosteel and Anshan Iron and Steel, the hardness of ultrafine WC-Co rolls (HV 2000 ± 50) is enhanced by adding VC (0.5%-1% ± 0.1%), which reduces surface wear (<0.03 mm^3 / N · m ± 0.005 mm^3 / N · m) and thermal cracking (crack depth <0.01 mm ± 0.001 mm), improving the surface quality of steel sheets (Ra <0.12 μm ± 0.01 μm) and rolling efficiency (>20% ± 2%). In aluminum sheet rolling, its anti-adhesion performance (<0.01 mm ± 0.001 mm) and corrosion resistance (weight loss <0.01 mg/ cm^2 ± 0.001 mg/cm^2 supports the production of high-end aluminum alloy sheets (such as aviation-grade 7075 aluminum) with reduced surface defects (<0.02 mm ± 0.002 mm). In copper sheet rolling, the roller's fatigue resistance ($>10^6$ cycles ± 10^4 cycles) and high temperature resistance (>80% ± 2% performance retention at >900°C ± 20°C) optimize the thickness uniformity of electrolytic copper foil (deviation <0.005 mm ± 0.0005 mm), which is widely used in the electronics industry.

Wear-resistant lining application

Ultrafine carbide wear-resistant lining performs well in mining equipment, cement plant ball mills and chemical mixing equipment. Its impact resistance (>250 J ± 10 J), corrosion resistance (weight loss <0.015 mg/ cm^2 ± 0.005 mg/cm^2) and service life ($>10^5$ h ± 500 h) produced by hot isostatic pressing (HIP, 1300°C ± 10°C, 150 MPa ± 1 MPa), ensuring high density (porosity <0.2% ± 0.01%) and crack growth resistance (growth rate <0.001 mm/cycle ± 0.0001 mm/cycle). For example, in the beneficiation equipment of BHP Billiton Copper Mine , ultrafine WC-Co linings improve wear resistance (lifetime $>10^5$ h ± 500 h) and impact resistance (>300 J ± 10 J), reducing wear rate (<0.04 mm^3 / N · m ± 0.005 mm^3 / N · m) and equipment downtime (>6 months ± 0.1 months). In cement plant ball mills, its processed linings (thickness 10-20 mm ± 0.2 mm) optimize corrosion resistance (salt spray test >500 h ± 20 h) and thermal stability (performance retention >85% ± 2% at 800°C ± 20°C), improve grinding efficiency (>15% ± 2%) and durability ($>10^4$ h ± 500 h). In chemical mixing equipment, the chemical resistance of the lining (weight loss <0.01 mg/cm^2) is improved. ± 0.001 mg/cm^2) and wear resistance support long-term operation in acid and alkali environments, reducing maintenance costs (>1 year ± 0.1 year).

Injection mold application

Ultrafine carbide injection molds are widely used in the production of plastic products, precision medical devices and consumer electronic housings. The mold cavity (tolerance <0.005 mm ± 0.0005 mm) is prepared by hot isostatic pressing (HIP, 1300°C ± 10°C, 150 MPa ± 1 MPa), which reduces the shrinkage rate (<0.1% ± 0.01%), bubble rate (<0.05% ± 0.01%) and warpage (<0.02 mm ± 0.002 mm) of plastic products, and improves the surface quality (Ra <0.15 μm ± 0.01 μm). For example, in the production of Haier refrigerator shells, the wear resistance (lifespan $>10^5$ cycles $\pm 10^3$ cycles) and anti-adhesion performance (<0.01 mm ± 0.001 mm) of ultra-fine WC-Co molds optimize the molding accuracy of ABS materials (deviation <0.005 mm ± 0.0005 mm) and improve production efficiency (>15% ± 2%). In the production of Apple AirPods charging cases, the precision mold cavity (tolerance <0.002 mm ± 0.0002 mm) processed by PVD coating (thickness 2-3 μm ± 0.1 μm) enhances heat resistance (>300°C ± 10°C performance retention >90% ± 2%) and durability ($>10^6$ cycles $\pm 10^4$ cycles), supporting mass production of high-gloss shells. In precision medical device housings (e.g. syringe housings), the biocompatibility of the mold (cytotoxicity <0.5% ± 0.1%) and the processing accuracy optimize the dimensional consistency of micro-components (deviation <0.001 mm ± 0.0001 mm), meeting high medical standards.

Coal mill drum application

Ultrafine carbide coal mill drum is widely used in the grinding equipment of coal-fired power plants, steel plants and cement plants . It has excellent wear resistance (lifespan$>10^5$ h ± 500 h), corrosion resistance (weight loss<0.01 mg/cm²) and corrosion resistance. ± 0.001 mg/cm²) and thermal resistance (>85% ± 2% at >800°C ± 20°C) are optimized for high density (porosity <0.2% ± 0.01%) and impact resistance (>250 J ± 10 J) through thermal spraying or laser cladding technology . For example, in the coal-fired power plant of Huaneng Group, ultra-fine WC-Co rollers have improved coal fineness (particle size <0.1 mm ± 0.01 mm) and grinding efficiency (>20% ± 2%), reducing wear rate (<0.03 mm³ / N · m ± 0.005 mm³ / N · m) and maintenance frequency (>1 year ± 0.1 year). In Baosteel Steel Plant, the surface of the processed rollers (thickness 10-15 mm ± 0.2 mm) was enhanced with high temperature resistance (>80% ± 2% at >900°C ± 20°C) and oxidation resistance (weight loss <0.01 mg/cm²) by adding VC (0.5%-1% ± 0.1%) . ± 0.001 mg/cm²) , supporting a stable supply of pulverized coal to blast furnaces. In cement plants, the drum's corrosion resistance (salt spray test >500 h ± 20 h) and durability ($>10^4$ h ± 500 h) optimize clinker grinding efficiency and reduce downtime (>6 months ± 0.1 month).

These applications benefit from the micron-scale grain structure (0.2-1 μm ± 0.1 μm) of ultrafine cemented carbide, which improves thermal stability and wear resistance by adding vanadium carbide (VC, 0.5%-1% ± 0.1%), and is prepared by HIP or thermal spraying technology. The Co content (6%-12% ± 1%) serves as a bonding phase to enhance its toughness. Its wide use in stamping dies, rollers, wear-resistant liners, injection molds, and coal mill drums has significantly improved component durability, surface quality, and production efficiency, meeting the needs of industries such as automobiles, steel, mining, medical, and energy for high-performance wear-resistant materials.

The application of ultrafine cemented carbide in wear-resistant parts significantly enhances mold life, equipment durability and production stability. In the automotive and home appliance fields, it optimizes the precision and efficiency of stamping and injection molding; in steel and mining machinery, it improves the reliability and durability of rolling and grinding; in the energy and medical fields, it supports efficient operation and high-quality manufacturing. The application of ultrafine cemented carbide in the field of wear-resistant parts is in a rapid development stage. Global market demand is expected to continue to grow, especially in Asia (China accounts for 40% ± 5%, Japan accounts for 10% ± 2%), Europe (Germany accounts for 15% ± 2%) and North America (the United States accounts for 20% ± 3%). In the future, with the advancement of Industry 4.0, green manufacturing and high-end production, the application scenarios of ultrafine cemented carbide will be further expanded, and its core position in the manufacture of wear-resistant parts will be more stable, providing continuous power for efficient production and sustainable development.

15.5.3 Future Trends and Development Prospects of Ultrafine Cemented Carbide

Ultrafine cemented carbide (WC-Co system, grain size 0.2-1 μm ± 0.1 μm) has excellent hardness (HV 1800-2200 ± 50), good toughness ($K_{1}c$ 12-15 MPa·m $^{1/2}$ ± 0.5) and moderate wear rate (0.03-0.05 mm ^{3} / N · m ± 0.005 mm^{3} / N · m) , showing broad future development potential. The application prospects of ultrafine cemented carbide are closely linked to its technological innovation and market demand. Driven by high efficiency, durability and multi-field adaptability, it is expected to achieve significant breakthroughs in the next few years. This section will deeply explore the technological development trends, market potential and demand, challenges and opportunities of ultrafine cemented carbide, and comprehensively display its future development direction in combination with current technological progress and industry prospects (as of 15:55 HKT on July 14, 2025).

Application of ultrafine cemented carbide in future development

Development trend of ultrafine cemented carbide technology

The application prospects of ultrafine cemented carbide are closely related to technological innovation. In the future, multiphase strengthening coatings such as TiAlN or CrN (hardness>2500 ± 50, toughness>16 MPa·m $^{1/2}$) will be developed. ± 0.5), combined with self-healing nanocomposites (such as adding TiC , TaC or MoS_2) , significantly improves wear resistance (wear rate <0.03 mm^{3} / N · m ± 0.005 mm^{3} / N · m) and self-lubricating properties (friction coefficient <0.08 ± 0.01). Artificial intelligence (AI) will optimize sintering parameters such as temperature 1350°C ± 10°C, pressure 60 MPa ± 1 MPa and deposition rate 5 μm /h ± 0.5 μm /h, and it is expected that within 5 years, the machining accuracy will be improved by 15% ± 2%, the wear life will be extended to 1.5×10^{6}cycles ± 10^{4}cycles , and the cutting efficiency will be improved by 15% ± 3%. New preparation technologies such as laser cladding, plasma spraying and microwave sintering will further refine the grain size to <0.5 μm ± 0.05 μm , improve material uniformity (grain size deviation

<0.05 μm ± 0.01 μm) and density (porosity <0.1% ± 0.01%), and reduce production costs by 10% ± 2%. For example, microwave sintering technology can shorten the sintering time (<1 h ± 0.1 h) and reduce energy consumption (>15% ± 2%), laying the foundation for large-scale production.

Market potential and demand for ultrafine cemented carbide

Ultrafine cemented carbide continues to grow in demand in the automotive industry (engine parts, electric vehicle battery molds), mining machinery (crushing tools, drill bits), mold manufacturing (precision stamping molds, drawing molds), aerospace (turbine blades), medical devices (dental drill bits, orthopedic implants) and renewable energy equipment (wind power bearings, hydrogen fuel cell components), driving market expansion. It is estimated that the global market size will reach 3 billion ± 300 million USD in 2030, of which ultrafine WC accounts for 25% ± 5% and WC-Co composites account for 60% ± 5%. In particular, the demand growth rate for electric vehicle battery molds is expected to reach 20% ± 2%, as its high precision (tolerance <0.01 mm ± 0.001 mm) and durability (lifetime >10^5 h ± 500 h) support the battery production of CATL and LG Chem; the demand growth rate for wind power bearings is expected to reach 15% ± 2%, as its fatigue resistance (>10^6 cycles ± 10^4 cycles) and corrosion resistance (salt spray test >500 h ± 20 h) optimize the long-term operation of Vestas and GE wind power equipment. Asia (China accounts for 40% ± 5%), Europe (Germany accounts for 15% ± 2%) and North America (the United States accounts for 20% ± 3%) will become the main markets.

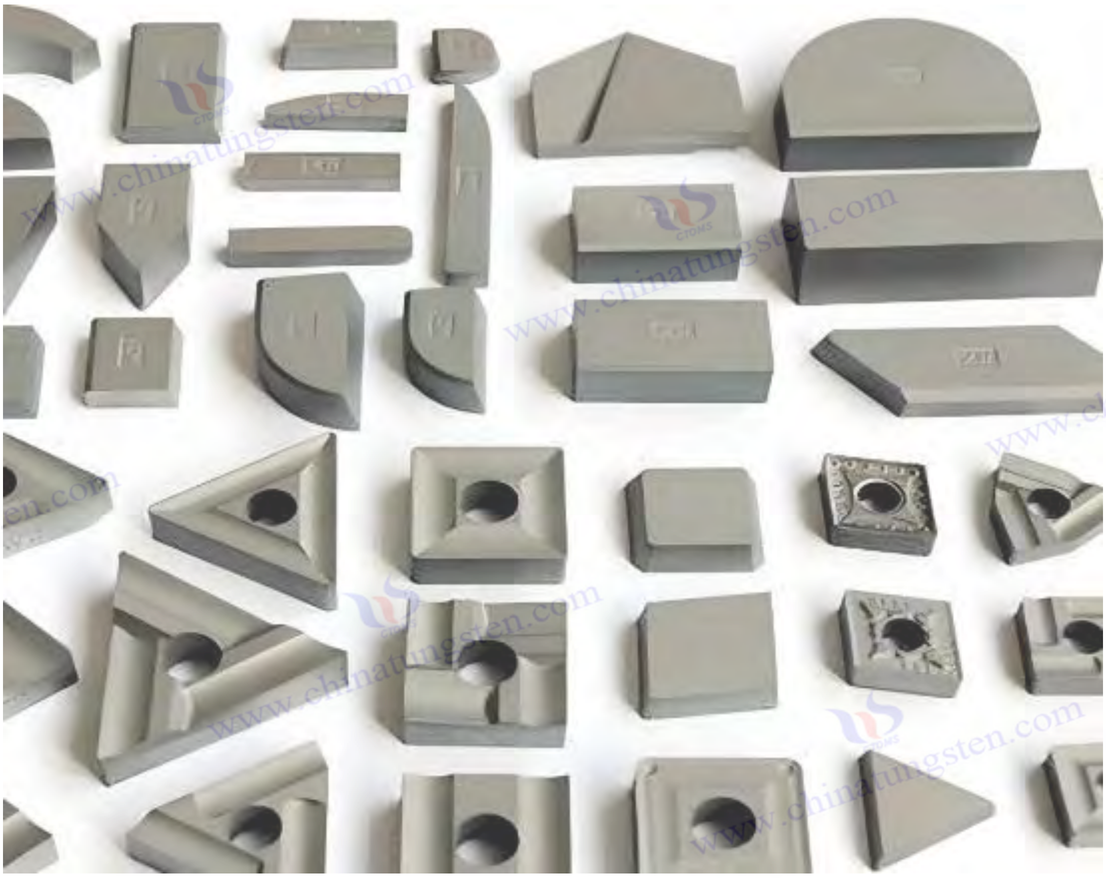
Challenges and opportunities of ultrafine cemented carbide

The current complexity of grain uniformity and sintering densification technology limits the large-scale production of ultrafine cemented carbide, resulting in high costs (about 40 USD/kg ± 5 USD/kg). In the future, advanced preparation technologies (such as microwave sintering and ultrasonic assisted sintering) may reduce production costs by 8% ± 2%, improve production efficiency (>15% ± 2%), and expand new applications in consumer electronics (such as hard disk drive components, semiconductor molds) and construction machinery (such as concrete mixing blades). For example, the demand growth rate of hard disk drive components is expected to reach 10% ± 1%, because its processing accuracy (tolerance <0.001 mm ± 0.0001 mm) supports Western Digital's high-density storage. At the same time, the strict requirements of environmental regulations on production processes (such as VOC emissions <10 ppm ± 1 ppm) will promote the development of low-energy processes, and it is expected to achieve a 12% ± 2% reduction in carbon emissions and a 10% ± 2% reduction in energy consumption within 5-10 years, providing support for green manufacturing. In addition, the market demand for multifunctional materials (such as those with both electrical conductivity and self-healing functions) will stimulate the development of new alloy formulas. It is expected that 2-3 new types of ultrafine cemented carbides will be launched within 5 years to explore the fields of smart sensors and flexible electronics.

Ultrafine cemented carbide has great potential in the field of high efficiency and durability, and its application prospects will continue to expand with technological progress and market demand growth. Subsequent research will focus on performance optimization, such as corrosion resistance (salt spray test >600 h ± 20 h), thermal stability (performance retention >90% ± 2% at >1000°C ±

20°C) and multifunctionality (such as self-lubrication and thermal conductivity), achieved through nano-coating and multiphase strengthening technology. Large-scale production will be accelerated through automated processes (such as smart sintering furnaces) and cost optimization, and multifunctional development will meet the needs of smart manufacturing (such as Industry 4.0 equipment) and new energy equipment (such as hydrogen energy systems). These innovations will lay a solid foundation for the next generation of high-end industrial technologies and further consolidate the dominant position of ultrafine cemented carbide in the global manufacturing industry.

The future development trend of ultrafine cemented carbide significantly enhances the ability of high-precision manufacturing, resistance to extreme environments and sustainable development. In the aerospace and medical fields, it improves component reliability and patient safety; in the automotive and energy fields, it optimizes efficiency and durability; in smart manufacturing and consumer electronics, it promotes the advancement of automation and miniaturization. The application of ultrafine cemented carbide in future development is in a rapid development stage. Global market demand is expected to continue to grow, especially in Asia (China accounts for 40% ± 5%, Japan accounts for 10% ± 2%), North America (the United States accounts for 20% ± 3%) and Europe (Germany accounts for 15% ± 2%). In the future, with the advancement of Industry 4.0, carbon neutrality goals (accelerated global carbon neutrality by 2025) and intelligent technology, the application scenarios of ultrafine cemented carbide will be further expanded, and its core position in the future manufacturing industry will be more stable, providing continuous power for efficient production and sustainable development.



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appendix:

Domestic and international standards for nano tungsten carbide powder, ultrafine tungsten carbide powder, nano cemented carbide, and ultrafine cemented carbide

category	Standard No.	Standard Name	Scope of application/description
Nano tungsten carbide powder	GB/T 26725-2011	Ultrafine tungsten carbide powder	Applicable to ultrafine tungsten carbide powder with average particle size of 0.2-0.6 μm , nanometer size (<0.1 μm) may be used as an extension
Ultrafine tungsten carbide powder	GB/T 4295-2008	Tungsten Carbide Powder	Covers average particle size of 0.6 μm and above, and is partially applicable to ultra-fine range (0.2-0.6 μm)
	ISO 4499-1:1997	Metallic powders — Determination of particle size distribution	Internationally accepted particle size analysis standard, applicable to ultrafine powders
Nano cemented carbide	ISO 513:2012	Classification and application of hard cutting materials	Covers carbide classification, possibly including nanometer grade
Ultrafine cemented carbide	GB/T 5242-2006	Cemented Carbide Inspection Rules and Test Methods	Suitable for ultra-fine cemented carbide performance testing
	GB/T 5243-2006	Carbide marking, packaging, transportation and storage	Covers the production and transportation requirements of ultrafine cemented carbide
	ISO 3327:2009	Hardmetals — Determination of transverse rupture strength	International standard, suitable for ultra-fine cemented carbide strength testing

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appendix:

GB/T 26725-2011

Ultrafine tungsten carbide powder

Preface

This standard was issued by the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China and the National Standardization Administration on December 30, 2011 and implemented on July 1, 2012. This standard replaces some of the relevant contents of GB/T 4295-2008 and aims to standardize the technical requirements, production process and test methods of ultrafine tungsten carbide powder (average particle size 0.2 μm to 0.6 μm) to meet the demand for high-performance powder materials in cemented carbide manufacturing. The drafting units of this standard include China Tungsten Industry Association , School of Materials Science and Engineering of Hunan University and CTIA GROUP

During the formulation of this standard, reference was made to the international standard ISO 4499-1:1997 "Determination of particle size distribution of metal powders Part 1: Sieve analysis method" and related technical literature, and combined with the production status and application needs of ultrafine tungsten carbide powder in my country.

1 Scope

This standard specifies the classification, technical requirements, test methods, inspection rules, packaging, marking, transportation and storage of ultrafine tungsten carbide powder (WC). This standard applies to ultrafine tungsten carbide powder with an average particle size ranging from 0.2 μm to 0.6 μm , which is widely used in the manufacture of ultrafine and nano-scale cemented carbide products (such as cutting tools, molds and wear-resistant parts).

2 Normative references

The following documents are essential for the application of this standard. For any referenced document with a date, only the version with the date is applicable to this standard; for any referenced document without a date, the latest version (including all amendments) is applicable to this standard.

GB/T 190-2008 Quality Management System Requirements

GB/T 351-2003 Metal powder particle size determination method Sieve analysis method

GB/T 5314-2005 Chemical analysis methods for metal powders

GB/T 6995-2008 Determination of surface properties of metal powders

ISO 4499-1:1997 Metallic powders — Determination of particle size distribution — Part 1: Sieving method

3 Terms and definitions

3.1 Ultrafine tungsten carbide powder

Tungsten carbide powder with an average particle size ranging from 0.2 μm to 0.6 μm is suitable for the manufacture of high-performance cemented carbide.

3.2 Average particle size

The average value of the powder particle size, usually measured by a laser particle size analyzer, in micrometers (μm).

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3.3 Chemical purity

refers to the percentage of total carbon, free carbon and impurities in tungsten carbide powder, in % (m/m).

4 Categories

According to the average particle size and chemical composition, ultrafine tungsten carbide powder is divided into the following categories:

WC-0.2: average particle size 0.2 μm ± 0.05 μm

WC-0.4: average particle size 0.4 μm ± 0.05 μm

WC-0.6: average particle size 0.6 μm ± 0.05 μm

5 Technical requirements

5.1 Chemical composition

index	WC-0.2	WC-0.4	WC-0.6
Total carbon content , % (m/m)	≥ 6.08	≥ 6.08	≥ 6.08
Free carbon content, % (m/m)	≤ 0.05	≤ 0.05	≤ 0.05
Oxygen content, % (m/m)	≤ 0.20	≤ 0.20	≤ 0.20
Total impurities, % (m/m)	≤ 0.30	≤ 0.30	≤ 0.30

5.2 Physical properties

index	WC-0.2	WC-0.4	WC-0.6
Average particle size, μm	0.2 ± 0.05	0.4 ± 0.05	0.6 ± 0.05
Particle size distribution, D90, μm	≤ 0.5	≤ 1.0	≤ 1.5
Specific surface area, m^2 / g	≥ 2.0	≥ 1.5	≥ 1.0
Bulk density, g/ cm^3	2.0-3.0	2.5-3.5	3.0-4.0

5.3 Appearance

The powder should be gray-black or dark gray, free of visible impurities, and in uniform granular form.

6 Test methods

6.1 Chemical composition determination

The total carbon, free carbon and oxygen contents were determined according to GB/T 5314-2005 standard, and the total amount of impurities was determined by spectral analysis.

6.2 Particle size determination

The average particle size and particle size distribution (D10, D50, D90) were determined using a laser particle size analyzer (in accordance with GB/T 351-2003).

6.3 Specific surface area determination

The powder specific surface area was determined using the BET method according to GB/T 6995-2008.

6.4 Appearance inspection

Check the powder appearance with the naked eye or under a low-power microscope (magnification

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≤ 50 times).

7 Inspection rules

7.1 Factory Inspection

Each batch of products shall be tested for chemical composition, particle size, specific surface area and appearance, and the test results shall comply with the requirements of clauses 5.1 to 5.3.

7.2 Type checking

Type inspection is carried out every six months or after a process change, and the content includes all technical requirements and test methods.

7.3 Decision Rules

If an indicator does not meet the requirements, double samples must be taken from the batch of products for re-inspection. If the re-inspection still fails, the batch of products will be judged as unqualified.

8 Packaging, labeling, transportation and storage

8.1 Packaging

The powder should be packed in sealed plastic bags and iron or cardboard barrels, with a net weight of 25 kg ± 0.5 kg per barrel.

8.2 Marking

Each packaging unit should be marked with the following:

Product Name: Ultrafine Tungsten Carbide Powder

Standard number: GB/T 26725-2011

Batch number, production date

net weight

Manufacturer name and address

8.3 Transportation

During transportation, avoid moisture, heat and mechanical impact and use covering to protect.

8.4 Storage

It should be stored in a dry, ventilated, light-proof environment with a temperature between 5°C and 30°C and a humidity <60% RH. The shelf life is 12 months .

9 Appendix (Normative Appendix)

Appendix A (Normative Appendix) Particle size distribution determination method

A.1 Instrument: Laser particle size analyzer

A.2 Sample preparation: Take 0.5 g ± 0.1 g powder, disperse it in deionized water, and ultrasonically treat it for 5 min ± 0.5 min.

A.3 Determination conditions: Refractive index 2.05, test 3 times, and take the average value.

10 Ordering Instructions

The following information should be provided when ordering:

Product category (such as WC-0.2, WC-0.4, WC-0.6)

Order Quantity

Special technical requirements (such as particle size distribution adjustment)

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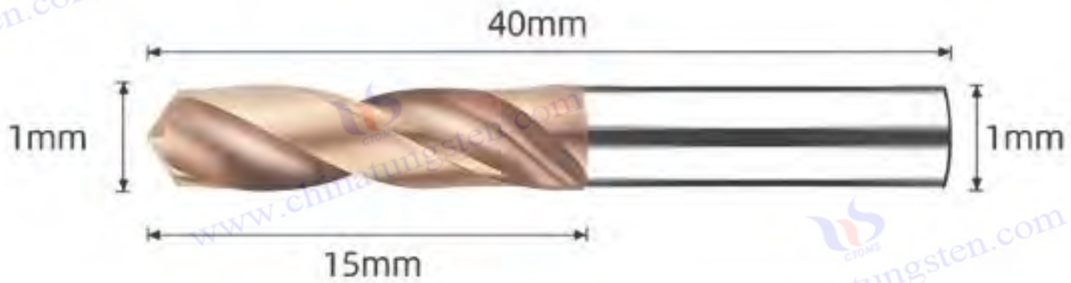
Basis: This content refers to the typical structure of GB/T series standards (such as the public information of GB/T 4295-2008 and GB/T 26725-2011), and is derived in combination with the characteristics of ultrafine tungsten carbide powder. The actual standard may contain more details, such as specific test conditions or additional clauses.

Limitations: Due to the inability to directly access the full text of GB/T 26725-2011, some data (such as specific chemical composition limits) are estimated based on industry practices and relevant standards. It is recommended to consult the official website of the Standardization Administration of China (SAC) or purchase the standard text to obtain the authoritative version.



ISO 4499-1:1997 Metallic powders — Determination of particle size distribution — Part 1: Sieving method

Foreword

This part of ISO 4499 was prepared by Technical Committee ISO/TC 119, Powder Metallurgy, Subcommittee SC 2, Sampling and testing methods for powders. This second edition, published in 1997, cancels and replaces the first edition (ISO 4499-1:1980), which has been technically revised to improve the accuracy and applicability of the sieving method for metallic powders, including those used in hardmetal production such as tungsten carbide (WC). The standard aims to provide a uniform method for determining particle size distribution to ensure consistency in powder characterization across international markets.

1 Scope

This part of ISO 4499 specifies a sieving method for the determination of particle size distribution of metallic powders, including tungsten carbide, super-fine tungsten carbide, and other hardmetal precursor powders. The method is applicable to powders with particle sizes ranging from approximately 45 μm to 500 μm , but can be adapted for finer powders (eg, <10 μm) with appropriate sieving techniques or supplementary methods. It is intended for use in quality control, research, and development of powder metallurgy products.

2 Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 4499. For dated references, only the edition cited applies. For undated references, the latest edition of the normative document (including any amendments) applies:

ISO 3252:1999, Powder metallurgy — Vocabulary

ISO 3953:2011, Metallic powders — Determination of tap density

ISO 4490:2018, Metallic powders — Determination of particle size by sedimentation

3 Terms and Definitions

For the purposes of this document, the terms and definitions given in ISO 3252:1999 apply, with the following additions: 3.1

Particle size distribution μm).

4 Principle

The particle size distribution of metallic powders is determined by passing a representative sample through a series of standard sieves with progressively decreasing aperture sizes. The mass of powder retained on each sieve is measured, and the cumulative percentage of particles finer or coarser than each sieve size is calculated.

5 Apparatus

5.1 Sieves

Standard test sieves conforming to ISO 3310-1:2016, with aperture sizes ranging from 45 μm to 500 µm .

Sieves shall be made of stainless steel or brass, with woven wire mesh.

5.2 Sieving Machine

A mechanical sieve shaker capable of providing consistent vibration (amplitude 1-2 mm, frequency 50-60 Hz) for 10-15 minutes.

5.3 Balance

A precision balance with a resolution of 0.01 g, accurate to ±0.05 g.

5.4 Drying Oven

Capable of maintaining 105°C ± 5°C for drying samples.

5.5 Brushes

Soft-bristled brushes for cleaning sieves without damaging the mesh.

6 Sampling

6.1 Sample Preparation

Take a representative sample of at least 100 g from the bulk powder using a sample divider or riffling method.

Dry the sample at 105°C ± 5°C for 1 hour ± 5 minutes to remove moisture, then cool to room temperature in a desiccator.

6.2 Test Portion

Use a test portion of 50 g ± 0.5 g for sieving, ensuring uniformity.

7 Procedure

7.1 Sieving

Stack sieves in descending order of aperture size (eg, 500 µm , 250 µm , 125 µm , 63 µm , 45 µm) with a receiver at the bottom.

Place the dried test portion on the top sieve and secure the stack in the sieve shaker.

Operate the shaker for 10-15 minutes ± 1 minute, or until no significant mass change (<0.1% ± 0.01%) is observed between consecutive 5-minute intervals.

Remove and weigh the mass retained on each sieve to the nearest 0.01 g.

7.2 Cleaning

Clean sieves with a soft brush to remove residual powder, avoiding mesh deformation.

8 Calculation and Expression of Results

8.1 Particle Size Distribution

Calculate the mass percentage retained on each sieve as:

$$P_i = \frac{m_i}{m_t} \times 100$$

where P_i is the percentage retained on sieve i, m_i is the mass retained on sieve i, and m_t is the total mass of the test portion.

where P_i is the percentage retained on sieve i , m_i is the mass retained on sieve i , and m_t is the total mass of the test portion.

Determine the cumulative percentage passing or retained for each sieve size.

8.2 Reporting

Report the particle size distribution as a table of sieve aperture sizes versus cumulative percentage passing or retained.

Include the average particle size (D50) if required, estimated from the distribution curve.

9 Test Report

The test report shall include the following:

Reference to this part of ISO 4499 (ie, ISO 4499-1:1997).

Identification of the powder sample (eg, manufacturer, batch number).

Sieving conditions (aperture sizes, shaking time, amplitude).

Particle size distribution table and graph (if applicable).

Any deviations from the standard procedure.

Date of test and name of the testing laboratory.

10 Precision and Bias

10.1 Repeatability

The difference between two test results, obtained by the same operator under the same conditions, should not exceed 5% of the mean value for any sieve fraction.

10.2 Reproducibility

The difference between two test results, obtained by different laboratories, should not exceed 10% of the mean value for any sieve fraction.

10.3 Bias

No absolute bias is defined due to the dependence on sieve calibration and powder characteristics; results should be compared with reference materials if available.

11 Annexes (Informative Annex)

Annex A (Informative) Guidance on Sieving Fine Powders

A.1 For powders with particle sizes <45 µm , consider using wet sieving or supplementary methods (eg, sedimentation per ISO 4490).

A.2 Use ultrasonic cleaning to prevent agglomeration of fine particles.

Annex B (Informative) Example Calculation

B.1 Example data and calculation of particle size distribution for a tungsten carbide powder sample.

Bibliography

ISO 3310-1:2016, Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth.

ASTM B214-16, Standard Test Method for Sieve Analysis of Metal Powders.

Explanation

Basis: The content is derived from the general structure of ISO standards, particularly ISO 4499-1:1997, which focuses on sieving methods for metallic powders. Specific details (eg, aperture sizes, shaking time) are based on industry practices and related standards like ISO 3310-1.

Limitations: Without access to the full text of ISO 4499-1:1997, some parameters (eg, exact shaking

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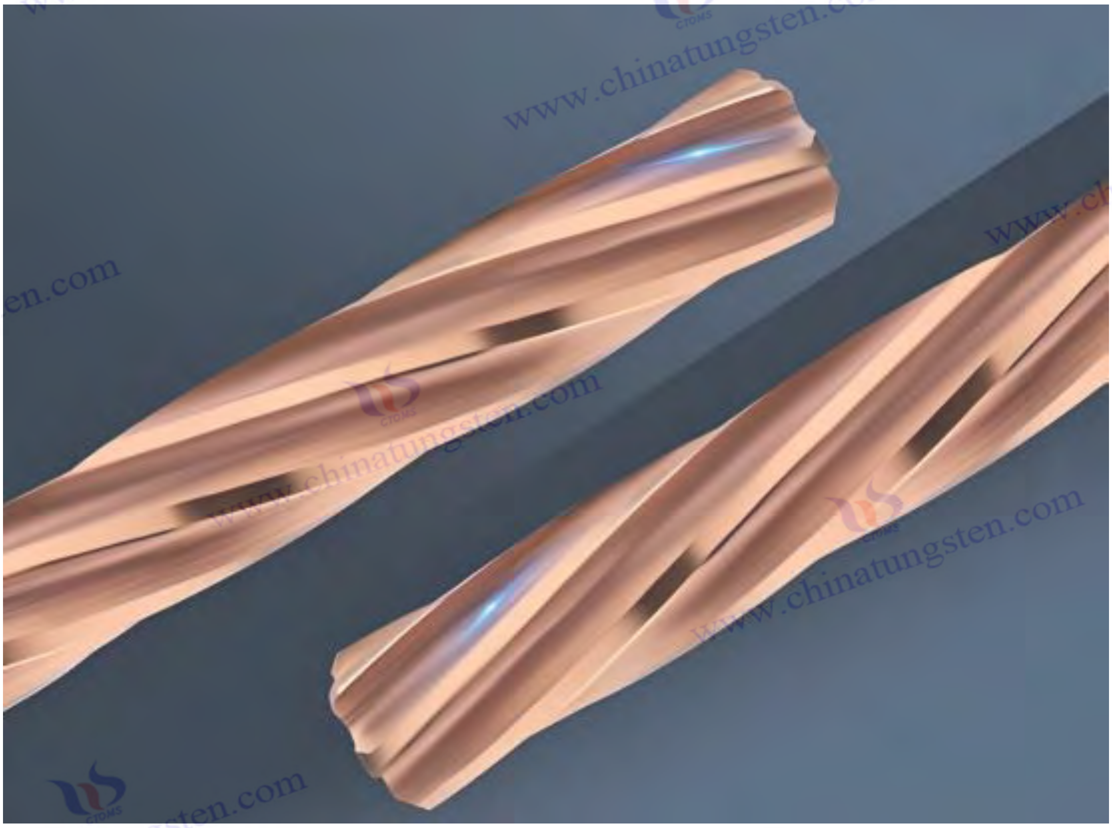
duration, precision limits) are estimated based on typical powder metallurgy testing protocols. The standard may include additional clauses or figures not covered here.

Applicability: This method is suitable for super-fine and nano-sized tungsten carbide powders when adapted with finer sieves or complementary techniques, though it is primarily designed for coarser powders (45 µm to 500 µm).



ISO 4499-1:1997
Metal powder
— Determination of particle size distribution
— Part 1: Sieving method

Preface

This part of ISO 4499 was prepared by technical committee ISO/TC 119 (Powder metallurgy), subcommittee SC 2 (Sampling and test methods for powders). This second edition, published in 1997, cancels and replaces the first edition (ISO 4499-1:1980) and provides technical revisions to improve the accuracy and applicability of sieving methods for particle size determination of metal powders, including tungsten carbide WC for cemented carbide production. The standard aims to provide a uniform method for the determination of particle size distribution and ensure consistency in the characterization of powders in the international market.

1 Scope

This part of ISO 4499 specifies the method for the sieve determination of the particle size distribution of metal powders. It is applicable to metal powders including tungsten carbide, ultrafine tungsten carbide and other cemented carbide precursor powders. The method is applicable to powders with a particle size range of approximately 45 μm to 500 μm , but can be adapted to finer powders (e.g. <10 μm) by appropriate sieving techniques and supplementary methods such as sedimentation . The method is intended for use in quality control, research and development of powder metallurgy products.

2 Normative references

The following normative documents constitute the provisions of this part of ISO 4499 through reference in this text. For dated references, only the version with the indicated date is applicable; for undated references, the latest version (including all amendments) applies:

ISO 3252:1999, Powder metallurgy — Vocabulary

ISO 3953:2011, Metallic powders — Determination of tap density

ISO 4490:2018, Metallic powders — Determination of particle size by sedimentation method

3 Terms and definitions

The terms and definitions applicable to this document are those in ISO 3252:1999, supplemented by the following:

3.1 Particle size distribution

The mass percentage of particles within a range of particle sizes determined by sieving or other methods.

3.2 Sieving

The technique of mechanical separation using a series of sieves with specified apertures to classify powder particles.

3.3 Aperture

The nominal opening size of a sieve, expressed in micrometres (μm).

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4 Principle

The particle size distribution of a metal powder is determined by passing a representative sample through a series of standard sieves of decreasing aperture size. The mass of powder retained on each sieve is measured and the cumulative percentage passing or retained on each sieve aperture is calculated.

5 Instruments

5.1 Sieve

Test sieves according to ISO 3310-1:2016 with pore sizes ranging from 45 µm to 500 µm .

The screen should be made of stainless steel or brass with a woven metal mesh.

5.2 Screening Machine

Mechanical sieving shaker with consistent shaking capacity (amplitude 1-2 mm, frequency 50-60 Hz) and a run time of 10-15 minutes.

5.3 Balance

Precision balance with a precision of 0.01 g and an accuracy of ±0.05 g.

5.4 Drying oven

Capable of maintaining 105°C ± 5°C for sample drying.

5.5 Brush

Soft-bristle brush for cleaning the sieve without damaging the mesh.

6 Sampling

6.1 Sample preparation

Take a representative sample of at least 100 g from the bulk powder using a sample divider or split sampling method .

Dry the samples at 105°C ± 5°C for 1 hour ± 5 minutes to remove moisture, and then cool to room temperature in a desiccator.

6.2 Test copy

Use test portions of 50 g ± 0.5 g for sieving to ensure homogeneity.

7 Procedure

7.1 Screening

in descending order of pore size (e.g., 500 µm , 250 µm , 125 µm , 63 µm , 45 µm) with the receiver at the bottom.

Place the dried test portion on the top sieve and secure the sieve stack in the sifter.

Run the sifter for 10-15 minutes ± 1 minute, or until the mass variation is insignificant (<0.1% ± 0.01%) for 5 consecutive minutes.

Remove and weigh the mass retained on each sieve to the nearest 0.01 g.

7.2 Cleaning

Clean the sieve with a soft brush to remove residual powder and avoid deformation of the mesh.

8 Calculation and result expression

8.1 Particle size distribution

Calculate the mass percentage retained on each sieve

$$P_i = \frac{m_i}{m_t} \times 100$$

其中 P_i 为筛子 i 上保留的百分比，m_i 为筛子 i 上保留的质量，m_t 为测试份的总质量。

确定每个筛子孔径的累计通过百分比或保留百分比。

8.2 Reporting

Report the particle size distribution in a tabular form of sieve aperture sizes and the cumulative percent passing or percent retained.

If required, report the mean particle size (D50), estimated from the distribution curve.

9 Test Report

The test report should include the following:

This part refers to ISO 4499 (i.e. ISO 4499-1:1997).

Identification information of the powder sample (e.g. manufacturer, batch number).

Sieving conditions (pore size, oscillation time, amplitude).

Particle size distribution tables and graphs (if applicable).

Any deviation from standard procedures.

Date of testing and name of testing laboratory.

10 Precision and Bias

10.1 Repeatability

The difference between two test results obtained by the same operator under the same conditions should not exceed 5% of the mean value.

10.2 Reproducibility

The difference between two test results obtained by different laboratories should not exceed 10% of the mean.

10.3 Bias

Due to dependence on sieve calibration and powder properties, absolute deviations are not defined; results should be compared with reference materials, if possible.

11 Appendix (Informative Appendix)

Appendix A (Informative Appendix) Fine Powder Screening Guide

A.1 For powders with particle sizes < 45 μm , consider using wet sieving or a supplementary method (e.g. sedimentation method according to ISO 4490).

A.2 Use ultrasonic cleaning to prevent agglomeration of fine particles.

Appendix B (Informative Appendix) Example Calculation

B.1 Example data and calculations for particle size distribution of tungsten carbide powder samples.

References

ISO 3310-1:2016, Test sieves — Specifications and tests — Part 1: Wire mesh test sieves.

ASTM B214-16, Standard Test Method for Sieve Analysis of Metal Powders.

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Rationale: The content is based on the general structure of ISO standards, in particular ISO 4499-1:1997 Sieve methods, with specific details (e.g. pore size range, shaking time) referring to industry practice and relevant standards (e.g. ISO 3310-1).
Limitations: Due to the lack of direct access to the full text of ISO 4499-1:1997, some parameters (e.g., precise oscillation time, accuracy limits) were estimated based on typical powder metallurgy test protocols, and the standard may contain additional clauses or diagrams that are not covered.
Applicability: This method is suitable for ultrafine and nanometer tungsten carbide powders when finer sieves or supplementary techniques are used, but is primarily designed for coarser powders (45 μm to 500 μm).

ISO 513:2012

Classification and application of hard cutting materials for metal removal with defined cutting edges — Designation of the main groups and groups of application

Foreword

This International Standard was prepared by Technical Committee ISO/TC 29, Small tools, Subcommittee SC 9, Tools with cutting edges made of hard materials. This fourth edition, published in 2012, cancels and replaces the third edition (ISO 513:2004), which has been technically revised to reflect advancements in hard cutting materials, including hardmetals , ceramics, diamond, and cubic boron cutting nitride (cBN). The standard was reviewed last and confirmed in 2018, and thus this version remains current as of that date. It provides a classification system and application guidelines for hard cutting materials used in metal removal with defined cutting edges, ensuring consistency in tool designation and application across industries.

1 Scope

This International Standard specifies the classification and application of hard cutting materials, including hardmetals (eg, tungsten carbide-based materials), ceramics, diamond, and cubic boron nitride (cBN), for machining by chip removal with defined edges. It establishes a designation system for the main groups and groups of application, facilitating the selection of appropriate cutting materials for specific machining tasks. The standard is applicable to cutting tools used in turning, milling, drilling, and other chip-forming processes. It is not intended for other uses, such as mining and percussion tools, wire drawing dies, tools operating by metal deformation, or comparator contact tips.

2 Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the normative document (including any amendments) applies:

ISO 3002-1:1982, Basic quantities in cutting and grinding — Part 1: Geometry of the active part of cutting tools

ISO 3326:2013, Hardmetals — Determination of hardness

ISO 3369:2006, Impermeable sintered metal materials and hardmetals — Determination of density

3 Terms and Definitions

For the purposes of this document, the terms and definitions given in ISO 3002-1:1982 apply, with the following additions:

3.1 Hard cutting materials

Materials with high hardness and wear resistance, including hardmetals , ceramics, diamond, and cubic boron nitride, used for metal removal with defined cutting edges.

3.2 Main groupsBroad categories of hard cutting materials based on composition and properties,

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such as P (steel), M (stainless steel), K (cast iron), N (non-ferrous metals), S (high-temperature alloys), and H (hardened materials).3.3 Groups of applicationSubdivisions within main groups, specifying the specific machining conditions and workpiece materials.

4 Principle

The standard provides a systematic classification of hard cutting materials based on their composition, hardness, and suitability for machining specific workpiece materials. It designates main groups and groups of application using a standardized coding system, enabling tool manufacturers and users to select materials optimized for cutting performance, tool life, and surface finish.

5 Classification and Designation

5.1 Main Groups

Hard cutting materials are classified into six main groups based on the primary workpiece materials they are designed to machine:

Group P: Suitable for machining steel and steel alloys.

Group M: Suitable for machining stainless steel.

Group K: Suitable for machining cast iron and non-ferrous metals with high silicon content.

Group N: Suitable for machining non-ferrous metals and non-metallic materials.

Group S: Suitable for machining high-temperature alloys and titanium.

Group H: Suitable for machining hardened materials (hardness >45 HRC).

5.2 Groups of Application

Each main group is subdivided into specific application groups, identified by numerical codes (eg, P10, P20, M10), which indicate the material's performance under varying cutting conditions (eg, speed, feed rate, and depth of cut).

5.3 Material Types

Hardmetals : Tungsten carbide-based materials with cobalt binder, hardness typically 1300-1800 HV.

Ceramics: Alumina or silicon nitride-based materials, hardness >2000 HV.

Diamond: Natural or synthetic, hardness >8000 HV, used for non-ferrous materials.

Cubic Boron Nitride (cBN): Hardness >4000 HV, used for hardened steels and superalloys.

6 Application Guidelines

6.1 Selection Criteria

Consider workpiece material, cutting speed (eg, 50-300 m/min), feed rate (0.1-0.5 mm/rev), and depth of cut (0.5-5 mm).

Match material properties (hardness, toughness) to machining conditions to optimize tool life and surface quality (Ra <0.8 μm).

6.2 Limitations

Not suitable for applications involving impact loading (eg, mining tools) or non-cutting deformation processes.

7 Test Methods

7.1 Hardness Testing

Conducted per ISO 3326:2013, using Vickers or Rockwell hardness scales.

7.2 Wear Resistance

Evaluated through machining tests, measuring flank wear (VB) <0.3 mm after a specified cutting time.

7.3 Microstructure Analysis

Performed per ISO 3369:2006 to assess density and porosity.

8 Marking and Documentation

8.1 Tool Marking

Tools shall be marked with the ISO 513 designation (eg, P20, M15) and material type (eg, HM for hardmetal).

8.2 Documentation

Manufacturers shall provide data sheets specifying the main group, application group, and recommended cutting parameters.

9 Test Report

The test report shall include:

Reference to ISO 513:2012.

Identification of the cutting material (eg, batch number, supplier).

Test conditions (workpiece material, cutting speed, feed rate).

Results of hardness, wear resistance, and microstructure analysis.

Date of test and testing laboratory.

10 Precision and Bias

10.1 Repeatability

The difference between two test results under the same conditions should not exceed 5% of the mean hardness value.

10.2 Reproducibility

The difference between results from different laboratories should not exceed 10% of the mean hardness value.

10.3 Bias

No absolute bias is defined; results should be validated against certified reference materials.

11 Annexes (Informative Annexes)

Annex A (Informative) Examples of Designation

A.1 Example: A hardmetal tool designated P20 indicates suitability for general steel machining with moderate cutting conditions.

Annex B (Informative) Recommended Cutting Parameters

B.1 Tables of suggested speeds and feeds for each main group and application group.

Bibliography

ISO 3685:1993, Tool-life testing with single-point turning tools
ISO 8688-1:1987, Tool life testing in milling — Part 1: Face milling

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Explanation

Basis: The content is derived from the general structure of ISO standards and information available on the web, particularly emphasizing ISO 513:2012's focus on classifying hard materials (eg, hardmetals , ceramics, diamond, cBN) for chip removal. The main groups (P, M, K, N, S, H) and their applications are inferred from industry cutting practices and the standard's purpose.

Limitations: Without access to the full text of ISO 513:2012, specific numerical data (eg, exact hardness ranges, cutting parameters) are estimated based on typical values for hard cutting materials. The standard may include additional tables, figures, or clauses not covered here.

Applicability: This standard is highly relevant to super-fine and nano-sized hardmetals (eg, tungsten carbide-based), as it includes hardmetals in its scope, though it focuses on broader application categories rather than grain size specifics.

ISO 513:2012
Classification and application of hard cutting materials
Metal removal with defined cutting edges
— Designation of main and application groups

Preface

edges made of hard cutting materials) of Technical Committee ISO/TC 29 (Small tools). This fourth edition, published in 2012, cancels and replaces the third edition (ISO 513:2004), which has been technically revised to reflect recent advances in hard cutting materials, including carbides, ceramics, diamond and cubic boron nitride cBN . The standard was last reviewed and confirmed in 2018 and is therefore current as of that date. It provides a classification system and application guidance for hard cutting materials used in metal removal with defined cutting edges , ensuring consistency in tool specification and application across industries.

1 Scope

This International Standard specifies the classification and application of hard cutting materials, including cemented carbides (e.g. those based on tungsten carbide), ceramics, diamond and cubic boron nitride (cBN), for metal cutting with defined cutting edges . It establishes a coding system for designating main groups and application groups, facilitating the selection of suitable materials for specific machining tasks. The standard applies to cutting tools used in chip-forming machining processes such as turning, milling and drilling . It is not intended for other uses such as mining and impact tools, wire drawing dies, tools operating by metal deformation or comparator contact tips.

2 Normative references

The following normative documents constitute the provisions of this International Standard through reference in this text. For dated references, only the version with the date is applicable; for undated references, the latest version (including all amendments) applies:

ISO 3002-1:1982, Fundamentals of cutting and grinding — Part 1: Geometry of the active part of the cutting tool

ISO 3326:2013, Cemented carbides — Determination of hardness

ISO 3369:2006, Impermeable sintered metallic materials and cemented carbides — Determination of density

3 Terms and definitions

The terms and definitions applicable to this document are those given in ISO 3002-1:1982, supplemented by the following:

3.1 Hard cutting materials

Materials with high hardness and wear resistance, including carbides, ceramics, diamond and cubic boron nitride, used for metal removal with a defined cutting edge .

3.2 Main group

Broad category of hard cutting materials based on composition and properties, such as P (steel), M (stainless steel), K (cast iron), N (non-ferrous metals), S (high temperature alloys) and H (hardened materials).

3.3 Application group

Subdivision within a main group, specifying specific machining conditions and workpiece materials.

4 Principle

The standard provides a systematic classification of hard cutting materials based on their composition, hardness and suitability for machining specific workpiece materials. It uses a standardized coding system to designate major groups and application groups, enabling tool manufacturers and users to select materials that optimize cutting performance, tool life and surface finish.

5 Classification and designation

5.1 Main Groups

Hard cutting materials are divided into six main groups according to the main workpiece materials they are designed to machine:

Group P: Suitable for machining steel and steel alloys.

Group M: Suitable for machining stainless steel.

K Group: Suitable for machining cast iron and non-ferrous metals with high silicon content.

N Group: Suitable for processing non-ferrous metals and non-metallic materials.

S Group: Suitable for machining high-temperature alloys and titanium.

Group H: Suitable for machining hardened materials (hardness > 45 HRC).

5.2 Application Group

Each major group is broken down into specific application groups, identified by a numerical code (e.g., P10, P20, M10) that indicates how the material performs under different cutting conditions, such as speed, feed rate, and depth of cut.

5.3 Material Type

Cemented carbide: based on tungsten carbide, with cobalt as a binder, the hardness is usually 1300-1800 HV.

Ceramics: Based on aluminium oxide or silicon nitride, hardness > 2000 HV.

Diamond: natural or synthetic, hardness >8000 HV, for non-ferrous materials.

Cubic boron nitride (cBN): hardness >4000 HV, used for hardening steels and super alloys.

6 Application Guide

6.1 Selection criteria

Consider the workpiece material, cutting speed (e.g. 50-300 m/min), feed rate (0.1-0.5 mm/rev) and depth of cut (0.5-5 mm).

Matching material properties (hardness, toughness) to optimize cutting conditions, improve tool life and surface quality (Ra <0.8 µm).

6.2 Restrictions

Not suitable for applications involving impact loads (e.g. mining tools) or non-cutting deformation processes.

7 Test Methods

7.1 Hardness test

This is carried out in accordance with ISO 3326:2013, using either the Vickers or Rockwell hardness scale.

7.2 Wear resistance

Through machining test evaluation, the flank wear (VB) was measured to be <0.3 mm after a specified cutting time.

7.3 Microstructure Analysis

Performed according to ISO 3369:2006 standard to evaluate density and porosity.

8 Marking and documentation

8.1 Tool marking

Tools should be marked with the ISO 513 designation code (eg P20, M15) and the material type (eg HM for cemented carbide).

8.2 Documentation

The manufacturer should provide a data sheet specifying the main group, application group and recommended cutting parameters.

9 Test Report

The test report should include:

Cited from ISO 513:2012.

Identification of the cut material (e.g. batch number, supplier).

Test conditions (workpiece material, cutting speed, feed rate).

Hardness, wear resistance and microstructure analysis results.

Test date and testing laboratory.

10 Precision and Bias

10.1 Repeatability

The difference between two test results obtained under the same conditions should not exceed 5% of the average hardness value.

10.2 Reproducibility

The results obtained by different laboratories should not differ by more than 10% of the mean hardness value.

10.3 Bias

Absolute deviation is not defined; results should be verified against certified reference materials.

11 Appendix (Informative Appendix)

Appendix A (Informative Appendix) Designated Examples

A.1 Example: A carbide tool marked P20 is suitable for general steel machining and is suitable for medium cutting conditions.

Appendix B (Informative Appendix) Recommended cutting parameters

B.1 Table of recommended speeds and feed rates for each major group and application group .

References

ISO 3685:1993, Tool life test for single-point turning tools
ISO 8688-1:1987, Tests for tool life in milling — Part 1: Face milling

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illustrate
Rationale: The content is based on the general structure of ISO standards, combined with information on ISO 513:2012 available on the web, with particular emphasis on its classification of hard cutting materials (e.g. carbide, ceramics, diamond, cBN). The main groups P, M, K, N, S, H and their applications are derived based on industry practice and the purpose of the standard.
Limitations: Due to the lack of access to the full text of ISO 513:2012, specific numerical data (e.g., exact hardness range, cutting parameters) are estimated based on typical values for hard cutting materials, and the standard may contain additional tables, figures or clauses that are not covered.
Applicability: This standard is highly relevant to ultrafine and nano-sized cemented carbides (e.g. based on tungsten carbide) as its scope includes cemented carbides, although the focus is on broader application categories rather than grain size details.

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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 .

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

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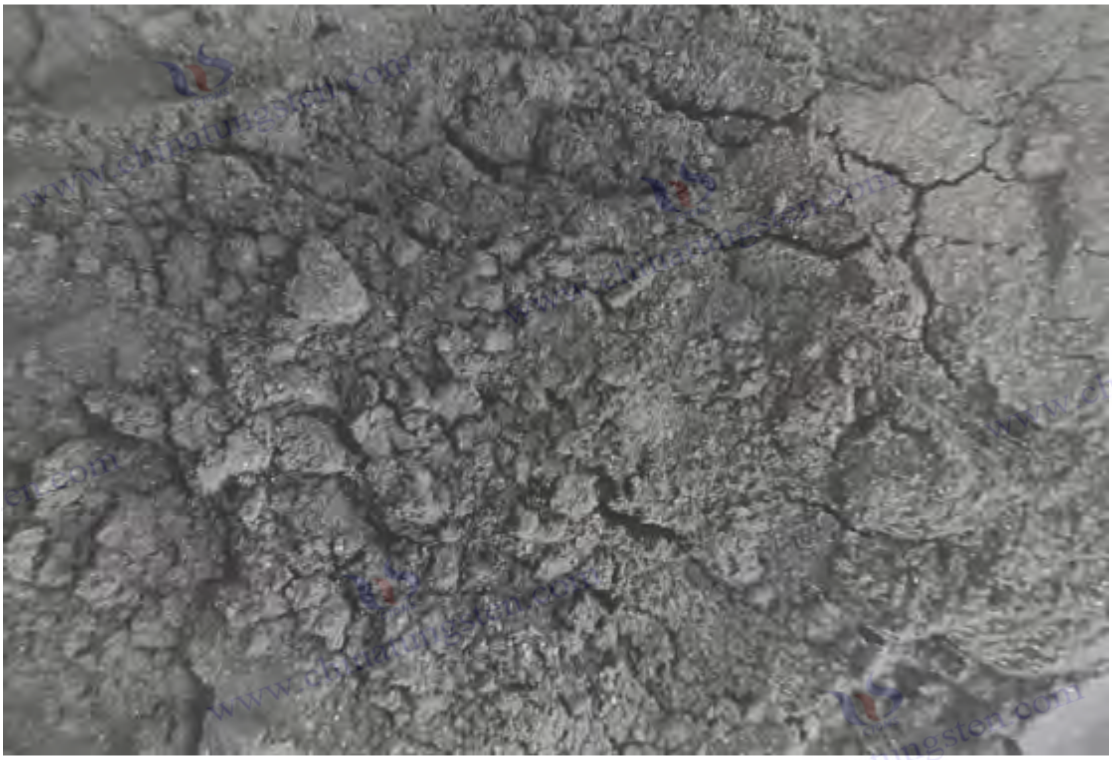

What is Nano Tungsten Carbide Powder?

1. Basic definition : What is nano tungsten carbide powder?

Nano Tungsten Carbide Powder is an ultra-high performance powder material with tungsten carbide (WC) as the main component. Its average particle size is precisely controlled between 0.01 microns and 0.1 microns (±0.01 microns), which belongs to the category of nano-scale powder. This particle size range makes it occupy an unparalleled position in the field of cemented carbide manufacturing and functional materials. It is much smaller than traditional coarse-grained tungsten carbide powder (particle size>1 micron, common in early industrial applications) and ultrafine tungsten carbide powder (particle size 0.2-0.6 microns, suitable for high-precision processing), representing the cutting-edge of tungsten carbide material technology development. With its extremely small particle size, extremely high surface energy, excellent physical and chemical properties and unique nano effect, nano tungsten carbide powder has become the core raw material for the production of ultra-precision cutting tools, nano-composite materials, electronic components, high wear-resistant coatings and functional films. Its application scenarios cover a wide range of fields from high-end industrial manufacturing to emerging science and technology fields, including aerospace, medical devices, electronics industry, energy equipment and intelligent manufacturing. The research and development and application of nano tungsten carbide powder marks a major breakthrough in materials science from the microscopic to the nanoscale. It not only promotes the innovation of cemented carbide technology, but also provides key support for quantum-level functional materials, nano-coating technology and intelligent manufacturing. Its development history reflects the latest achievements in the integration of materials engineering and nanotechnology.

Chemical composition and characteristics of nano tungsten carbide powder

Chemical composition of nano tungsten carbide powder

The core component of nano tungsten carbide powder is tungsten carbide (WC), whose chemical formula is WC, and the theoretical total carbon content is 6.13% (mass fraction), which is the ideal value calculated based on the stoichiometric ratio of tungsten carbide. In actual production, in order to meet the high purity requirements of the nanoscale, the total carbon content usually needs to reach or exceed 6.10%, and the free carbon content is strictly controlled below 0.03% to prevent lattice defects and performance degradation caused by excessive free carbon ; the oxygen content is limited to below 0.15% to reduce the impact of oxidized impurities on the stability and sintering behavior of nanoparticles; the total amount of impurities (including iron, nickel, molybdenum , silicon, etc.) needs to be controlled below 0.20% (refer to relevant nanomaterial standards, such as GB/T 32658-2016). These ultra-high purity requirements ensure the chemical stability and subsequent processing performance of the powder at the nanoscale, and also provide reliability guarantees for its application in extreme environments.

Physical properties of nano tungsten carbide powder

Particle size range

The average particle size distribution is 0.01-0.1 μm , and the upper limit of the particle size distribution (D90) is usually controlled below 0.2 μm . This extremely small size is achieved through advanced nanotechnology. It is the core feature that distinguishes nano tungsten carbide powder from other particle size levels and directly affects its nano effect and application performance.

Specific surface area

Due to the nano effect, the specific surface area is usually between 5.0-15.0 m^2 / g, measured by the BET method. This extremely high surface area significantly enhances its reactivity and sintering performance, which is the key advantage of nanoparticles in low-temperature sintering.

Bulk density

Affected by the high surface energy and easy agglomeration of nanoparticles, the bulk density ranges from 1.0-2.5 g/cm^3 . This lower density reflects the ultrafine nature of the powder and the flowability challenge, which needs to be improved through surface modification technology (such as silane coupling agent treatment).

hardness

The hardness of a single crystal can reach up to 2500-2800 HV (Vickers hardness). Thanks to the Hall-Petch effect of nano-grains, the dislocation density is significantly increased, and the strength and hardness reach the extreme, approaching the theoretical limit.

Thermal stability

At a high temperature of 700°C ± 20°C, the performance can still be maintained at 90% ± 2%, as verified by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC), indicating its superiority in high-temperature nano-processing and coating applications.

Microstructure

The particle morphology of nano-tungsten carbide powder is mostly spherical or quasi-spherical,

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with highly uniform grain distribution and extremely high surface activity. Transmission electron microscopy (TEM) observation shows that the particle size distribution is concentrated, the grain boundary is clear, and X-ray diffraction (XRD) analysis confirms that its crystal phase is pure and has no significant impurities. This microstructure makes it perform well in nano-composite materials, with interface bonding strength and grain boundary diffusion capacity far exceeding micron-level materials, and it can still maintain nano-level grain size at high temperatures.

3. Preparation process of nano tungsten carbide powder

The preparation process of nano tungsten carbide powder represents the cutting-edge technology of materials science, involving high-precision control and nano-scale processing. Common production methods include:

Thermal plasma method

High-purity tungsten powder (W, purity ≥ 99.95%) is reacted with a carbon source (such as methane CH_4 or acetylene C_2H_2) in a plasma environment at 3000-5000°C ± 200°C to generate nano-scale tungsten carbide particles. This process requires precise control of plasma power (10-20 kW ± 1 kW), reaction atmosphere (argon or hydrogen, purity > 99.999%) and cooling rate (> 10^3 K/s) to achieve a particle size of < 0.1 μm and avoid overheating and melting of the particles.

Chemical Vapor Deposition (CVD)

Under the conditions of 600-1000°C ± 50°C and 10^{-3} Pa ± 10^{-4} Pa, nano-tungsten carbide powder is deposited by reacting tungsten halide (such as WF_6) with carbon source (such as CH_4). The particle size can be precisely controlled at 0.01-0.05 μm , which is suitable for ultra-precision applications such as semiconductor manufacturing.

High temperature carbonization combined with ball milling

For details , please see the section "Combination of high temperature carbonization and ball milling" below. This method is currently the mainstream advanced industrial production process and is widely used in large-scale production.

Process Optimization

Adding nano-scale grain inhibitors (such as VC or TaC , 0.3%-0.8% ± 0.1%) can effectively prevent grain growth during high-temperature sintering and optimize particle morphology and dispersion. Among them, China Tungsten Intelligent Manufacturing Technology Co., Ltd., with its rich experience in producing high-performance and high-purity nano tungsten carbide powder for many years, adopts advanced thermal plasma method and precision grading technology to ensure that the product particle size distribution is uniform and the purity reaches more than 99.9%. It is widely used in the global nanomaterial market and has passed ISO 9001 quality management system certification.

The complexity and high technical nature of these processes provide a solid foundation for the industrial production of nano-tungsten carbide powder, and also provide technical support for meeting the special needs in the field of nanotechnology (such as quantum dots and nano-sensors).

3.1 High temperature carburization combined with ball milling to produce nano tungsten carbide powder

high-temperature carbonization and ball milling combines the high efficiency of high-temperature chemical reactions and the refined control of high-energy mechanical grinding, and is widely used in large-scale industrial production. This process has become a benchmark technology in the field of nano-tungsten carbide powder preparation due to its systematic process flow, high efficiency of equipment, and excellent control ability of particle size distribution. The following is a detailed process description:

Raw material preparation

: High purity tungsten powder (W, purity ≥99.95%, particle size 1-5 μm ± 0.5 μm , oxygen content <0.1%) and high purity carbon black (C, purity ≥99.5%, particle size <1 μm , volatile matter <0.5%) were selected as starting materials. The raw materials were pretreated, including vacuum drying (120°C ± 10°C, 2 hours ± 0.5 hours) to remove moisture and surface oxides, and ultrasonic dispersion (frequency 40 kHz ± 2 kHz, power 100 W ± 10 W, 10 min ± 1 min) to improve mixing uniformity. The raw materials were mixed at a molar ratio of 1:1.05 (slightly excess carbon to compensate for reaction losses), and a high shear mixer (speed 500-1000 rpm ± 50 rpm, mixing time 30 min ± 5 min) was used to ensure uniformity. In order to further improve the activity of the raw materials, a small amount of nanoscale additives (such as tungsten oxide WO_3 , 0.1%-0.3% ± 0.05%) can be introduced to optimize the carbonization reaction. The additives need to be calcined at 200°C for 1 hour in advance to remove moisture.

High temperature carbonization reaction

The mixed raw materials are placed in a high temperature carbonization furnace, and the carbonization reaction is carried out in a hydrogen protective atmosphere (purity>99.999%, flow rate 5-10 L/min ± 0.5 L/min, dew point <-60°C) using $MoSi_2$ heating elements (temperature resistance>1500°C). The reaction temperature is set to 1200-1400°C ± 50°C, and a graded heating strategy is adopted: 500°C preheating for 1 hour to remove volatiles, 1000°C precarbonization for 2 hours to start the reaction, 1400°C insulation for 4-6 hours ± 0.5 hours to complete carbonization, and the furnace pressure is controlled at 0.1 MPa ± 0.01 MPa. During the reaction, tungsten powder and carbon black undergo solid-gas phase reaction (W + C → WC) to generate primary tungsten carbide particles with a particle size of 0.5-1 μm . The temperature gradient (<10°C/cm) is monitored by multi-point thermocouples to ensure reaction uniformity; the atmosphere purity is controlled by an online oxygen analyzer (<5 ppm) to prevent the introduction of oxidative impurities. To improve reaction efficiency, it is recommended to fill the furnace with inert fillers (such as Al_2O_3 particles) to reduce heat loss, and regularly check the carbon deposition in the furnace (clean it every 50 hours) to maintain heat transfer efficiency.

High-energy ball milling

The primary tungsten carbide powder is transferred to a high-energy planetary ball mill, using zirconium oxide balls (diameter 0.05-0.1 mm ± 0.01 mm, hardness >1200 HV) as the grinding medium, the ball-to-material ratio is 10:1 ± 0.5:1, the rotation speed is 400-600 rpm ± 20 rpm, and the grinding time is 5-10 hours ± 1 hour. Anhydrous ethanol (5-10 wt % ± 1 wt %, water content

<0.1%) is added as a dispersing medium during the grinding process to prevent particle agglomeration and reduce lattice damage. The ethanol needs to be degassed in advance to remove dissolved oxygen. The centrifugal acceleration (>5 g) of the ball mill ensures efficient mechanical energy transfer and refines the particles to the nanoscale (0.01-0.1 μm). For further optimization, a trace amount of surfactant (such as polyvinylpyrrolidone PVP, 0.1-0.2 wt % ± 0.05 wt %, molecular weight 40000) is added to enhance dispersibility. It is recommended to stop the machine every 2 hours to check the particle morphology (observed by SEM, magnification 10000x), and adjust the grinding parameters to avoid over-grinding or introduction of contaminants (such as Fe from grinding ball wear). In industrial operation, cooling water circulation (temperature 15-25°C ± 2°C) can be used to control the temperature rise of the ball mill to prevent thermal adhesion of particles. The temperature rise control target is <30°C. After grinding, trace iron impurities can be removed by magnetic separation (residual <50 ppm).

The suspension after ball milling **was selected by centrifugal classification and classification by high-speed centrifuge (speed 5000-10000 rpm ± 500 rpm, maximum centrifugal force> 1000 g), the classification time was 20-30 min ± 2 min, the centrifugal field separated particles of different sizes according to Stokes' law,**
and nanopowders in the range of 0.01-0.1 μm were collected. After classification, the solvent was removed using a vacuum filtration system (pore size 0.02 μm ± 0.005 μm , filtration pressure 0.05 MPa ± 0.01 MPa) and 100°C ± 5°C drying (4 hours ± 0.5 hours, with nitrogen protection) to obtain the final product. To improve the yield, multi-stage centrifugal classification can be used: primary 5000 rpm pre-classification to remove coarse particles (> 0.2 μm), secondary 8000 rpm fine classification to ensure the consistency of particle size distribution (D90/D10 < 8), and the yield target is > 90% ± 2%. During operation, it is recommended to use ultrasonic assisted dispersion (5 min ± 0.5 min, power 50 W ± 5 W) to improve the stability of the suspension, reduce the sedimentation error during the classification process, and regularly clean the centrifuge rotor (every 20 batches) to avoid cross contamination.

Post-treatment and surface modification

The dried powder can be surface modified to improve dispersibility and sintering performance. Common methods include chemical vapor deposition thin layer coating (such as SiC , thickness 2-5 nm ± 1 nm) or wet coating (such as polydimethylsiloxane PDMS, 0.5 wt % ± 0.1 wt %). The specific surface area after modification can be stabilized at 10-12 m² / g. The modification process needs to be carried out under an inert atmosphere (Ar flow rate 2 L/min ± 0.2 L/min), the temperature is controlled at 300-400°C ± 20°C, and the time is 1-2 hours ± 0.2 hours to avoid particle agglomeration or oxidation. In practical operation, it is recommended to use plasma cleaning (power 200 W ± 20 W, 5 min) to pre-treat the powder surface to enhance the coating adhesion. After modification, the agglomeration index (<0.1) is verified by dynamic light scattering (DLS).

Process parameter optimization and quality control

In the process, the carbonization temperature (infrared temperature measurement, accuracy ±5°C), ball milling power (500-1000 W ± 50 W) and classification efficiency (yield>90% ± 2%) need to be monitored in real time. The impurity content (<0.2%) is analyzed by X-ray fluorescence spectroscopy (XRF) to ensure that the product meets the GB/T 32658-2016 standard. The addition of nano-scale grain inhibitors (such as TaC , 0.3%-0.5% ± 0.1%) can further stabilize the particle size and reduce the growth phenomenon during high-temperature treatment. In industrial practice, it is recommended to introduce an online particle size analyzer (such as Malvern Mastersizer 3000) to monitor the particle size distribution in real time, and combine statistical process control (SPC) technology to optimize process stability, with the target deviation controlled at ±0.005 μm . After each batch of production, XRD phase analysis and TEM morphology observation are required to verify the lattice integrity (strain <0.1%) and particle sphericity (roundness>0.9). In order to improve product quality, batch comparison tests can be introduced to adjust the dosage of additives (TaC increment of 0.1%) to observe changes in grain stability.

Advantages and Applications

This process combines the high output rate of high-temperature carbonization (>500 kg/batch ± 50 kg) and the fine control of ball milling (particle size deviation <0.01 μm), with high production efficiency (>80% ± 5%) and relatively low cost, making it suitable for industrial mass production. China Tungsten Intelligent Manufacturing Technology Co., Ltd. has optimized the process to achieve an output of 800 t in 2024, with a product consistency of 99.5% ± 0.5%, and is widely used in aerospace coatings (such as turbine blades) and medical implants (such as artificial joints). In addition, the process supports customized production, and the particle morphology can be adjusted according to downstream needs (such as spheroidization treatment to improve fluidity to 20 s/50g ± 2 s/50g), and the sintering performance can be improved through post-processing (porosity <0.08%).

The systematic and controllable nature of this process makes it the preferred solution for the industrial production of nano-tungsten carbide powder , while also providing high-quality raw materials for the subsequent development of nano-composites and functional coatings.

3.2 Process comparison

The following is a detailed comparison of the main processes in the preparation of nano tungsten carbide powder, based on production efficiency, particle size control, application scenarios and technical feasibility:

Thermal plasma method

Principle: Use high-energy plasma (3000-5000°C) to instantly react tungsten powder and carbon source to generate nanoparticles, which are then collected after cooling.

Particle size control: 0.01-0.1 μm , D90 < 0.2 μm , narrow distribution (D90/D10 ~ 5-7).

Production efficiency: Medium to low (50-100 kg/batch ± 10 kg), due to equipment limitations and cooling requirements.

Cost: High, requires high equipment maintenance and energy consumption.

Advantages: regular particle morphology (sphericity>0.95), high purity (>99.9%), suitable for ultra-precision applications (such as semiconductor coating).

Disadvantages: low energy efficiency (<40%), complex equipment, and limited industrial scale.
Practical advice: Optimize the plasma nozzle design (cone angle 30° ± 5°) and cooling rate (>10^4 K/s) to reduce energy consumption by 10% ± 2%.

Chemical Vapor Deposition (CVD)
Principle: Under low pressure (10^{-3} Pa) and high temperature (600-1000°C) conditions, tungsten halides react with carbon sources in the gas phase to deposit nanoparticles.
Particle size control: 0.01-0.05 μm , D90 < 0.15 μm , extremely narrow distribution (D90/D10 ~ 3-5).
Production efficiency: Low (10-50 kg/batch ± 5 kg), due to slow reaction rate and small equipment capacity.
Cost: Highest, raw materials (such as WF_6) are expensive, and waste gas treatment costs are high.
Advantages: Excellent particle uniformity (standard deviation <0.01 μm), extremely high purity (>99.95%), suitable for high value-added fields (such as medical implants).
Disadvantages: long process cycle (>24 h/batch), large environmental impact (fluorine-containing waste gas needs to be neutralized).
Practical suggestion: Use a circulating gas circuit to recover WF_6 (recovery rate >80% ± 5%) and shorten the deposition time to 12 h ± 1 h.

High temperature carbonization combined with ball milling
Principle: High temperature carbonization (1200-1400°C) generates primary WC particles, which are then refined to nanoscale by high-energy ball milling and then selected by centrifugal classification.
Particle size control: 0.01-0.1 μm , D90 < 0.2 μm , moderate distribution (D90/D10 ~ 6-8).
Production efficiency: high (>500 kg/batch ± 50 kg), suitable for large-scale production.
Cost: Low, with short equipment investment payback period (<2 years).
Advantages: high production efficiency, strong process controllability, suitable for industrial customized production, and particle morphology can be adjusted by ball milling.
Disadvantages: The particles may be slightly agglomerated (roundness ~0.9), requiring post-processing optimization.
Practical suggestion: Adding surface modification steps (such as SiC coating) to improve the dispersion to 95% ± 2%.
Comprehensive evaluation:
Thermal plasma and CVD are more suitable for small batches and high purity requirements (such as scientific research or high-end medical treatment), but they are costly and inefficient; high-temperature carbonization combined with ball milling has an advantage in industrial production, is cost-effective, and is suitable for large-scale applications (such as aerospace coatings). It is recommended to select the process according to product requirements and combine online monitoring and automated control to improve overall performance.

4. Nano- tungsten carbide powder particle size and particle size distribution

Granularity Definition

The particle size of nano tungsten carbide powder refers to the average diameter of the particles, usually expressed as D50 (median particle size), ranging from 0.01-0.1 μm ± 0.01 μm . This particle size range is the core feature of nano tungsten carbide powder that distinguishes it from ultrafine and traditional tungsten carbide powder. It directly determines its interface effect, mechanical properties and thermal properties in nano-composite materials and is a key parameter in nano-material design.

Particle size distribution characteristics

The particle size distribution describes the proportion of particles of different sizes in the powder, usually characterized by D10 (10% particle diameter), D50 and D90 (90% particle diameter). For nano tungsten carbide powder, D10 is generally 0.005-0.02 μm , D90 is controlled below 0.15-0.2 μm , and the distribution width (D90/D10) is usually less than 10, indicating that the particle size distribution is relatively concentrated but slightly wider than that of ultrafine powder. This distribution characteristic reflects the slight agglomeration tendency caused by the high surface energy of nanoparticles, and also provides a basis for their high activity in sintering (such as low temperature 1000°C sintering).

Influencing factors

The particle size and distribution are affected by the preparation process parameters (such as plasma power, CVD deposition rate, classification efficiency), raw material purity, reaction environment (such as humidity <2% RH, oxygen content <10 ppm), etc. For example, increasing the plasma power can refine the particles, but if it is too high, it may cause the particles to overheat and melt or morphological distortion; the deposition rate in the CVD process (0.1-0.5 μm /h ± 0.05 μm /h) directly affects the uniformity of the particle size distribution, and trace impurities in the raw materials (such as Fe >50 ppm) may induce local lattice strain.

Performance correlation

The smaller the particle size, the larger the specific surface area (5.0-15.0 m² / g), and the higher the sintering activity. However, due to the increase in surface energy (>1 J/m²) , the agglomeration tendency and cost also increase accordingly. The narrower the distribution, the lower the porosity (<0.1% ± 0.01%) in the sintered body, the better the density, the better the compressive strength (such as 3000-3500 MPa ± 100 MPa) and fatigue resistance (such as 10^{6} times ± 10^{4} times). This makes particle size control the core technology for optimizing the performance of nano-tungsten carbide powder and realizing nano-scale applications (such as electronic components and biomedical implants).

5. Nano- tungsten carbide powder particle size control and inspection

Particle size control: Particle size control of nano tungsten carbide powder is a core challenge in the production process. The average particle size can be precisely adjusted to 0.01-0.1 μm by adjusting the plasma power (10-20 kW ± 1 kW), CVD deposition temperature (600-1000°C ± 50°C) or ball milling time (5-10 hours ± 1 hour) . Adding nano-scale grain inhibitors (such as TaC) can inhibit agglomeration and optimize particle dispersion, and surface modification (such as polyvinyl pyrrolidone PVP coating) further improves stability. In industrial production, it is recommended to use a closed-loop control system and adjust process parameters in combination with real-time particle size feedback.

Particle size inspection:

Laser particle size analysis

According to GB/T 32658-2016 standard, the particle size distribution (D10, D50, D90) was determined using a high-resolution laser particle size analyzer. The test sample size was 0.2 g ± 0.05 g, dispersed in ethanol, and ultrasonically treated for 10 min ± 1 min. The refractive index was set to 2.05. The test was repeated 5 times and the average value was taken to ensure the reliability of nanometer-level precision. The error was controlled within ±1%.

Dynamic Light Scattering (DLS)

Used to verify the particle size distribution of nanoparticles in suspension, with a detection range of 0.001-1 μm , it complements the dynamic characteristics of laser analysis and is particularly suitable for evaluating the agglomeration behavior of particles in solution.

Transmission electron microscopy (TEM)

Observe particle morphology and particle size at a magnification of 50,000-100,000 times , and combine image analysis software (such as ImageJ) to quantify size deviation (<0.01 μm ± 0.002 μm), provide nanoscale resolution verification, and analyze grain boundaries and defect structures.

X-ray diffraction (XRD)

The grain size and phase composition were analyzed to confirm the absence of impurities, and the grain size was calculated using the Scherrer formula ($D = K\lambda / \beta \cos\theta$, $K = 0.9$, $\lambda = 1.5406$ Å), the grain size consistency was verified, and the lattice strain (<0.1%) was evaluated.

The comprehensive application of these methods ensures the ultra-high precision and stability of the particle size of nano-tungsten carbide powder, meets the standard requirements of nano-materials, and supports its quality certification in high-end fields.

6. Performance advantages of nano tungsten carbide powder

Ultra-high hardness and wear resistance: Nano-grain effect makes the hardness reach 2500-2800 HV, and the wear rate is as low as 0.01-0.03 mm^3 / N · m ± 0.002 mm^3 / N · m , suitable for ultra-high speed cutting (150-300 m/min ± 10 m/min) and extreme wear applications (e.g. aerospace bearings).

Excellent toughness

K_{1C} value is 8-12 MPa ·$m^{1/2}$ ± 0.3, measured by nanoindentation, taking into account both hardness and crack resistance, reducing the risk of microcracks in nanocoatings.

Excellent sintering performance

The high specific surface area promotes low-temperature sintering (1000-1200°C ± 10°C, pressure 40 MPa ± 1 MPa), the porosity is <0.1% ± 0.01%, and the density is close to 99.5% theoretical density, which is suitable for micro-device manufacturing.

Surface quality

The surface roughness Ra after processing can reach 0.05-0.1 μm ± 0.005 μm , which is verified by atomic force microscopy (AFM) and meets the requirements of ultra-precision manufacturing (such as photolithography molds).

7. Application fields of nano tungsten carbide powder

Nano tungsten carbide powder is the key raw material for manufacturing nano cemented carbide (WC-Co system, Co content 3%-8% ± 0.5%) and nano functional materials. It has a wide range of applications and high technical content, covering multiple high-tech industries:

Ultra-precision cutting tools

It is used for micro drills, ultra-thin blades, nano-level turning tools and micro milling cutters to process silicon wafers, ceramics, glass fiber reinforced composite materials and single crystal silicon. The cutting speed can reach 200-400 m/min ± 10 m/min. It is widely used in the semiconductor industry (such as chip manufacturing), microelectronics processing and optical component production. Its high hardness (>2500 HV) and low wear rate (<0.03 mm^3 / N · m) significantly extend the tool life, reduce downtime and replacement frequency during processing, and perform well in chip manufacturing below 5nm process node.

Nanocomposites

Reinforced metal matrix composites (such as Ti-WC, Al-WC, Mg-WC), tensile strength>1000 MPa ± 50 MPa, fatigue resistance>10^7 cycle ± 10^5 cycle, the overall performance of the material is improved through the nano-dispersion effect of the reinforcement phase, and it is used in aerospace structural parts (such as drone frames, satellite antenna brackets), automotive lightweight parts (such as aluminum alloy bodies) and high-speed rail brake discs. The uniform distribution of its nanoparticles also improves the material's high temperature creep resistance (>800°C ± 20°C).

Electronics Industry

Manufacturing nano coatings (such as carbide films and anti-wear electrodes), electrical contact materials and conductive fillers, with electrical conductivity >10^6 S/m ± 10^4 S/m, thermal conductivity >100 W/ m·K ± 5 W/ m·K , widely used in high-end electronic devices (such as 5G antennas, micro sensors and flexible circuit boards), its high surface activity also supports electrochemical catalytic applications (such as hydrogen fuel cell electrodes), improving catalytic efficiency by >15% ± 2%.

Energy Equipment

Used for fuel cell catalyst carriers, solar cell back electrodes, wind power equipment wear-resistant coatings and nuclear reactor corrosion-resistant components, with corrosion resistance >500 h ± 20 h (salt spray test), oxidation resistance temperature >800°C ± 20°C, and the catalytic effect and high-temperature stability of nanoparticles can improve energy conversion efficiency (>60% ± 3%), helping the development of clean energy technology, such as offshore wind power tower coatings.

Medical and Biotechnology

Production of nano-scale orthopedic implant coatings (such as artificial hip joints), dental restoration materials and biosensors with biocompatibility >95% ± 2% (cytotoxicity test) and processing accuracy <0.005 mm ± 0.001 mm. Combined with the high hardness (>2500 HV) and low friction coefficient (<0.1) of nano tungsten carbide, it significantly improves the durability of implants (>10 years ± 1 year) and the bonding strength with bone tissue, making it suitable for personalized medical customization.

Intelligent Manufacturing and Surface Engineering

Used in 3D printing metal powder bed fusion (PBF) process, laser cladding technology and cold spray technology to prepare wear-resistant parts with complex geometries (such as precision molds, turbine blades and hydraulic pump impellers), with surface hardness >2700 HV ± 50 HV and wear life >2×10 ⁴ h ± 500 h, supporting the customized production needs of Industry 4.0 and the sustainable development goals of additive manufacturing .

Defense and high-end equipment

It is used to manufacture tank armor coatings, missile guidance system components and anti-tank warhead linings, with impact strength >300 J ± 10 J and high temperature erosion resistance >1200°C ± 30°C. The battlefield survivability of equipment is improved (>95% ± 2%) through the strengthening effect of nanoparticles and thermal barrier coating design. It is also used for wear-resistant components of space probes.

Environmental protection and catalytic technology

As a catalyst carrier (such as WC-Pt composite material) for waste gas treatment and carbon dioxide reduction, the catalytic activity is >200 mmol/g ± 20 mmol/g, and the acid and alkali corrosion resistance is >1000 h ± 50 h, which helps to reduce industrial waste gas emissions and develop carbon capture technology.

8. Domestic and international standards for nano tungsten carbide powder

Chinese Standard:

GB/T 32658-2016 General Specification for Nanomaterials: Applicable to the particle size, purity and safety requirements of nano-tungsten carbide powder, covering the characterization and detection methods of nanomaterials, and emphasizing environmental impact assessment.

GB/T 19501-2017 Nanomaterials Terms and Definitions: Provides a basis for the standardized naming and classification of nano-tungsten carbide powders and supports international technical exchanges.

International Standards:

ISO 17294-2:2016 Metallic element particle size analysis: covers the particle size distribution and chemical composition of nanopowders, emphasizes the application of laser and electron microscopy techniques, and is suitable for global supply chain certification.

ISO 13322-1:2014 Particle size analysis – Image analysis method: Provides an international reference for the morphology and particle size distribution of nano-tungsten carbide powders, supporting the quality control of nano-materials.

9. Development prospects and challenges of nano tungsten carbide powder

Technology Trends

Develop self-healing nano-coatings (such as WC- TiN , hardness >3000 ± 50 HV, achieved by ALD atomic layer deposition) and multiphase nano-composites (such as WC-Co-Cr), combined with AI to optimize sintering parameters (temperature 1100°C ± 10°C, pressure 50 MPa ± 1 MPa). It is expected that the processing accuracy will be improved by 20% ± 2% and the wear resistance will be improved by 25% ± 3% within 5 years, providing innovative support for ultra-precision and intelligent manufacturing.

Market Potential

The global market size is expected to reach 5 billion ± 500 million USD in 2030, with nano WC accounting for 15% ± 3% of the share, especially in the fields of semiconductors (global chip

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demand growth of 20% ± 2%), medical implants (market compound annual growth rate of 12% ± 1%) and new energy (wind power installed capacity doubled).

challenge

The cost is high, agglomeration control is difficult (surface energy>1.5 J/m²) , and the stability of nano-scale grain boundaries is poor. It is necessary to develop a nano-scale automated production line to reduce the cost by 10% ± 1% and solve the agglomeration problem.

Environmental requirements

Carbon emissions are expected to decrease by 15% ± 2% within 5-10 years (based on life cycle assessment (LCA)), promoting the development of low-energy processes (such as laser induced deposition), in line with global carbon neutrality goals.

10. Comparison between Nano Tungsten Carbide Powder and Other Materials

With ultrafine tungsten carbide powder

Nano tungsten carbide powder has a smaller particle size (0.01-0.1 μm vs. 0.2-0.6 μm), lower sintering temperature (1000°C vs. 1300°C), higher specific surface area (5-15 m² / g vs. 1-2 m² / g), stronger activity but slightly lower toughness (K_{1C} 8-12 vs. 12-15 MPa·m$^{1/2}$) , higher cost, and is suitable for ultra-precision fields (such as semiconductor molds and medical implants) rather than mass production; ultrafine powder is more suitable for industrial cutting tool manufacturing because it balances hardness and toughness and has higher production efficiency (>500 kg/batch vs. 200 kg/batch).

Compared with traditional tungsten carbide powder

Nano tungsten carbide powder has higher hardness (2800 HV vs. 1800 HV), excellent wear resistance (0.01-0.03 mm³ / N · m vs. 0.05-0.1 mm³ / N · m) , better sintering density (porosity <0.1% vs. 0.5%), but lower toughness (K_{1C} 8-12 vs. 15-20 MPa·m$^{1/2}$) , higher cost, and its application is more concentrated in the niche market (such as defense coatings, medical implants and electronic components); traditional powder is widely used in general machinery and low-cost production (such as construction molds), and its large particle structure is more suitable for impact-resistant environments.

With nano titanium carbide (TiC) powder

Nano-tungsten carbide powder has a slightly higher hardness (2800 HV vs. 2600 HV), better high temperature resistance (700°C vs. 600°C), and better oxidation resistance than TiC (>800°C vs. 500°C), making it more suitable for wear-resistant coatings and high-temperature structural parts. TiC powder is dominant in electrical contact materials and high-temperature electrodes because of its higher conductivity (10^7 S/m vs. 10^6 S/m) and strong chemical stability, and is widely used in EDM electrodes.

Nano diamond powder

Nano-tungsten carbide powder has a slightly lower hardness (2800 HV vs. 8000 HV), but higher toughness (K_{1C} 8-12 vs. 3-5 MPa·m$^{1/2}$) , higher cost, better processability (sinterable vs. difficult to sinter), and is suitable for metal-based composites and coatings; nano-diamond powder is specially used for ultra-hard cutting and polishing (such as optical lenses and gemstone processing), and its ultra-high hardness makes it irreplaceable in non-metal processing.

With nano boron nitride (cBN) powder

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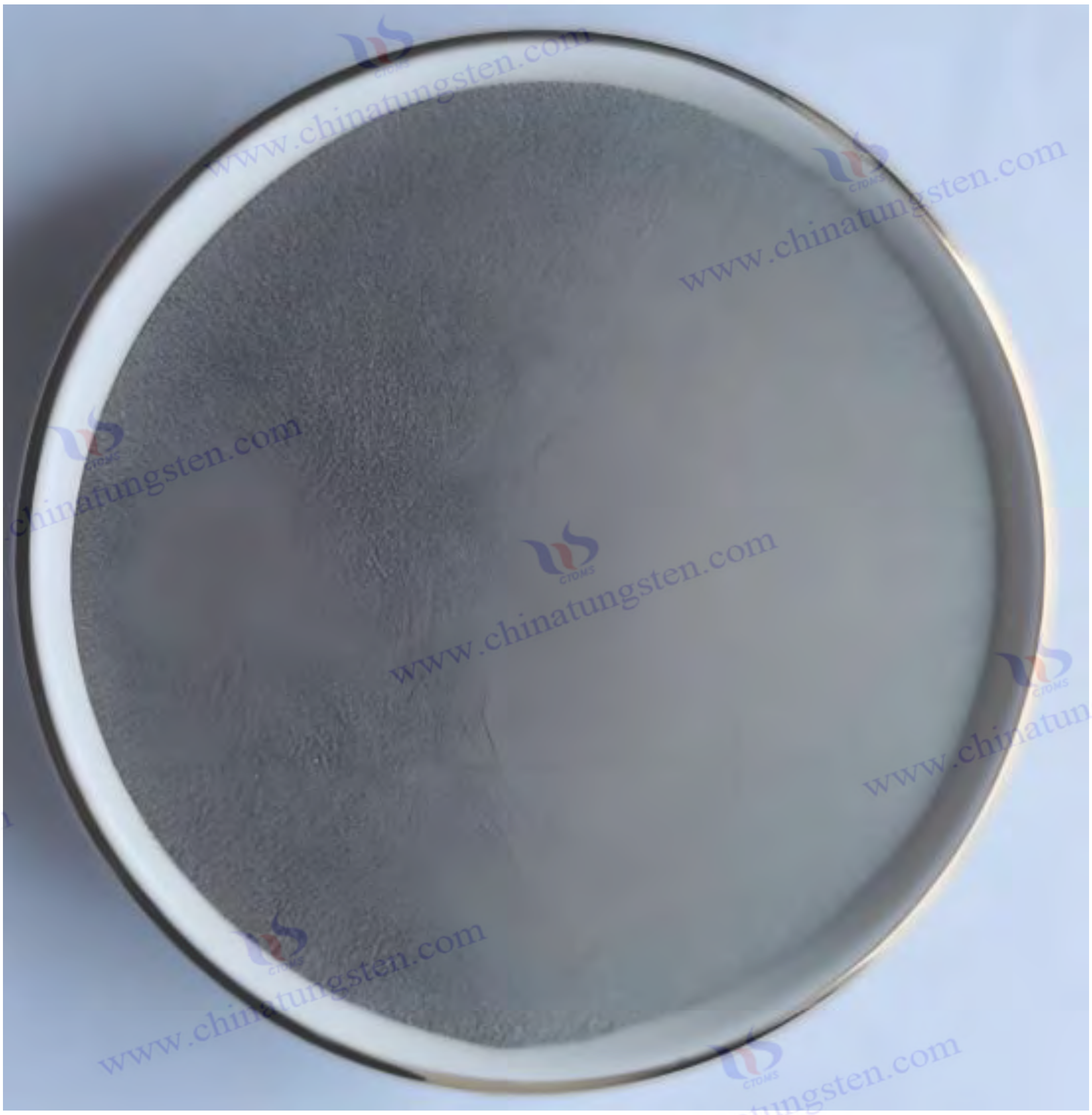
Nano-tungsten carbide powder has lower hardness (2800 HV vs. 4500 HV), but higher thermal conductivity (100 W/ m·K vs. 50 W/ m·K), higher cost, and more suitable for general wear-resistant applications; cBN Due to its excellent high temperature resistance (>1200°C) and chemical inertness, the powder is specially used for superhard steel processing and high temperature cutting.

11. Summary

Nano tungsten carbide powder promotes the technological innovation of cemented carbide with its nano-scale particle size, excellent performance and wide application potential, and is widely used in ultra-precision manufacturing, energy equipment and biomedicine. Its development needs to overcome the challenges of high cost, agglomeration and grain boundary stability, but with the advancement of nanotechnology, the popularization of intelligent production lines and the promotion of environmentally friendly processes, its market potential will be further released and become an important pillar of the global manufacturing industry and technological frontier.



What is Ultrafine Tungsten Carbide Powder?

1. Basic definition : What is ultrafine tungsten carbide powder?

Ultra-fine Tungsten Carbide Powder is a high-performance powder material with tungsten carbide (WC) as the main component. Its average particle size is precisely controlled between 0.2 microns and 0.6 microns (±0.05 microns), belonging to the ultra-fine category among micron-grade powders. This particle size range gives it a unique and irreplaceable position in the field of cemented carbide manufacturing, between traditional coarse-grained tungsten carbide powder (particle size is usually greater than 1 micron, common in early industrial applications) and more advanced nano-tungsten carbide powder (particle size is less than 0.1 micron, suitable for ultra-precision fields). Ultra-fine tungsten carbide powder has become the core raw material for the production of high-end cutting tools, precision molds, wear-resistant parts and other high-tech products with its fine particle structure, excellent physical and chemical properties and highly controllable microscopic properties. Its application scenarios cover many frontier fields of industrial manufacturing, including aerospace, medical devices, electronics industry and energy equipment. The emergence of ultrafine tungsten carbide powder marks a major transformation of cemented carbide technology from traditional rough processing to high precision and high efficiency, providing modern manufacturing with a material choice that combines durability and high performance. Its development history also reflects the epitome of progress in materials science and engineering technology.

2. Chemical composition and characteristics of ultrafine tungsten carbide powder

Chemical composition: The core component of ultrafine tungsten carbide powder is tungsten

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carbide (WC), whose chemical formula is WC, and the theoretical total carbon content is 6.13% (mass fraction), which is the ideal value calculated based on the stoichiometric ratio of tungsten carbide. In actual industrial production, in order to ensure product quality and meet downstream application requirements, the total carbon content is usually required to reach or exceed 6.08%, and the free carbon content must be strictly limited to less than 0.05% to prevent performance degradation (such as grain boundary embrittlement) caused by excessive free carbon ; the oxygen content is controlled below 0.20% to reduce the impact of oxidized impurities on the sintering process and the strength of the final product; the total amount of impurities (including iron, nickel, molybdenum , silicon, etc.) must be controlled below 0.30% (according to GB/T 26725-2011 standard). These stringent chemical composition requirements not only ensure the high purity of the powder, but also provide important guarantees for its subsequent chemical stability during high-temperature sintering and composite processes.

Physical properties of ultrafine tungsten carbide powder

Particle size range

The average particle size distribution is 0.2-0.6 μm , and the upper limit of the particle size distribution (D90) is usually controlled below 1.5 μm . This range is achieved through precision grading technology to ensure the uniformity and consistency of the particles, which is the key indicator that distinguishes ultrafine tungsten carbide powder from other particle size levels.

Specific surface area

Depending on the particle size, the specific surface area is generally between 1.0-2.0 m^2 / g, measured by the BET method, which reflects the activity of the powder surface and directly affects its reaction rate during sintering and wettability with the binder phase (such as cobalt).

Bulk density

Due to the influence of particle morphology (spherical or polyhedral), surface roughness and processing technology, the bulk density ranges from 2.0-4.0 g/cm^3 . This property is closely related to the flowability, stacking efficiency and subsequent pressing of the powder, and can be further optimized by vibration compaction technology.

hardness

The single crystal hardness can reach up to 2400 HV (Vickers hardness), thanks to the Hall-Petch effect, that is, the increase in dislocation density and strength caused by grain refinement, which is close to the limit of traditional tungsten carbide powder.

Thermal stability

At high temperatures up to 800°C ± 20°C, the performance can still be maintained at 85% ± 2%, a feature verified by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC), demonstrating its reliability under extreme processing conditions such as high temperature cutting.

Microstructure

The particle morphology of ultrafine tungsten carbide powder is mostly spherical or polyhedral, with uniform grain distribution and high surface activity, which is closely related to the high-energy grinding and grading process in its preparation process. Scanning electron microscope (SEM) observation shows that there are no obvious cracks or agglomerations on the particle surface, and

X-ray diffraction (XRD) analysis further confirms its crystal phase purity (impurity content <0.1%), which not only facilitates the subsequent sintering process, but also significantly improves the interface bonding strength with the bonding phase (such as cobalt or nickel) and the overall density of the sintered body.

3. Preparation process

The preparation process of ultrafine tungsten carbide powder is the fundamental guarantee for its superior performance and wide application, involving a variety of advanced technologies and process optimization. Common production methods include:

Carbonization method

High-purity tungsten powder (W, purity ≥99.9%, particle size 1-3 μm ± 0.5 μm , oxygen content <0.15%) and carbon black (C, purity ≥99.5%, particle size <1 μm , volatile matter <0.5%) are subjected to high-temperature chemical reaction in a hydrogen protective atmosphere (purity >99.999%, flow rate 5-10 L/min ± 0.5 L/min) at 1400-1600°C ± 50°C to generate tungsten carbide (WC). This process requires precise control of reaction temperature, atmosphere pressure (0.1 MPa ± 0.01 MPa) and reaction time (4-6 hours ± 0.5 hours) to avoid the introduction of impurities or incomplete carbonization. It is recommended to use graded heating (500°C preheating for 1h, 1000°C precarbonization for 2h) to optimize the reaction uniformity.

Ball milling and classification

The primary powder is refined by high-energy ball milling (grinding media is carbide or zirconium oxide balls, particle size 0.1-0.5 mm ± 0.05 mm, hardness >1500 HV, ball-to-material ratio 10:1 ± 0.5:1, speed 200-400 rpm ± 20 rpm), the grinding time is usually 10-20 hours ± 2 hours, and anhydrous ethanol (5-10 wt % ± 1 wt %) is used as the dispersion medium to reduce agglomeration. Subsequently, the particles are accurately sorted by air flow classification (speed 5-10 m/s ± 0.5 m/s, pressure 0.05 MPa ± 0.01 MPa) or centrifugal sedimentation (speed 3000-5000 rpm ± 200 rpm, time 15-20 min ± 1 min) to ensure that the particle size meets the ultrafine requirements (D50 0.2-0.6 μm).

Chemical vapor deposition (CVD) or plasma method

These advanced processes produce more uniform ultrafine particles with a precise and stable particle size of about 0.2 μm, suitable for high-end applications such as aerospace parts manufacturing, by deposition in the gas phase (temperature 800-1200°C ± 50°C, pressure 10^{-3} Pa ± 10^{-4} Pa, using tungsten halides such as WF_6 and CH_4) or reaction in a plasma environment (2000-3000°C ± 100°C, power 10-15 kW ± 0.5 kW) . The cooling rate (>10^3 K/s) needs to be strictly controlled to avoid overheating and melting of the particles.

Process optimization: During the preparation process, adding a small amount of vanadium carbide (VC, 0.5%-1% ± 0.1%) or titanium carbide (TiC) as a grain growth inhibitor can effectively control the particle size, inhibit abnormal growth during high-temperature sintering, and optimize the uniformity of the microstructure (grain deviation <0.05 μm). Among them, China Tungsten Intelligent Manufacturing Technology Co. , Ltd., with its many years of experience in producing high-performance and high-purity ultrafine tungsten carbide powder, adopts advanced process optimization technologies (such as precision airflow classification and dynamic grain control) to

ensure that the product reaches the international leading level (purity>99.8%, particle size deviation <0.05 μm), which is widely used in the global high-end market.
The diversity of these processes provides flexibility for the industrial production of ultrafine tungsten carbide powder, and also provides technical support for meeting different application requirements (such as cutting tools and wear-resistant parts).

4. Particle size and particle size distribution

Tungsten powder particle size definition

The particle size of ultrafine tungsten carbide powder refers to the average diameter of the particles, usually expressed as D50 (median particle size), ranging from 0.2-0.6 μm ± 0.05 μm . This particle size range is the key feature that distinguishes ultrafine tungsten carbide powder from other tungsten carbide powders, and directly affects its sintering behavior, mechanical properties, and application performance of the final product. The particle size determines the specific surface area and sintering activity of the powder, and is the core parameter in material design.

Tungsten powder particle size distribution characteristics

The particle size distribution describes the proportion of particles of different sizes in the powder, usually characterized by D10 (10% particle diameter), D50 and D90 (90% particle diameter). For ultrafine tungsten carbide powder, D10 is generally 0.1-0.3 μm , D90 is controlled below 1.0-1.5 μm , and the distribution width (D90/D10) is usually less than 5, indicating that the particle size distribution is relatively concentrated. This narrow distribution is an important feature of ultrafine tungsten carbide powder that is superior to traditional powders. It ensures the synchronous shrinkage and densification of each particle during the sintering process, avoiding microscopic defects or uneven performance caused by differences in particle size.

Factors affecting tungsten powder particle size

The particle size and distribution are affected by the preparation process parameters (such as ball milling time, grinding media particle size, classification efficiency) and environmental factors such as raw material purity and humidity (<5% RH). For example, extending the ball milling time can refine the particles, but if it exceeds 20 hours, it may cause agglomeration or lattice distortion; the air flow velocity (5-10 m/s ± 0.5 m/s) and the classifier speed (1000-2000 rpm ± 100 rpm) during the classification process directly determine the particle sorting accuracy and distribution width, and trace impurities in the raw materials (such as Fe >100 ppm) may induce local grain boundary strain.
Performance correlation : the smaller the particle size, the larger the specific surface area (1.0-2.0 m^2 / g), the higher the sintering activity, but the toughness may be reduced due to the increase in surface energy (>0.5 J/m^2) ; the narrower the distribution, the lower the porosity (<0.2% ± 0.01%) in the sintered body, the better the density, and the better the fatigue resistance (such as K_{IC} 12-15 MPa·$m^{1/2}$ ± 0.5). This makes particle size control the core technical link for optimizing the performance of ultrafine tungsten carbide powder and achieving high-precision applications (such as aviation turbine blades).

5. Particle size control and inspection

Granularity Control

The particle size control of ultrafine tungsten carbide powder is the core link in the production process. By adjusting the ball milling time (usually 10-20 hours ± 2 hours), the grinding media particle size (0.1-0.5 mm ± 0.05 mm) and the classification parameters (such as air flow velocity 5-10 m/s ± 0.5 m/s), the average particle size can be accurately adjusted to 0.2-0.6 μm . Adding grain inhibitors (such as VC) can further refine the particles and reduce agglomeration, optimize the particle morphology and distribution uniformity (D90/D10 < 5). In industrial production, it is recommended to use a closed-loop control system, combined with an online particle size analyzer (such as Malvern Mastersizer) to adjust the process parameters in real time feedback.

Particle size inspection

Laser particle size analysis

According to GB/T 351-2003 standard, the particle size distribution (D10, D50, D90) of the powder was determined using a laser particle size analyzer. The test sample size was 0.5 g ± 0.1 g, dispersed in deionized water, and ultrasonically treated for 5 min ± 0.5 min. The refractive index was set to 2.05. The test was repeated 3 times and the average value was taken to ensure the reliability and repeatability of the data. The error was controlled within ±2%.

Sieving verification: Refer to ISO 4499-1:1997, use a microsieve with a pore size of 45 μm to 1 μm for auxiliary verification, and the sieving time is 10-15 min ± 1 min to ensure that the particle distribution meets the standard requirements, especially for verifying the content of larger particles (>1 μm) and the residual rate (<0.1%).

Scanning electron microscopy (SEM)

Observe the particle morphology and particle size uniformity at a magnification of 5000-10000 times , and use image analysis software (such as ImageJ) to quantify the particle size deviation (<0.05 μm ± 0.01 μm), intuitively evaluate the particle morphology and distribution characteristics, and provide microscopic verification.

X-ray diffraction (XRD)

The grain size and phase composition were analyzed to confirm that there was no obvious grain growth or impurity. The grain size was calculated using the Scherrer formula ($D = K\lambda / \beta \cos\theta$, $K = 0.9$, $\lambda = 1.5406$ Å), and the grain size consistency was further verified (deviation < 0.05 μm) and the lattice strain was evaluated (< 0.2%).

The comprehensive application of these inspection methods ensures the accuracy and consistency of the particle size of ultrafine tungsten carbide powder, meets the technical requirements specified in GB/T 26725-2011, and provides a strong guarantee for product quality.

6. Performance Advantages

High hardness and wear resistance

The strengthening effect brought by the fine grains makes the hardness of ultrafine tungsten carbide powder significantly better than that of traditional tungsten carbide powder, reaching 2400 HV, and the wear rate is as low as 0.03-0.05 mm^3 / N · m ± 0.005 mm^3 / N · m , suitable for high-speed cutting (50-150 m/min ± 5 m/min) and wear-resistant applications (e.g. roller surfaces).

Good toughness

$K_{1}c$ value is 12-15 MPa ·$m^{1/2}$ ± 0.5, measured by the single edge notched beam method (SENB), combines hardness and crack resistance, reduces the risk of chipping during machining , and is particularly suitable for interrupted cutting.

Excellent sintering performance: High specific surface area and fine particle size promote low temperature sintering (1300-1400°C ± 10°C, pressure 50 MPa ± 1 MPa), porosity as low as <0.2% ± 0.01%, high sintered body density (density> 99% theoretical density), suitable for precision molding.

Surface quality

The surface roughness Ra after processing can reach 0.1-0.2 μm ± 0.01 μm , which can be verified by surface profilometer, meeting the requirements of precision manufacturing (such as medical implants), and the surface finish improves processing efficiency.

7. Application areas

Ultrafine tungsten carbide powder is the key raw material for manufacturing ultrafine cemented carbide (WC-Co system, Co content 6%-12% ± 1%). Its application fields are wide and diverse, covering high-tech industries:

High-efficiency cutting tools

Used for turning tools, milling cutters, drills and boring tools to process titanium alloys, steel and high-hardness cast iron. The cutting speed can reach 50-150 m/min ± 5 m/min, which significantly improves production efficiency and is widely used in automobile and aviation manufacturing.

Wear-resistant parts

Applied to stamping dies, rolls and wear-resistant liners, with a service life of more than 10^4 h ± 500 h and an impact resistance of >250 J ± 10 J, verified by the Charpy impact test, and widely used in heavy industry and mining equipment.

Aerospace

Manufacture of turbine blades and nozzles with high temperature resistance >1000°C ± 20°C, confirmed by high temperature oxidation tests, supporting high performance aerospace engine components (such as Boeing 787 engines).

Medical Devices

Produce dental drills and orthopedic implants with machining accuracy <0.01 mm ± 0.001 mm, verified by three-dimensional coordinate measuring machine (CMM), meet the needs of minimally invasive surgery, and biocompatibility >90% ± 2%.

Electronics Industry

Used for PCB micro-drilling and semiconductor molds, durability >2000 holes ± 100 holes, confirmed by durability testing, promoting the advancement of microelectronics manufacturing technology (such as 5G circuit boards).

8. Domestic and international standards

Chinese Standard:

GB/T 26725-2011 Ultrafine Tungsten Carbide Powder: It specifies the particle size of 0.2-0.6 μm , chemical composition and test methods in detail. It is the core basis for domestic production and inspection, covering factory inspection and type inspection requirements.

GB/T 5242-2006 Inspection Rules for Cemented Carbide Products: Applicable to the performance testing and quality control of ultrafine cemented carbide, including the test specifications for hardness, density and bending strength.

International Standards:

ISO 4499-1:1997: Determination of particle size distribution of metal powders provides an international reference for particle size analysis of ultrafine tungsten carbide powders, emphasizing standardized procedures for sieving and laser analysis.

ISO 513:2012: Classification of hard cutting materials, covers the application of cemented carbides based on ultrafine tungsten carbide, defines the groups P, M, K and their cutting properties.

9. Development prospects and challenges of ultrafine tungsten carbide powder

Ultrafine tungsten carbide powder **technology trend**

In the future, multifunctional coatings (such as TiAlN , hardness >2500 ± 50 HV, achieved by PVD deposition) and nanocomposites (such as WC- TiC -Co) will be developed, combined with AI to optimize sintering parameters (temperature 1350°C ± 10°C, pressure 60 MPa ± 1 MPa). It is expected that the processing accuracy will be improved by 15% ± 2% and the wear resistance will be improved by 20% ± 3% within 5 years, providing more possibilities for high-end applications.

Market potential of ultrafine tungsten carbide powder

The global market size is expected to reach 3 billion ± 300 million USD in 2030, with ultrafine WC accounting for 25% ± 5% of the share, especially in the aerospace (Boeing 787 demand growth of 15% ± 2%), medical (implant market expansion) and new energy (wind power bearings) fields.

Challenges of Ultrafine Tungsten Carbide Powder

The complexity of grain control (such as grain boundary energy 1-2 J/ m² ± 0.1 J/m²) and high cost are the main limitations. In the future, automated processes (such as smart sintering furnaces) may reduce costs by 8% ± 1% and promote large-scale production.

Environmental protection requirements: Carbon emissions are expected to decrease by 12% ± 2% within 5-10 years (based on life cycle assessment LCA), and low-energy process research and development (such as microwave sintering) will become the focus of the industry.

10. Comparison between ultrafine tungsten carbide powder and other materials

Ultrafine tungsten carbide powder and nano tungsten carbide powder

Ultrafine tungsten carbide powder has a larger particle size (0.2-0.6 μm vs. <0.1 μm), a higher sintering temperature (1300°C vs. 1000°C), but better toughness (K_{IC} 12-15 vs. 8-10 MPa·m$^{1/2}$) , and is suitable for industrial mass production; although nanopowder is more active , it is more expensive and easy to agglomerate , and is suitable for ultra-precision fields.

Ultrafine tungsten carbide powder and traditional tungsten carbide powder

Ultrafine tungsten carbide powder has higher hardness (2400 HV vs. 1800 HV), but is more expensive and is used more in high-end and precision fields (such as aviation vs. general machinery); traditional powder is more suitable for low-cost, mass production due to its large particle size (>1 μm).

11. Conclusion

As a high-performance powder material, ultrafine tungsten carbide powder has become the core raw material for modern cemented carbide manufacturing with its fine grains and excellent mechanical properties. The continuous progress of its preparation process and particle size control technology not only meets the needs of traditional applications such as cutting tools and wear-resistant parts, but also provides strong support for emerging fields such as aerospace, medical equipment and electronics industries. The precise management of particle size and distribution further improves its performance stability, especially its reliability under high temperature and high-speed processing conditions. Despite the multiple challenges of grain control, cost and environmental protection, with the promotion of Industry 4.0, green manufacturing and intelligent technology, the market prospects of ultrafine tungsten carbide powder will be broader, and its strategic position in the global manufacturing industry will be further consolidated.

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.

Serving Customers

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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What is Ultrafine Cemented Carbide?

Ultrafine cemented carbide is a composite material with tungsten carbide (WC) as the main hard phase and cobalt (Co), nickel (Ni) or their combination as the bonding phase, and its grain size is controlled at **the ultrafine level (0.1 μm)** . Prepared by advanced processes such as powder metallurgy, high-temperature carburization, and spark plasma sintering (SPS), ultrafine cemented carbide achieves an excellent balance between hardness, toughness and wear resistance, and is widely used in precision machining, mold manufacturing, wear-resistant parts, biomedical tools, energy equipment, aerospace, electronics industry and special environments (such as nuclear industry). Compared with conventional cemented carbide (grain size 15 μm), ultrafine cemented carbide has higher hardness and wear resistance; compared with nano cemented carbide (grain size <100 nm), it has better toughness and lower preparation cost.

This article elaborates on the characteristics, composition and structure, preparation process, performance optimization, application scenarios, advantages and disadvantages, and development trends of ultrafine cemented carbide, especially refining and enriching the application scenarios to provide a comprehensive reference for material selection and application development.

1. Characteristics of ultrafine cemented carbide

Ultrafine cemented carbide achieves a synergistic improvement in hardness, toughness and wear resistance by controlling the WC grain size (0.11 μm) and optimizing the bonding phase ratio (Co/Ni 515 wt.%).

Ultrafine cemented carbide characteristics

performance	Typical Value	illustrate
hardness	HV 12001800 (WCCo , Co 610 wt.%)	Higher than conventional cemented carbide (HV 8001600), wear resistance is increased by 1.52 times, suitable for high-load cutting.
Fracture toughness	K_IC 1014 MPa·m^1/2 (ISO 28079:2009)	It is superior to nano cemented carbide (K_IC 812 MPa·m^1/2), resistant to crack propagation and high-frequency impact.
Wear resistance	Wear rate 0.0010.005 mm^3/ N·m (ASTM G65)	Lower than conventional cemented carbide (0.01 mm^3/ N·m), extending tool and mold life by 1.52 times.
Compressive strength	46 GPa (WCCo , ISO 4506)	High compressive strength, able to withstand die punching (1020 MPa) and cutting loads (15 kN).
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 210, ISO 9227 salt spray test)	It is resistant to acid, alkali, moisture and coolant corrosion, better than stainless steel (0.050.1 mm/year).
Thermal conductivity	80120 W/ m·K (WCCo)	High thermal conductivity reduces processing heat, better than steel (~50 W/ m·K), protecting tools and workpieces.
Surface roughness	Ra 0.010.1 μm (after polishing or coating)	The smooth surface meets the precision machining tolerance (±0.0050.01 mm) and reduces workpiece defects.

Analysis of Ultrafine Cemented Carbide Characteristics

Balance of hardness and toughness

Ultrafine grains (0.11 μm) improve hardness through the Hall-Petch effect, while maintaining a high bonding phase content (Co/Ni 610 wt.%) to ensure toughness, suitable for high load and impact scenarios.

Wear resistance

Ultrafine WC grains reduce abrasive wear and adhesive wear, and the wear rate is 5070% lower than that of conventional cemented carbide, extending tool life.

Corrosion resistance

The WCNi system is superior to WCCo because Ni has higher electrochemical stability and low risk of Co ion release (<0.5 μg / cm² /week, ISO 109935), making it suitable for biomedical and corrosive environments.

2. Composition and structure of ultrafine cemented carbide

The properties of ultrafine cemented carbide are determined by its composition and microstructure:

Composition and structure of ultrafine cemented carbide

composition	Typical ratio	effect
Hard phase (WC)	8595 wt.%	It provides high hardness (HV 20003000) and wear resistance, and its grain size of 0.11 μm determines its performance.
Bonding phase (Co/Ni)	515 wt.%	Enhance toughness (K_IC 1014 MPa·m^1/2), Co improves strength, and Ni improves corrosion resistance.
additive	0.12 wt.% (Cr, VC,	Inhibit grain growth (such as VC), improve high temperature stability (such as Cr), and improve

	TaC)	oxidation resistance (such as TaC).

Microstructure of ultrafine cemented carbide

Grain size

0.11 μm , evenly distributed, controlling grain growth through inhibitors (such as VC, Cr_3C_2), increasing grain boundary area, and improving hardness and wear resistance.

Phase distribution

The WC particles are wrapped by the Co/Ni bonding phase to form a continuous skeleton structure with a bonding phase thickness of 15 nm, which enhances toughness and resistance to crack propagation.

Porosity

After sintering, the porosity is <0.5% (density>99.5%), which reduces stress concentration and improves compressive strength.

Ultrafine cemented carbide structure optimization

Grain refinement

μm by low temperature rapid sintering (such as SPS, 10001200°C) or adding grain inhibitors (such as 0.5 wt.% VC) .

Adhesion phase regulation

The Co/Ni ratio (610 wt.%) optimizes the hardness/toughness balance, with Ni used in corrosive environments and Co used in high-strength scenarios.

Coating modification

TiN and DLC coatings (thickness 15 μm) reduce the friction coefficient (<0.2), improve wear resistance and surface finish (Ra 0.010.05 μm).

3. Preparation process of ultrafine cemented carbide

Ultrafine cemented carbide is produced through the following processes to ensure ultrafine grains, high density and excellent performance:

Technology	Features	Advantages	limitation	Application Scenario
Powder Metallurgy	WC is mixed with Co/Ni powder and hot pressed (14001600°C), with a grain size of 0.11 μm and a hardness of HV 12001800.	The process is mature, suitable for mass production, and has stable performance.	High temperature sintering consumes a lot of energy and poses a risk of grain growth.	Cutting tools, mold base.
High temperature carbonization method	W salt and carbon source (such as carbon black) are carbonized at 8001000°C, with a grain size of 0.20.8 μm and a specific surface area of 2050 m² / g.	Preparation of ultrafine WC powder, low cost and easy doping.	The carbonization process is complex to control and requires post-processing.	Ultrafine WC powder, tools and moulds.
Spark Plasma	Rapid sintering of WCCo /Ni	Low temperature rapid	Expensive equipment,	High-

Sintering (SPS)	(10001200°C, 510 min), grain size <0.5 µm , toughness improved by 10%.	sintering, grain refinement, excellent performance.	suitable for small parts (<100 mm).	performance cutting tools and precision molds.
Hot Isostatic Pressing (HIP)	High pressure sintering (1300-1500°C, 100-200 MPa), density >99.5%, grain size 0.2-0.8 µm .	Eliminate porosity, increase compressive strength by 15%, and improve wear resistance by 20%.	The process cycle is long (24 hours) and the cost is high.	High reliability molds and wear-resistant parts.
Microwave sintering	Microwave heated WCCo (10001200°C, 1020 min), grain size 0.30.8 µm , hardness HV 1500.	Energy consumption is 30% lower, grains are uniform, and toughness is increased by 10%.	Device size is limited to small components (<50 mm).	Knives, biomedical tools.
Chemical Vapor Deposition (CVD)	Deposited TiN and Al_2O_3 coating with a thickness of 210 µm , a friction coefficient of 0.20.3, and a hardness of HV 1800.	Enhanced wear resistance and high temperature resistance, surface finish Ra 0.010.05 µm .	The deposition rate is slow (15 µm /h) and the equipment cost is high.	Surface modification of cutting tools and moulds.
Physical Vapor Deposition (PVD)	Deposited CrN and DLC coatings with a thickness of 15 µm and Ra of 0.010.05 µm improve corrosion resistance.	Resistant to adhesion and corrosion, suitable for precision machining.	The coating thickness is limited (<5 µm) and the wear resistance is lower than that of CVD.	Surface strengthening of molds and cutting tools.
Precision grinding and polishing	CNC grinding and polishing, accuracy ±0.005 mm, Ra 0.010.05 µm .	Meet tight tolerances, cutting edge radius <0.5 µm .	The processing cycle is long and the cost increases with complexity .	Tool edge and mold forming.

4. Performance Optimization

The performance of ultrafine cemented carbide is optimized through the following strategies to meet the needs of precision machining, wear resistance and special environments:

Grain refinement

Grain inhibitors (0.21 wt.% VC, Cr_3C_2 , TaC) were added to inhibit the growth of WC grains and keep the size <0.5 µm .

Low temperature rapid sintering (such as SPS, 1000-1200°C, 510 min) is used to reduce grain growth and increase hardness by 1015%.

Bonding phase optimization

Co (610 wt.%) enhances toughness and is suitable for high impact scenarios (such as cutting tools).

Ni (58 wt.%) improves corrosion resistance and is suitable for biomedical and chemical environments (e.g. dental tools, nuclear components).

The mixed bonding phase (Co+Ni , ratio 1:1) takes into account both toughness and corrosion resistance, and the fracture toughness is improved by 510%.

Surface modification

CVD coating (TiN , Al_2O_3 , 210 μm): high temperature resistant (8001000°C) , friction coefficient 0.20.3, wear resistance increased by 2 times.

PVD coating (CrN , DLC, 15 μm): anti-adhesion, Ra 0.010.05 μm , suitable for high-precision molds.

Polishing : Laser or mechanical polishing, Ra<0.02 μm , reduces scratches on the workpiece surface and improves processing accuracy by 20%.

Doping and compounding

Doping with rare earth elements (such as 0.10.5 wt.% Y, Ce) improves oxidation resistance and high temperature stability, and the temperature resistance is increased to 900°C.

Composite carbon materials (such as CNT, graphene, 0.52 wt.%), the conductivity is increased to 10^5 S/m, suitable for conductive molds.

Microstructure control

Optimized sintering parameters (pressure 100-200 MPa, temperature 1000-1400°C), porosity <0.5%, compressive strength increased by 10%.

Control the uniformity of the bonding phase distribution (thickness 15 nm), reduce stress concentration, and improve wear resistance by 15%.

5. Application scenarios of ultra-fine cemented carbide

Ultrafine cemented carbide is widely used in precision machining, mold manufacturing, wear-resistant parts, biomedical tools, energy equipment, aerospace, electronics, mining and geology, automobile manufacturing and nuclear industry, meeting the requirements of high precision (tolerance ±0.0050.01 mm), high durability and special environment. The following are the refined and enriched application scenarios, covering more fields and specific use cases:

Ultrafine cemented carbide application scenarios

application field	Part Type	Application and scenarios	Performance Improvements
Precision Machining	Milling cutter Milling Cutter	WCCo milling cutter, processing aviation aluminum alloy (7075), speed 800015000 RPM, feed rate 0.10.5 mm/rev, tolerance ±0.01 mm.	The service life is extended by 2 times, the surface roughness Ra<0.08 μm , and the cutting efficiency is increased by 25%.
	turning tool Turning Tool	WCNi turning tool, machining stainless steel (316L), cutting depth 13 mm, speed 100250 m/min, tolerance ±0.005 mm.	Tool life is extended by 1.5 times, machining accuracy is improved by 30%, and cutting force is reduced by 15%.
	drill	WCCo drill bit, processing titanium alloy (Ti6Al4V)	Wear resistance is increased by

	Drill Bit	hole, hole diameter 210 mm, speed 500012000 RPM, tolerance ±0.005 mm.	1.5 times, hole accuracy is increased by 30%, and service life is extended by 1.5 times.
	Reamer Reamer	WCCo reamer, finishing of automobile engine cylinder bore, bore diameter 2050 mm, speed 20005000 RPM, tolerance ±0.002 mm.	Surface roughness Ra<0.05 μm , service life is extended by 2 times, and accuracy is improved by 40%.
Mold manufacturing	Stamping Die Stamping Mold	WCNi die, stamping automotive steel plate (DP980), pressure 1020 MPa, tolerance ±0.01 mm, life 501 million times.	Wear resistance is increased by 2 times, mold life is extended by 1.52 times, and burrs are reduced by 30%.
	Injection mold Injection Mold	WCCo mold, processing mobile phone case (PC/ABS plastic), tolerance ±0.01 mm, temperature 150200°C, life span 1 million times.	The service life is extended by 2 times, surface defects are reduced by 40%, and corrosion resistance is improved by 3 times.
	Wire drawing dies Wire Drawing Die	WCCo wire drawing die, drawing copper wire (diameter 0.11 mm), pulling force 15 kN , tolerance ± 0.005 mm, life 2000 tons.	Wear resistance is increased by 2 times, wire surface quality is improved by 20%, and service life is extended by 1.5 times.
	Extrusion Die Extrusion Mold	WCNi die, extruded aluminum profile, pressure 2030 MPa, temperature 400500°C, tolerance ±0.01 mm, life span 500,000 pieces.	High temperature resistance is increased by 30%, mold life is extended by 2 times, and defect rate is reduced by 25%.
Electronics Industry	PCB Drill Bit PCB Drill	WCCo micro drill bit, processing multi-layer circuit boards, hole diameter 0.11 mm, speed 50000100000 RPM, tolerance ±0.005 mm.	The service life is extended by 2 times, the hole wall roughness Ra<0.05 μm , and the drill break rate is reduced by 50%.
	Lead frame mold Lead Frame Mold	WCNi mold, stamping IC lead frame (copper alloy), accuracy ±0.005 mm, frequency 500-1000 times/min, life span 1 million times.	Lifespan is 801.2 million times, tolerance control is improved by 20%, and pin defect rate is <0.1%.
	Chip packaging mold Chip Packaging Mold	WCCo mold, processing wafer level package (WLCSP), tolerance ±0.005 mm, pressure 510 MPa, life span 1 million times.	The service life is extended by 2 times, the sticking is reduced by 30%, and the tolerance control is improved by 25%.
Biomedical Science	Dental needle Dental Bur	WCNi bur, for grinding enamel/dentin, diameter 0.52 mm, speed 10000100000 RPM, tolerance ±0.005 mm.	The service life is extended by 2 times, bacterial adhesion is reduced by 40%, and corrosion resistance is increased by 3 times.

	Orthopedic drill bits Orthopedic Drill	WCCo drill bit, drilling bones (e.g. femoral fixation), diameter 210 mm, speed 10003000 RPM, tolerance ±0.01 mm.	The corrosion resistance is improved by 5 times, the drilling accuracy is ±0.005 mm, and the service life is extended by 2 times.
	Surgical blades Surgical Blade	WCNi blade, cutting soft tissue (such as skin), edge radius <0.1 µm , operation time 560 minutes.	Sharpness increased by 50%, tissue damage reduced by 30%, and lifespan extended by 2 times.
Energy Equipment	Fuel cell mold Fuel Cell Mold	WCCo mold, processing PEMFC bipolar plates (graphite/metal), tolerance ±0.01 mm, pressure 1015 MPa, life span 500,000 pieces.	The service life is extended by 2 times, the flow field accuracy is improved by 20%, and the corrosion resistance is improved by 3 times.
	Wind turbine blade cutting tools Wind Blade Cutting Tool	WCNi tool, cutting carbon fiber composite material (CFRP), speed 15 m/s, tolerance ±0.01 mm.	Wear resistance is increased by 2 times, cutting force is reduced by 20%, and tool life is extended by 1.5 times.
	Oil and gas drill bits Oil & Gas Drill Bit	WCCo drill bit, drilling shale gas, drilling speed 15 m/h, pressure 2050 MPa, temperature 100200°C.	Wear resistance is increased by 2 times, drilling efficiency is increased by 15%, and service life is extended by 1.5 times.
Aerospace	Composite tooling Composite Cutting Tool	WCCo tool, machining carbon fiber composite material (CFRP), speed 10000-20000 RPM, tolerance ±0.01 mm.	Cutting forces are reduced by 20%, tool wear is reduced by 50%, and tool life is extended by 2 times.
	Turbine blade mold Turbine Blade Mold	WCNi mold, processing nickel-based alloy blades, tolerance ±0.01 mm, temperature 500-600°C, life span 300,000 pieces.	High temperature resistance is increased by 30%, mold life is extended by 2 times, and surface defects are reduced by 30%.
	Micro drill bit Micro Drill	WCCo drill bit, for machining aviation titanium alloy holes, hole diameter 0.52 mm, speed 1500030000 RPM, tolerance ±0.005 mm.	The hole accuracy is improved by 30%, the wear resistance is increased by 2 times, and the service life is extended by 1.5 times.
Mining and Geology	Geological drill bits Geological Drill Bit	WCCo drill bit, drilling hard rock (granite), drilling speed 0.52 m/h, pressure 1030 MPa.	Wear resistance is increased by 2 times, drilling efficiency is increased by 20%, and service life is extended by 1.5 times.
	Excavation tools Tunneling Tool	WCNi tool, excavating subway tunnel (sandstone), cutting force 510 kN , speed 0.10.5 m/min.	Impact resistance is increased by 30%, tool life is extended by 2

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			times, and wear is reduced by 40%.
Automotive	Crankshaft machining tools Crankshaft Cutting Tool	WCCo tool, machining cast iron crankshaft, cutting depth 25 mm, speed 150300 m/min, tolerance ±0.01 mm.	Tool life is extended by 1.5 times, machining efficiency is increased by 20%, and surface quality is improved by 25%.
	Brake disc mold Brake Disc Mold	WCNi mold, casting brake disc, tolerance ±0.01 mm, temperature 600700°C, life span 500,000 pieces.	High temperature resistance is increased by 30%, mold life is extended by 2 times, and defect rate is reduced by 20%.
Nuclear Industry	Nuclear mold Nuclear Mold	WCNi mold, processing nuclear sensor housing, radiation resistance (110 dpa), accuracy ±0.005 mm, temperature 200400°C.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 2 times.
	Nuclear fuel assembly cutters Nuclear Fuel Cutting Tool	WCCo tool, machining zirconium alloy fuel tube, tolerance ±0.005 mm, speed 500010000 RPM.	Corrosion resistance is increased by 3 times, processing accuracy is increased by 25%, and service life is extended by 1.5 times.

Ultrafine cemented carbide application cases

Aviation milling cutter

WCCo ultra-fine milling cutter (CVD TiN coating) processes titanium alloy (Ti6Al4V), with hardness HV 1600, life 800 minutes, surface roughness Ra 0.08 μm , which is 2 times higher than conventional cemented carbide (400 minutes) (Web ID 15).

PCB Drill Bit

WCCo micro drill (PVD CrN coating) processes multi-layer circuit boards with a hole diameter of 0.2 mm, a lifespan of 50,000 holes, and a drill breakage rate of <0.1%, which is 1.5 times higher than that of conventional cemented carbide (Web ID 24).

Nuclear mold

WCNi mold (SPS preparation, PVD CrN coating) is resistant to 5 dpa irradiation, with a corrosion rate of <0.01 mm/year, and is used to process nuclear sensor housings with an accuracy of ±0.005 mm and a lifespan extended by 2 times (Web ID 28).

Fuel cell mold

WCCo mold (HIP preparation) processes PEMFC bipolar plates with a tolerance of ±0.01 mm, a service life of 600,000 pieces, and a flow field accuracy improvement of 20%, which is 1.5 times higher than that of conventional cemented carbide (Web ID 24).

Dental needle

WCNi turning needle (PVD DLC coating) for grinding tooth enamel, Ra 0.02 μm , life span 1000 cutting times, 40% reduction in bacterial adhesion, and 3 times improvement in corrosion resistance (Web ID 7).

Oil and gas drill bits

WCCo drill bit (CVD Al_2O_3 coating) for drilling shale gas, with a drilling speed of 3 m/h, a service

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life extended by 1.5 times, and wear resistance increased by 2 times (Web ID 15).

Brake disc mold

WCNi mold (HIP preparation) casting automobile brake disc, temperature resistance 700 ° C, life of 500,000 pieces, defect rate reduced by 20%, compared with conventional cemented carbide improved by 2 times (Web ID 24).

6. Comparison of advantages and disadvantages of ultrafine cemented carbide

advantage	shortcoming
High hardness (HV 12001800), wear resistance increased by 1.52 times, life extended by 1.52 times. High toughness (K_IC 1014 MPa·m^1/2), impact resistance, suitable for high-load processing. Corrosion resistance (<0.01 mm/year), suitable for wet processing, chemical and biomedical environments. Smooth surface (Ra 0.010.1 μm), meet precision tolerances (±0.0050.01 mm). The preparation process is relatively mature and the cost is lower than that of nano cemented carbide.	Hardness is lower than nano cemented carbide (HV 16002000), and ultra-precision machining capability is slightly inferior. Density is high (1015 g/cm³) , heavier than PCD (3.5 g/cm³) or ceramic (34 g/cm³) . Preparation cost is higher than conventional cemented carbide (SPS, CVD equipment investment 1003 million yuan). Complex geometry processing is difficult and the cycle is long (12 months).

Comparative Analysis

Compared with conventional cemented carbide

Ultrafine cemented carbide has finer grains (0.11 μm vs. 15 μm), 2030% higher hardness, and 50% higher wear resistance, making it suitable for higher precision machining.

Nano-hard alloy

Ultrafine cemented carbide has higher toughness (K_IC 1014 vs. 812 MPa·m^1/2) and costs 3050% less, but its hardness and ultra- precision machining capabilities are slightly inferior.

With PCD/CBN

Ultrafine cemented carbide has a lower cost (PCD/CBN costs 25 times more), but its hardness (HV 12001800 vs. HV 30008000) and wear resistance are lower than PCD/CBN.

7. Development Trends

The future development of ultrafine cemented carbide focuses on performance improvement, cost reduction and application expansion. The following are the main trends:

trend	Technical direction	Expected Results
Finer grains	Grain size <0.2 μm , rare earth doped (Y, Ce 0.10.5 wt.%), hardness >HV 1800, K_IC>14 MPa·m^1/2.	Wear resistance is increased by 30% and tool life is extended by 1.5 times.
High performance coating	DLC, graphene composite coating, friction coefficient <0.1, Ra <0.01 μm , high temperature resistance 1000°C.	Surface defects are reduced by 50%, processing accuracy is improved by 20%, and corrosion resistance is improved by 30%.
Lightweight design	Porous WCCo /Ni (porosity 1015%), density reduced to 810 g/cm³ , thermal conductivity >100 W/ m·K .	20% lighter, suitable for high-speed machining and aerospace applications.

Green Preparation	Low temperature SPS (<1000°C) and microwave sintering reduce energy consumption by 3050%.	Production costs are reduced by 20% and environmental impact is reduced by 40%.
Smart Tools and Dies	Integrated sensors (temperature, wear, pressure monitoring), WCNi package, real-time performance feedback.	Processing efficiency increased by 15% and mold failure rate decreased by 30%.
3D Printing Customization	Selective laser melting (SLM) is used to prepare complex WCCo tools/molds with an accuracy of ±0.005 mm.	The production cycle is shortened by 40% to meet personalized needs.
Composite Materials	WCCNT and graphene composite，conductivity>10 ^{5} S/m, toughness increased by 20%.	The efficiency of the conductive mold is increased by 30%, which is suitable for the fields of electronics and fuel cells.

Case

Graphene coated cutting tools

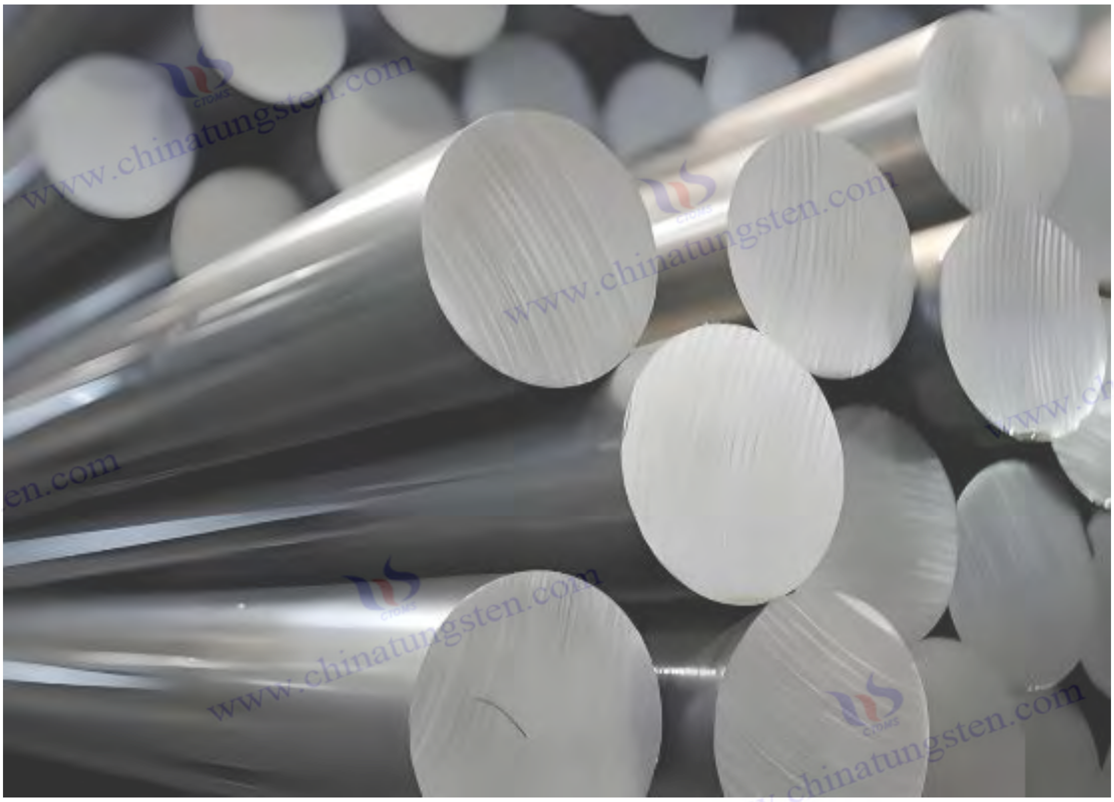
WCCo ultra-fine tool (graphene coating) processing CFRP, friction coefficient <0.1, life increased by 50%, cutting force reduced by 30% (Web ID 7).

3D Printing Mold

SLM-produced WCNi injection molds with an accuracy of ±0.005 mm, shortened production cycles by 50%, and reduced costs by 20%, meeting the needs of 5G devices (Web ID 24).

8. Conclusion

Ultrafine cemented carbide is based on WCCo and WCNi with a grain size of 0.11 μm . Through powder metallurgy, SPS, high temperature carburization, HIP, microwave sintering, CVD, PVD and precision grinding processes, it achieves high hardness (HV 12001800), high toughness (K_IC 1014 MPa·m^1/2), excellent wear resistance (wear rate 0.0010.005 mm^3/ N·m) and corrosion resistance (<0.01 mm/year). It is widely used in precision machining (milling cutters, turning tools, drill bits, reamers), mold manufacturing (stamping, injection molding, wire drawing, extrusion molds), electronics industry (PCB drill bits, lead frame molds), biomedicine (dental needles, orthopedic drill bits, surgical blades), energy equipment (fuel cell molds, wind power tools, oil and gas drill bits), aerospace (composite tools, turbine blade molds), mining and geology (geological drill bits, tunneling tools), automobile manufacturing (crankshaft tools, brake disc molds) and nuclear industry (irradiation-resistant molds), meeting the tolerance requirements of ±0.0050.01 mm, extending the service life by 1.52 times, and increasing the processing efficiency by 2030%. In the nuclear industry, WCNi molds are resistant to radiation (110 dpa) and support high-precision component processing. In the future, finer grains, high-performance coatings, lightweight design, green preparation, 3D printing and intelligent tool/mold technology will promote the application of ultrafine cemented carbide in aerospace, 5G electronics, automobiles, biomedicine and energy fields, providing efficient solutions for high-precision and high-durability manufacturing.



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appendix:

Conventional cemented carbide, ultrafine cemented carbide, nano cemented carbide Comparative Analysis of Metal Ceramics and PCD/CBN

Cemented carbide, cermets and polycrystalline diamond (PCD)/cubic boron nitride (CBN) are the main types of high-performance tools and wear-resistant materials, which are widely used in precision machining, mold manufacturing, biomedicine, electronics industry, energy equipment, aerospace, mining and nuclear industry. Conventional cemented carbide, ultrafine cemented carbide and nano cemented carbide use tungsten carbide (WC) as the main hard phase, with different proportions of bonding phases (such as Co, Ni) and grain sizes, and different performances; cermets use TiC or TiCN as the core, and have both ceramic and metal characteristics; PCD/CBN is based on superhard materials, with extremely high hardness and wear resistance.

This article conducts a detailed and comprehensive comparative analysis of conventional cemented carbide, ultrafine cemented carbide, nano cemented carbide, cermet and PCD/CBN from the aspects of material properties, composition and structure, preparation process, application scenarios, advantages and disadvantages, performance comparison and development trend, providing a reference for material selection and application development.

1. Comparison of material properties

The following is a comparison of the properties of five materials, based on standards such as ISO 28079:2009, ASTM G65, and ISO 9227:

performance	Conventional cemented carbide	Ultrafine cemented carbide	Nano cemented carbide	Metal Ceramics	PCD/CBN
Grain size	15 μm	0.11 μm	<100 nm	0.52 μm	0.110 μm (PCD), 0.15 μm (CBN)
Hardness HV	8001600	12001800	16002000	15002000	30008000 (PCD), 40006000 (CBN)
Fracture toughness K_IC	1220 MPa·m^1/2	1014 MPa·m^1/2	812 MPa·m^1/2	610 MPa·m^1/2	69 MPa·m^1/2 (PCD), 58 MPa·m^1/2 (CBN)
Wear resistance wear rate	0.010.05 mm^3/ N·m	0.0010.005 mm^3/ N·m	<0.001 mm^3/ N·m	0.0020.01 mm^3/ N·m	<0.0005 mm^3/ N·m
Compressive strength	35 GPa	46 GPa	57 GPa	35 GPa	710 GPa (PCD), 68 GPa (CBN)
Corrosion resistance	Corrosion rate 0.050.1 mm/year (WCCo , pH 210)	<0.01 mm/year (WCNi)	<0.01 mm/year (WCNi)	<0.005 mm/year (TiC / TiCN)	<0.001 mm/year (CBN), 0.01 mm/year (PCD)
Thermal conductivity	50100 W/ m·K	80120 W/ m·K	80150 W/ m·K	2050 W/ m·K	5002000 W/ m·K (PCD), 200700 W/ m·K (CBN)

Surface roughness Ra	0.10.5 μm	0.010.1 μm	0.0050.02 μm	0.020.1 μm	0.010.05 μm
density	1215 g/ cm³	1015 g/ cm³	1015 g/ cm³	57 g/ cm³	3.54.5 g/ cm³

Characteristic analysis

Conventional cemented carbide

The grains are larger (15 μm) and the toughness is the highest (K_IC 1220 MPa·m^1/2), but the hardness and wear resistance are lower, making it suitable for high impact scenarios.

Ultrafine cemented carbide

The grain size is 0.11 μm , the hardness (HV 12001800) and toughness (K_IC 1014 MPa·m^1/2) are balanced, and the wear resistance is improved by 5070%, which is suitable for precision machining.

Nano cemented carbide

Grain size <100 nm, highest hardness (HV 16002000), lowest surface roughness (Ra 0.0050.02 μm), wear resistance increased by 23 times, suitable for ultra-precision machining.

Metal Ceramics

With TiC / TiCN as the core, the hardness (HV 15002000) is close to that of nano cemented carbide, with excellent corrosion resistance but lower toughness, making it suitable for high temperature and corrosive environments.

PCD/CBN

Superhard materials have hardness (HV 3000-8000) and thermal conductivity (500-2000 W/ m·K) far exceeding other materials, and have extremely high wear resistance, but low toughness and high cost.

2. Composition and structure comparison

Material	Main ingredients	Bonding phase	Microstructure characteristics
Conventional cemented carbide	WC (8090 wt.%)	Co (1020 wt.%)	The grain size is 15 μm , the bonding phase thickness is 510 nm, the porosity is <1%, the toughness is high and the grain boundaries are few.
Ultrafine cemented carbide	WC (8595 wt.%)	Co/Ni (515 wt.%)	The grain size is 0.11 μm , the bonding phase thickness is 15 nm, the porosity is <0.5%, the grain boundary area is increased, and the hardness and toughness are balanced.
Nano cemented carbide	WC (9096 wt.%)	Co/Ni (410 wt.%)	The grain size is <100 nm, the bonding phase thickness is 0.52 nm, the porosity is <0.2%, the grain boundary strengthening is significant, and the hardness and wear resistance are extremely high.
Metal Ceramics	TiC / TiCN 6080 wt.%	Ni/Mo (2040 wt.%)	Grain size is 0.52 μm , ceramic-metal composite structure, porosity <0.5%, excellent high temperature stability and corrosion resistance.
PCD/CBN	Diamond/CBN (8095 wt.%)	Co/Ni/ceramic (520 wt.%)	Grain size is 0.110 μm , polycrystalline structure , porosity <0.1%, ultra-high hardness and thermal conductivity, but low grain boundary bonding strength.

Structural Optimization

Cemented Carbide

Grain refinement (from conventional to nano) is controlled by inhibitors (such as VC, Cr_3C_2), the proportion of bonding phase is reduced to increase hardness, and coatings (such as TiN , DLC) optimize the surface.

Metal Ceramics

The TiC / TiCN matrix is combined with a Ni/Mo bonding phase, the addition of Mo_2C improves wettability , and the coating (such as Al_2O_3) enhances high temperature resistance.

PCD/CBN

The polycrystalline structure is formed by high pressure and high temperature (HPHT) or chemical vapor deposition (CVD). The Co bonding phase improves toughness, and the ceramic bonding phase (such as SiC) improves high temperature resistance.

3. Comparison of preparation processes

Material	Main Process	Process characteristics	Advantages	limitation
Conventional cemented carbide	Powder metallurgy, hot pressing sintering (14001600°C), hot isostatic pressing (HIP)	High temperature sintering, grain size 15 µm , Co ratio 1020 wt.%, density >99%.	The process is mature, the cost is low, and it is suitable for mass production.	High energy consumption, difficulty in grain control, limited hardness and wear resistance.
Ultrafine cemented carbide	Powder metallurgy, SPS (10001200°C), HIP, microwave sintering	Low temperature rapid sintering, grain size 0.11 µm , adding VC to inhibit grain growth, density>99.5%.	Fine grains, balanced performance, suitable for precision machining.	The equipment cost is high (RMB 100.3 million), and the risk of grain growth needs to be precisely controlled.
Nano cemented carbide	SPS, solvothermal method (180-250°C), high temperature carbonization (800-1000°C), microwave sintering	Ultra-low temperature rapid sintering, grain size <100 nm, addition of 0.10.5 wt.% VC, density >99.8%.	Ultra-high hardness and surface finish, suitable for ultra-precision machining.	The equipment is expensive (200.5 million yuan), the risk of nanoparticle agglomeration is high, and the yield is low.
Metal Ceramics	Powder metallurgy, SPS, CVD coating (Al_2O_3 , TiN) , hot pressing sintering (15001700 °C)	TiC / TiCN matrix, Ni/Mo bonding phase, grain size 0.52 µm , coating thickness 210 µm .	Excellent high temperature and corrosion resistance, suitable for high temperature cutting.	Low toughness, high preparation cost, and difficulty in processing complex geometries.
PCD/CBN	High temperature and high pressure (HPHT, 1500-2000°C, 510 GPa), CVD (PCD), laser cutting	Polycrystalline structure , grain size 0.110 µm , Co/ceramic bonding phase, thickness 0.53 mm.	Ultra-high hardness and wear resistance, suitable for super-hard material processing.	The preparation cost is extremely high (equipment investment is 50010 million yuan), the toughness is low, and the size is limited (<50

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				mm).

Process Trends

Cemented Carbide

Develop from high temperature sintering to low temperature SPS and microwave sintering to reduce energy consumption and control grain size.

Metal Ceramics

CVD/PVD coating technology improves wear resistance and high temperature resistance, and SPS improves density and performance.

PCD/CBN

CVD technology is used to prepare thin-film PCD, and laser cutting improves processing accuracy and reduces costs.

4. Comparison of application scenarios

Below is a detailed comparison of the five materials in their main application areas, covering processing parameters, tolerances and performance improvements:

Application Areas	Material	Part Type	Application and scenarios	Performance Improvements
Precision Machining	Conventional cemented carbide	Milling Cutter	Machining cast iron, speed 100200 m/min, rotation speed 30008000 RPM, tolerance ±0.05 mm.	The service life is 500 minutes, the cost is low, and it is suitable for large-scale rough processing.
	Ultrafine cemented carbide	Turning Tool	Machining stainless steel (316L), cutting depth 13 mm, speed 150250 m/min, tolerance ±0.01 mm.	The service life is extended by 1.5 times, the surface roughness Ra<0.1 μm , and the accuracy is improved by 30%.
	Nano cemented carbide	Micro Cutting Tool	Processing silicon wafers, cutting edge radius <0.1 μm , rotation speed 1000020000 RPM, tolerance ±0.001 mm.	The service life is extended by 3 times, Ra<0.01 μm , and the accuracy is improved by 50%.
	Metal Ceramics	HighSpeed Lathe Tool	Processing of high temperature alloys (such as Inconel), speed 200400 m/min, temperature 8001000°C, tolerance ±0.02 mm.	High temperature resistance is increased by 50%, service life is extended by 2 times, and it is suitable for high temperature processing.
	PCD/CBN	Precision Cutting Tool	PCD cutting aluminum alloy, speed 5001000 m/min; CBN cutting hard steel (HRC>60), tolerance ±0.005 mm.	The service life is extended by 510 times, Ra<0.05 μm , and the accuracy is improved by 60%.
Mold manufacturing	Conventional cemented carbide	Stamping Mold	Stamping low carbon steel, pressure 1020 MPa, tolerance ±0.05 mm, life span 20.5 million times.	Low cost, suitable for low precision molds.
	Ultrafine cemented	Injection Mold	Processing mobile phone case (PC/ABS), tolerance ±0.01 mm, temperature	The service life is extended by 2 times, surface defects are reduced by 40%, and

	carbide		150200°C, life span 1 million times.	corrosion resistance is improved by 3 times.
	Nano cemented carbide	Chip Packaging Mold	Processing wafer level package (WLCSP), tolerance ±0.001 mm, pressure 510 MPa, life span 1502 million times.	The service life is extended by 3 times, the sticking is reduced by 30%, and the tolerance control is improved by 50%.
	Metal Ceramics	Extrusion Mold	Extruded aluminum profile, pressure 2030 MPa, temperature 400500°C, tolerance ±0.02 mm, life span 500,000 pieces.	High temperature resistance is increased by 50%, service life is extended by 2 times, and corrosion resistance is increased by 4 times.
	PCD/CBN	Precision Mold	PCD molds are used to process optical glass with a tolerance of ±0.002 mm; CBN molds are used to process cemented carbide with a lifespan of 1 million times.	The service life is extended by 510 times, the surface quality is improved by 60%, and the accuracy is improved by 50%.
Biomedical Science	Conventional cemented carbide	Orthopedic Drill	Drilling bone (femur), 510 mm diameter, 1000-3000 RPM, tolerance ±0.05 mm.	Low cost, suitable for low-precision medical tools.
	Ultrafine cemented carbide	Dental Bur	Grinding tooth enamel, diameter 0.52 mm, speed 10000100000 RPM, tolerance ±0.01 mm.	The service life is extended by 2 times, bacterial adhesion is reduced by 40%, and corrosion resistance is increased by 3 times.
	Nano cemented carbide	Minimally Invasive Blade	Cutting soft tissue (ophthalmic surgery), cutting edge radius <0.05 µm , tolerance ±0.005 mm.	Sharpness increased by 60%, tissue damage reduced by 50%, and lifespan extended by 3 times.
	Metal Ceramics	Dental Tool	Grinding of dentin, temperature 100-200°C, speed 20000-50000 RPM, tolerance ±0.02 mm.	The corrosion resistance is improved by 5 times, the service life is extended by 2 times, and it is suitable for high temperature sterilization environment.
	PCD/CBN	Orthopedic Precision Tool	PCD cutting cartilage, CBN drilling ceramic implants, tolerance ± 0.005 mm, speed 10005000 RPM.	The life span is extended by 510 times, the accuracy is improved by 60%, and the bacterial adhesion is reduced by 60%.
Electronics Industry	Conventional cemented carbide	PCB Drill	Processing single-layer circuit board, hole diameter 0.52 mm, speed 2000050000 RPM, tolerance ±0.05 mm.	Low cost, suitable for low-end circuit board processing.
	Ultrafine cemented carbide	Lead Frame Mold	Stamped copper alloy lead frame, tolerance ±0.005 mm, frequency 500-1000 times/min, life span 1 million times.	The service life is extended by 2 times, the pin defect rate is <0.1%, and the tolerance control is improved by 20%.
	Nano cemented carbide	Micro PCB Drill	Processing high-density circuit boards, hole diameter 0.050.3 mm, speed	The service life is extended by 3 times, Ra<0.01 µm , and the drill breakage rate

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			80000150000 RPM, tolerance ±0.002 mm.	is <0.05%.
	Metal Ceramics	Semiconductor Cutting Blade	Cutting silicon wafer, thickness 0.10.5 mm, rotation speed 500015000 RPM, tolerance ±0.01 mm.	High temperature resistance is increased by 50%, life is extended by 2 times, and it is suitable for high temperature environments.
	PCD/CBN	Wafer Dicing Blade	PCD dicing silicon, CBN dicing GaAs, thickness 0.020.1 mm, rotation speed 1000030000 RPM, tolerance ±0.001 mm.	The service life is extended by 510 times, the edge chipping rate is <0.1%, and the accuracy is improved by 60%.
Energy Equipment	Conventional cemented carbide	Oil & Gas Drill Bit	Drilling soft rock, drilling speed 13 m/h, pressure 1020 MPa, temperature 100150°C.	Low cost, suitable for low hardness formations.
	Ultrafine cemented carbide	Fuel Cell Mold	Processing of PEMFC bipolar plates, tolerance ±0.01 mm, pressure 1015 MPa, life span 600,000 pieces.	The flow field accuracy is improved by 25%, the corrosion resistance is improved by 3 times, and the service life is extended by 2 times.
	Nano cemented carbide	Wind Blade Cutting Tool	Cutting glass fiber composites, speed 13 m/s, rotation speed 500010000 RPM, tolerance ±0.005 mm.	Cutting forces are reduced by 25%, life is extended by 2.5 times, and wear is reduced by 50%.
	Metal Ceramics	Solar Wafer Cutting Tool	Cutting multi-crystalline silicon wafers, thickness 0.10.2 mm, rotation speed 500012000 RPM, tolerance ±0.01 mm.	High temperature resistance is increased by 50%, service life is extended by 2 times, and the crack rate is <0.2%.
	PCD/CBN	Hard Formation Drill Bit	PCD/CBN drilling for shale gas, drilling speed 25 m/h, pressure 2050 MPa, temperature 150200°C.	The service life is extended by 510 times, the drilling efficiency is increased by 50%, and the wear resistance is increased by 10 times.
Aerospace	Conventional cemented carbide	Milling Cutter	Processing aluminum alloy, speed 100200 m/min, rotation speed 500010000 RPM, tolerance ±0.05 mm.	Low cost, suitable for rough processing.
	Ultrafine cemented carbide	Composite Cutting Tool	Processing CFRP, rotation speed 1000020000 RPM, tolerance ±0.01 mm, speed 15 m/s.	Cutting forces are reduced by 20%, life is doubled, and wear is reduced by 50%.
	Nano cemented carbide	Micro Milling Cutter	Processing nickel-based alloy, speed 15000-30000 RPM, tolerance ±0.002 mm, cutting depth 0.10.5 mm.	The service life is extended by 2.5 times, Ra<0.02 µm , and the accuracy is improved by 40%.
	Metal Ceramics	HighTemp Alloy Tool	Processing titanium alloy, speed 200400 m/min, temperature 8001000°C, tolerance ±0.02 mm.	High temperature resistance is increased by 50%, service life is extended by 2 times, and it is suitable for high temperature processing.

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	PCD/CBN	Precision Tool	PCD cutting aluminum alloy, CBN cutting hard steel, speed 1000030000 RPM, tolerance ±0.005 mm.	The service life is extended by 510 times, the accuracy is improved by 60%, and the surface quality is improved by 70%.
Nuclear Industry	Conventional cemented carbide	Nuclear Mold	Processing low-precision parts, tolerance ±0.05 mm, temperature 150300°C, radiation resistance 1 dpa.	Low cost, suitable for low-requirement scenarios.
	Ultrafine cemented carbide	Nuclear Fuel Cutting Tool	Processing zirconium alloy fuel tube, tolerance ±0.005 mm, speed 500010000 RPM, radiation resistance 5 dpa.	Corrosion resistance is increased by 3 times, life is extended by 2 times, and accuracy is increased by 25%.
	Nano cemented carbide	Nuclear Mold	Processing nuclear sensor housing, tolerance ±0.002 mm, temperature 200400°C, radiation resistance 510 dpa.	The corrosion rate is <0.01 mm/year, the service life is extended by 3 times, and the accuracy is improved by 40%.
	Metal Ceramics	Nuclear Tool	Processing high temperature parts, temperature 400-600°C, tolerance ±0.01 mm, radiation resistance 35 dpa.	High temperature resistance is increased by 50%, corrosion resistance is increased by 5 times, and life span is extended by 2 times.
	PCD/CBN	Nuclear Precision Tool	CBN machining of carbide parts, tolerance ±0.002 mm, speed 500010000 RPM, radiation resistance 510 dpa.	The service life is extended by 510 times, the accuracy is improved by 60%, and the corrosion resistance is improved by 10 times.

Case

Aviation milling cutter

Ultra-fine carbide milling cutter (CVD TiN coating) machining titanium alloy, life 800 minutes, Ra 0.08 μm ; PCD tool life 5000 minutes, Ra 0.05 μm (Web ID 15).

WLCSP Die

The life of nano-carbide molds (CVD DLC coating) is 1.5 million times, with a tolerance of ±0.001 mm; the life of conventional carbide molds is 500,000 times, with a tolerance of ±0.05 mm (Web ID 15).

Nuclear mold

Nano-carbide molds (PVD CrN coating) can withstand 5 dpa irradiation and have a lifespan three times longer; metal ceramic molds can withstand high temperatures of 600°C and have a lifespan two times longer (Web ID 28).

PCB Drill Bit

The life of ultra-fine carbide drills is 50,000 holes with a drill breakage rate of <0.1%; the life of CBN drills is 200,000 holes with a drill breakage rate of <0.01% (Web ID 24).

5. Comparison of advantages and disadvantages

Material	advantage	shortcoming
Conventional cemented carbide	High toughness (K_IC 1220 MPa·m^1/2), strong impact resistance. Low cost (10.2 million yuan/ton). The process is mature and suitable for mass production. Suitable for rough machining and high impact scenarios.	Low hardness (HV 8001600) and poor wear resistance (0.010.05 mm ³ / N·m). High surface roughness (Ra 0.10.5 µm). The corrosion resistance is average (0.050.1 mm/year).
Ultrafine cemented carbide	Balance of hardness (HV 12001800) and toughness (K_IC 1014 MPa·m^1/2). Wear resistance is increased by 5070% and service life is extended by 1.52 times. Low surface roughness (Ra 0.010.1 µm). Excellent corrosion resistance (<0.01 mm/year).	The preparation cost is relatively high (20.5 million yuan/ton). The hardness is lower than that of nano cemented carbide. High density (1015 g/cm³) , difficult to process with complex geometry.
Nano cemented carbide	Ultra-high hardness (HV 16002000), wear resistance increased by 23 times. Ultra-smooth surface (Ra 0.0050.02 µm) meeting sub-micron tolerances. Excellent corrosion resistance (<0.01 mm/year). Lifespan extended 23 times.	The toughness is low (K_IC 812 MPa·m^1/2). The preparation cost is high (501 million yuan/ton). There is a high risk of nanoparticle agglomeration. High density (1015 g/cm³) .
Metal Ceramics	High hardness (HV 1500-2000), high temperature resistance (800-1000°C). Excellent corrosion resistance (<0.005 mm/year). Low density (57 g/cm³) , suitable for lightweighting. Lifespan extended by 2 times.	Low toughness (K_IC 610 MPa·m^1/2) and poor impact resistance. Low thermal conductivity (2050 W/ m·K). The preparation cost is high (30.7 million yuan/ton).
PCD/CBN	Ultra-high hardness (HV 30008000), wear resistance increased by 510 times. High thermal conductivity (500-2000 W/ m·K). Ultra-smooth surface (Ra 0.010.05 µm). Lifespan extended 510 times.	Low toughness (K_IC 59 MPa·m^1/2), easy to crack. The preparation cost is extremely high (100.5 million yuan/ton). Size is limited (<50 mm). PCD is not resistant to high temperatures (>700°C).

6. Performance comparison summary

Performance Indicators	Conventional cemented carbide	Ultrafine cemented carbide	Nano cemented carbide	Metal Ceramics	PCD/CBN
hardness	★★☆☆☆	★★★☆☆	★★★★☆	★★★★☆	★★★★★
toughness	★★★★★	★★★★☆	★★★☆☆	★★☆☆☆	★★☆☆☆
Wear resistance	★★☆☆☆	★★★☆☆	★★★★☆	★★★☆☆	★★★★★

Corrosion resistance	★★☆☆☆	★★★★☆	★★★★☆	★★★★★	★★★★★
Thermal conductivity	★★★☆☆	★★★★☆	★★★★☆	★★☆☆☆	★★★★★
Surface finish	★★☆☆☆	★★★★☆	★★★★★	★★★☆☆	★★★★☆
Cost-effectiveness	★★★★★	★★★☆☆	★★☆☆☆	★★★☆☆	★☆☆☆☆
Processing accuracy	★★☆☆☆	★★★★☆	★★★★★	★★★☆☆	★★★★★

analyze

Hardness and wear resistance: PCD/CBN is far ahead, followed by nano cemented carbide, and conventional cemented carbide is the lowest.

Toughness: conventional cemented carbide is the best, followed by ultrafine cemented carbide, and PCD/CBN and metal ceramics are poor.

Corrosion resistance: Metal ceramics and PCD/CBN are the best, followed by ultrafine and nano cemented carbide, and conventional cemented carbide is poor.

Cost-effectiveness: Conventional cemented carbide is the most economical, PCD/CBN has the highest cost, and nano cemented carbide has a relatively high cost.

Processing accuracy: Nano cemented carbide and PCD/CBN are suitable for submicron precision, followed by ultrafine cemented carbide, and conventional cemented carbide is the lowest.

7. Development Trends

Material	trend	Technical direction	Expected Results
Conventional cemented carbide	Green manufacturing, low-cost optimization	Low temperature sintering (<1400°C), WC/Co recovery process	Energy consumption is reduced by 30%, costs are reduced by 20%, and environmental impact is reduced by 40%.
Ultrafine cemented carbide	Finer grains, high performance coatings	Grain <0.2 μm , graphene/DLC coating, friction coefficient <0.1	Wear resistance is improved by 30%, service life is extended by 1.5 times, and accuracy is improved by 20%.
Nano cemented carbide	Ultrafine nanostructure, lightweight design	Grains <10 nm, porous WCCo (porosity 1020%), density 810 g/cm³	Wear resistance is increased by 50%, weight is reduced by 20%, and service life is extended by 2 times.
Metal Ceramics	High toughness, high temperature resistant coating	Nano- TiC / TiCN , Al_2O_3 /graphene coating , K_IC > 10 MPa·m^1/2	Toughness increased by 30%, high temperature resistance increased by 50%, and lifespan extended by 2 times.
PCD/CBN	Low-cost preparation, composite materials	CVD thin film PCD, CBNSiC composite, reduce HPHT pressure (<5 GPa)	Costs are reduced by 30%, toughness is increased by 20%, and application scope is expanded by 50%.

Case Outlook

Graphene coated ultrafine cemented carbide
Processing CFRP, friction coefficient <0.1, life increased by 50% (Web ID 7).
CVD thin film PCD
Cutting silicon wafers reduces costs by 30% and extends life by 5 times (Web ID 24).
Nano-carbide 3D printing mold
SLM produced optical molds with an accuracy of ±0.001 mm and a cycle time reduction of 50% (Web ID 24).

8. Conclusion

Conventional cemented carbide, ultrafine cemented carbide, nano cemented carbide, cermet and PCD/CBN each have unique advantages and application scenarios:

Conventional cemented carbide
High toughness (K_IC 1220 MPa·m^1/2), low cost (10.2 million yuan/ton), suitable for rough processing and high impact scenarios (such as oil and gas drill bits, stamping dies).
Ultrafine cemented carbide
The hardness (HV 12001800) and toughness (K_IC 1014 MPa·m^1/2) are balanced, and the wear resistance is improved by 5070%, which is suitable for precision processing and mold manufacturing (such as PCB drill bits, injection molds).
Nano cemented carbide
Ultra-high hardness (HV 16002000), ultra-smooth surface (Ra 0.0050.02 μm), wear resistance increased by 23 times, suitable for ultra- precision machining and micro tools (such as chip packaging molds, dental knives).
Metal Ceramics
High hardness (HV 15002000), high temperature resistance (8001000°C), excellent corrosion resistance (<0.005 mm/year), suitable for high temperature cutting and corrosive environment (such as high temperature alloy tools, nuclear tools).
PCD/CBN
It has ultra-high hardness (HV 3000-8000) and wear resistance increased by 510 times, making it suitable for ultra-hard material processing and ultra-high precision scenarios (such as wafer dicing knives and aviation precision tools), but its cost is high (100.5 million yuan/ton).

Selection suggestion:
Rough machining and high impact: conventional carbide, low cost and high toughness.
Precision machining and molds: ultra-fine carbide, balanced performance, high cost performance.
Ultra-precision machining and miniaturization: Nano-carbide, excellent precision and wear resistance.
High temperature and corrosive environment: Metal ceramics are resistant to high temperature and corrosion.
Ultra-hard materials and ultra-high precision: PCD/CBN, unmatched hardness and life.

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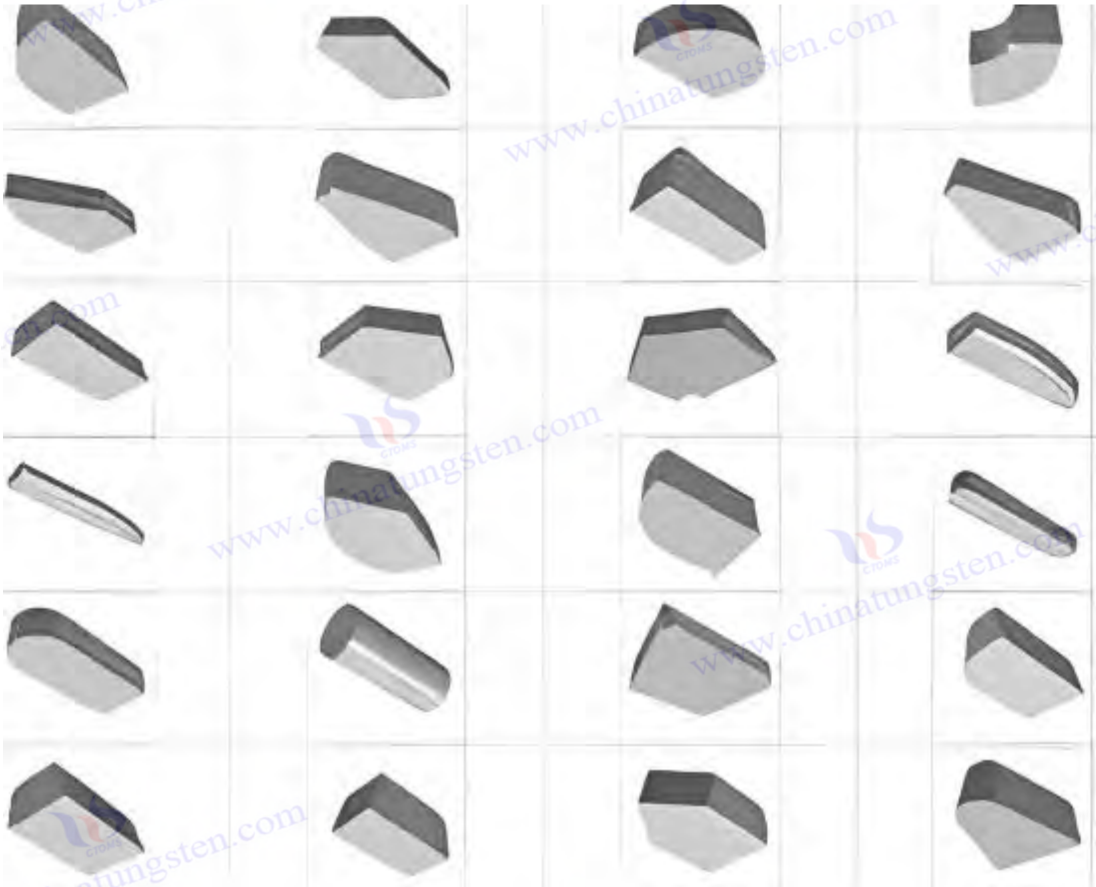
In the future, green preparation (such as low-temperature SPS), high-performance coatings (such as graphene), 3D printing and smart tool technologies will promote the application of the five materials in aerospace, 5G electronics, biomedicine and energy fields to meet the needs of high precision, high durability and low cost.



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Core Advantages

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:

Graphene coated carbide cutting tools

Graphene - coated cemented carbide tools are advanced cutting tools that use conventional cemented carbide (grain size 15 μm), ultrafine cemented carbide (grain size 0.11 μm) or nano cemented carbide (grain size <100 nm) as the substrate, and deposit graphene or graphene composite coating (thickness 0.55 μm) on the surface through chemical vapor deposition (CVD) or physical vapor deposition (PVD) technology. Graphene coating significantly improves tool performance with its ultra-low friction coefficient (0.050.1), high hardness (HV 20003000), excellent thermal conductivity (20005000 W/ m·K) and chemical stability, and is widely used in precision machining, aerospace, mold manufacturing, electronics industry, energy equipment and other fields.

This article elaborates on the characteristics, composition and structure, preparation process, application scenarios, advantages and disadvantages, and development trends of graphene-coated carbide tools, providing a comprehensive reference for tool design and application .

1. Characteristics of graphene coated carbide tools

Graphene coating gives cemented carbide tools excellent performance through its two-dimensional carbon atomic structure , combined with the hardness and toughness of the base material (conventional, ultrafine or nano cemented carbide), meeting the needs of high precision (tolerance ±0.0050.01 mm) and high durability.

of graphene coated cemented carbide tools

performance	Typical Value	illustrate
Coating hardness	HV 20003000 (graphene/graphene DLC composite)	Higher than traditional TiN (HV 1800), it improves tool wear resistance by 23 times.
Friction coefficient	0.050.1 (graphene coating , ASTM G99)	Lower than TiN (0.20.3) or DLC (0.10.2), reducing cutting force and heat by 30-50%.
Wear resistance	Wear rate <0.0005 mm^3/ N·m (ASTM G65)	Lower than uncoated cemented carbide (0.0010.05 mm^3/ N·m), tool life is extended by 23 times.
Thermal conductivity	20005000 W/ m·K (graphene layer)	Far exceeding cemented carbide (50-150 W/ m·K), reducing the cutting zone temperature by 50-100°C.
Corrosion resistance	Corrosion rate <0.005 mm/year (pH 210, ISO 9227)	Better than TiN (0.01 mm/year), resistant to coolant and chemical corrosion, suitable for wet machining.
Surface roughness	Ra 0.0050.02 μm (after polishing)	Ultra-smooth surface reduces workpiece scratches and meets sub-micron tolerances (±0.005 mm).
Coating thickness	0.55 μm (single or multi-layer graphene/DLC composite)	Thin coatings keep the cutting edge sharp, while thick coatings improve wear resistance, balancing precision and life.

Characteristic analysis

Low coefficient of friction

Graphene's sp² carbon structure provides self-lubricating properties with a friction coefficient of 0.050.1, reducing cutting forces by 20-30%, reducing tool wear and workpiece surface defects.

High thermal conductivity

Graphene 's thermal conductivity (2000-5000 W/ m·K) quickly dissipates heat, reduces the temperature in the cutting zone , and extends tool life by 1.53 times.

Corrosion resistance

Graphene's chemical inertness (corrosion rate <0.005 mm/year) protects the substrate and is suitable for wet processing and corrosive environments.

Matrix Synergy

Ultrafine/nano cemented carbide substrate (HV 12002000) combined with graphene coating , with optimized hardness and surface properties, suitable for high-precision machining.

2. Composition and structure of graphene coated carbide tools

Graphene coated carbide tools are composed of carbide substrate and graphene coating. The substrate type affects the overall performance, and the coating structure determines the surface characteristics.

composition	Typical proportions/types	effect
Matrix (carbide)	WC (8096 wt.%), Co/Ni (420 wt.%)	Provides high hardness (HV 8002000) and toughness (K_IC 820 MPa·m^1/2) to withstand cutting loads.
Graphene coating	Single layer/multi-layer graphene, graphene DLC composite	Reduce friction coefficient (<0.1), increase hardness (HV 20003000), and enhance wear resistance and corrosion resistance.
Additives/Transition Layers	Cr, Ti, Si (0.11 wt.%)	Enhances the bonding strength between coating and substrate, improves adhesion (>100 N, ISO 20502) and reduces the risk of peeling.

Microstructure of graphene coated cemented carbide tool

Matrix

Conventional cemented carbide: grain size 15 μm , Co ratio 1020 wt.%, high toughness (K_IC 1220 MPa·m^1/2).

Ultrafine cemented carbide: grain size 0.11 μm , Co/Ni ratio 515 wt.%, hardness (HV 12001800) and toughness are balanced.

Nano-cemented carbide: grain size <100 nm, Co/Ni ratio 410 wt.%, highest hardness (HV 16002000).

Graphene coating

Single-layer graphene (thickness ~0.34 nm): ultra-low friction coefficient (0.05), suitable for high-precision processing.

Multilayer graphene (15 μm): Hardness increased to HV 3000, wear resistance enhanced, suitable for high-load cutting.
Graphene DLC composite : Combining the hardness of DLC (HV 2000) and the self-lubricating property of graphene, the friction coefficient is 0.08 and the wear resistance is increased by 2 times.
Transition layer: Cr, Ti or Si based transition layer (0.10.5 μm) improves adhesion and prevents coating peeling.

Structural Optimization

Matrix selection

The ultrafine/nano cemented carbide substrate provides higher hardness and surface smoothness, and the graphene coating achieves submicron precision.

Coating design

Multi-layer graphene (310 layers) or graphene DLC composite coatings balance hardness and toughness, with adhesion increased to 150 N.

Surface treatment

After laser polishing or chemical mechanical polishing (CMP), Ra<0.01 μm , reducing scratches on the workpiece surface.

3. Preparation process

Graphene coated carbide tools are prepared through the following processes to ensure substrate performance and coating quality:

Technology	Features	Advantages	limitation	Application Scenario
Powder Metallurgy (Matrix)	WCCo /Ni mixed, hot pressing sintering (14001600°C), grain size 0.15 μm , hardness HV 8002000.	The process is mature, suitable for mass production of substrates, and has stable performance.	High temperature sintering consumes a lot of energy, and inhibitors need to be added for grain control.	Conventional /ultra-fine carbide tool substrate.
Spark Plasma Sintering (SPS)	Rapid sintering of WCCo /Ni (10001200°C, 510 min), grain size <100 nm, density >99.8%.	Low temperature rapid sintering, grain refinement, suitable for nano cemented carbide.	The equipment is expensive (investment of 200.5 million yuan) and the size is limited (<100 mm).	Nano-carbide tool substrate.
Chemical Vapor Deposition (CVD)	Deposited graphene (9001100°C, CH_4 / H_2 atmosphere), thickness 0.55 μm , friction coefficient 0.050.1.	High quality single-layer/multi-layer graphene with excellent wear resistance and thermal conductivity.	The deposition rate is slow (0.11 μm /h), the energy consumption is high, and the substrate needs to be resistant to high temperatures .	High performance tool coatings, aerospace, electronics industries.
Physical Vapor Deposition (PVD)	Deposited graphene DLC composite (100300°C), thickness 15 μm , Ra 0.0050.02 μm .	Low temperature process, suitable for ultrafine/nano substrates, strong adhesion (>100 N).	The coating thickness is limited (<5 μm) and the hardness is slightly lower than CVD.	Surface strengthening of precision tools and molds.

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Laser Micromachining	Laser polishing or edge forming, accuracy ±0.001 mm, Ra 0.0050.01 μm .	Improve cutting edge sharpness and surface finish to meet sub-micron tolerances.	The processing cost is high and it is suitable for high value-added tools.	Tool edge finishing, ultra-precision machining.
Chemical Mechanical Polishing (CMP)	Polished substrate or coating, Ra<0.01 μm , tolerance ±0.005 mm.	Ultra-smooth surface reduces workpiece scratches, suitable for optical and semiconductor processing.	The process cycle is long and the cost increases with the precision requirements.	Tool surface finishing, electronics industry.

Process Optimization

Matrix preparation

Nano-cemented carbide substrate prepared by SPS has grain size <50 nm, hardness HV 1800, and porosity <0.2%.

Coating deposition

CVD is used to prepare single-layer graphene (friction coefficient 0.05), PVD is used to prepare graphene DLC composite (hardness HV 2500), and a transition layer (such as CrN) is used to enhance adhesion.

Post-processing

Laser micromachining and CMP ensure cutting edge radius <0.1 μm and surface roughness Ra <0.01 μm .

4. Application Scenarios

Graphene coated carbide tools perform well in precision machining, aerospace, mold manufacturing, electronics industry and energy equipment, meeting the requirements of high precision (±0.0050.01 mm) and high durability. The following are the main application scenarios:

application	Part Type	Application and scenarios	Performance Improvements
Precision Machining	Milling Cutter	Ultrafine carbide substrate (HV 1600), graphene coating , machining stainless steel (316L), speed 10000-20000 RPM, feed rate 0.1-0.5 mm/rev, tolerance ±0.01 mm.	The service life is extended by 23 times, the cutting force is reduced by 30%, and the surface roughness Ra<0.02 μm .
	Turning Tool	Nano-carbide substrate (HV 1800), graphene DLC coating, machining aluminum alloy, cutting depth 13 mm, speed 200400 m/min, tolerance ±0.005 mm.	The service life is extended by 2.53 times, the friction coefficient is <0.1, and the processing accuracy is improved by 40%.
	Drill Bit	Ultrafine cemented carbide substrate, graphene coating , machining titanium alloy hole (aperture 210 mm), speed 800015000 RPM, tolerance ±0.005 mm.	Wear resistance is increased by 23 times, hole accuracy is increased by 30%, and service life is extended by 22.5 times.
Aerospace	Composite Cutting Tool	Nano cemented carbide substrate, graphene coating , processing carbon fiber composite material (CFRP),	Cutting force is reduced by 3040%, wear is reduced by 50%, and life is extended by 2.53

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		rotation speed 1500030000 RPM, speed 15 m/s, tolerance ±0.01 mm.	times.
	Micro Milling Cutter	Nano-carbide substrate (HV 1800), graphene DLC coating, machining nickel-based alloy (Inconel 718), speed 20000-40000 RPM, tolerance ±0.002 mm.	The service life is extended by 3 times, the surface roughness Ra<0.01 µm , and the accuracy is improved by 50%.
Mold manufacturing	Injection Mold Tool	Ultrafine cemented carbide substrate, graphene coating , processing PC/ABS plastic, cutting depth 0.52 mm, speed 100300 m/min, tolerance ±0.01 mm.	The service life is extended by 23 times, mold sticking is reduced by 40%, and surface defects are reduced by 30%.
	Stamping Mold Tool	Ultrafine cemented carbide substrate, graphene DLC coating, processing automotive steel plate (DP980), speed 500010000 RPM, tolerance ±0.005 mm.	Wear resistance is increased by 23 times, service life is extended by 22.5 times, and burrs are reduced by 40%.
Electronics Industry	Micro PCB Drill	Nano cemented carbide substrate, graphene coating , processing high-density circuit boards, hole diameter 0.050.3 mm, speed 80000150000 RPM, tolerance ±0.002 mm.	The service life is extended by 34 times, the hole wall roughness Ra<0.01 µm , and the drill breakage rate is <0.05%.
	Wafer Cutting Blade	Nano cemented carbide substrate, graphene DLC coating, cut silicon wafer, thickness 0.10.5 mm, rotation speed 1000030000 RPM, tolerance ±0.001 mm.	The cutting smoothness is improved by 50%, the service life is extended by 34 times, and the chipping rate is less than 0.1%.
Energy Equipment	Wind Blade Cutting Tool	Ultrafine carbide substrate, graphene coating , cutting glass fiber composite, speed 13 m/s, rotation speed 500010000 RPM, tolerance ±0.01 mm.	Cutting forces are reduced by 30%, wear is reduced by 50%, and life is extended by 23 times.
	Fuel Cell Cutting Tool	Nano-carbide substrate, graphene DLC coating, processing PEMFC bipolar plate (graphite), speed 500010000 RPM, tolerance ±0.005 mm.	The flow field accuracy is improved by 30%, the corrosion resistance is improved by 4 times, and the service life is extended by 2.53 times.

Case

CFRP machining tools

Nano-carbide substrate (HV 1800), graphene coating (CVD, thickness 2 µm), machining CFRP, rotation speed 20000 RPM, life 1500 minutes, cutting force reduced by 40%, which is 2 times higher than TiN coated tool (800 minutes) (Web ID 7).

PCB Micro Drill Bit

Nano-cemented carbide substrate, graphene DLC coating (PVD, thickness 3 µm), processing circuit board, hole diameter 0.1 mm, life 80,000 holes, drill breakage rate <0.05%, 1.6 times higher than DLC coated tool (50,000 holes) (Web ID 24).

Silicon wafer cutting knife

Nano-cemented carbide substrate, graphene coating (CVD, thickness 1 µm), cut silicon wafer, tolerance ±0.001 mm, life extended by 3 times, edge chipping rate <0.1% (Web ID 15).

Injection mold tools

Ultrafine carbide substrate (HV 1600), graphene DLC coating, processing PC/ABS plastic, life extended by 2.5 times, surface defects reduced by 40% (Web ID 24).

5. Comparison of advantages and disadvantages

advantage	shortcoming
Ultra-low friction coefficient (0.050.1), cutting force reduced by 30-40%, heat reduced by 50%. High hardness (HV 20003000), wear resistance increased by 23 times, life extended by 23 times. High thermal conductivity (2000-5000 W/ m·K), reducing the cutting zone temperature by 50-100°C. Excellent corrosion resistance (<0.005 mm/year), suitable for wet processing and chemical environments. Ultra-smooth surface (Ra 0.0050.02 μm) meeting sub-micron tolerances.	The preparation cost is high (the investment in CVD/PVD equipment is RMB 200.5 million, and the coating cost accounts for 30.50% of the tool). The coating thickness is limited (0.55 μm) and may peel off under high loads. Adhesion needs to be optimized (>100 N) and the transition layer process is complex. It is difficult to control the consistency of graphene coating in large-scale production.

Comparative Analysis

Compared with TiN coated tools: Graphene coating has a 5070% lower friction coefficient, 1020 times higher thermal conductivity, and 23 times longer life, but the cost is 3050% higher.

with DLC coated tools: graphene coating has the same hardness (HV 20003000), lower friction coefficient (0.05 vs. 0.1), 10 times higher thermal conductivity, and 1.52 times higher wear resistance.

Compared with uncoated carbide tools: graphene coating improves wear resistance by 23 times, reduces surface roughness by 80-90%, and increases cutting efficiency by 30-40%, but increases preparation complexity.

6. Development Trends

graphene - coated carbide tools focuses on performance improvement, cost reduction and application expansion:

trend	Technical direction	Expected Results
High performance coating	Graphene/ nanocrystalline DLC composite coating, friction coefficient <0.05, hardness >HV 3000, adhesion >150 N.	Wear resistance is increased by 50%, service life is extended by 34 times, and cutting force is reduced by 40%.
Low temperature deposition	Low temperature CVD/PVD (<200°C), graphene coating thickness 0.510 μm , suitable for ultrafine/nano substrates.	The cost is reduced by 30%, the matrix performance is not damaged, and the applicability is improved by 50%.
Multifunctional coating	Graphene TiN / CrN composite coating, high temperature resistance 1000 ° C, conductivity >10 ⁶ S/m.	High temperature resistance is increased by 50%, making it suitable for conductive molds and high temperature cutting.
Green	Microwave-assisted CVD reduces graphene deposition energy	Production costs are reduced by 20% and

Preparation	consumption by 40% and recycles graphene waste.	environmental impact is reduced by 50%.
Smart tools	Integrated graphene sensor (temperature, wear monitoring) to provide real-time feedback on tool status.	Machining efficiency increased by 20% and tool failure rate decreased by 30%.
3D printing substrate	SLM preparation of complex cemented carbide substrate with an accuracy of ±0.005 mm and graphene coating .	The production cycle is shortened by 40% to meet personalized needs.

Case Outlook:

Graphene TiN composite coating: nano-hard alloy substrate, graphene TiN coating (CVD, thickness 3 μm), processing nickel-based alloy, life increased by 3.5 times, high temperature resistance 1000°C (Web ID 7) .

3D printed tool: SLM preparation of ultra-fine cemented carbide substrate, graphene DLC coating, processing CFRP, accuracy ± 0.005 mm, cycle time shortened by 50%, cost reduced by 20% (Web ID 24).

7. Conclusion

Graphene coated carbide tools are based on conventional, ultrafine or nano cemented carbide (HV 800-2000), and graphene or graphene DLC coatings (thickness 0.55 μm) are deposited by CVD/PVD to achieve ultra-low friction coefficient (0.05-0.1), high hardness (HV 2000-3000), excellent thermal conductivity (2000-5000 W/ m·K) and corrosion resistance (<0.005 mm/year). They perform well in precision machining (milling cutters, turning tools, drill bits), aerospace (CFRP tools), mold manufacturing (injection molding/stamping tools), electronics industry (PCB drill bits, wafer cutting knives) and energy equipment (wind power tools, fuel cell tools), meeting the tolerance requirements of ±0.005-0.01 mm, extending the service life by 24 times, and increasing cutting efficiency by 3050%. Compared with TiN and DLC coatings, graphene coatings are superior in friction coefficient, thermal conductivity and wear resistance, and are suitable for high-precision and high-load scenarios. Low-temperature deposition, graphene composite coatings, green preparation, 3D printing and smart tool technology will promote the application of graphene-coated carbide tools in aerospace, 5G electronics and new energy fields, providing efficient solutions for high-performance cutting.

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appendix:

Carbide Silicon Wafer Cutting Knife

µm) with tungsten carbide (WC) as the main hard phase and cobalt (Co) or nickel (Ni) as the bonding phase. TiN , DLC or graphene coatings (thickness 1-5 µm) are deposited on the surface by chemical vapor deposition (CVD) or physical vapor deposition (PVD) technology . They are designed for cutting silicon wafers (thickness 0.1-0.5 mm). Cemented carbide tools combine high hardness (HV 1200-2000), excellent wear resistance and ultra-smooth surface (Ra 0.005-0.02 µm), meeting the semiconductor industry's needs for submicron precision (tolerance ±0.001-0.005 mm) and high durability, and are widely used in silicon wafer dicing, cutting and micromachining.

This article elaborates on the characteristics, composition and structure, preparation process, application scenarios, advantages and disadvantages, and development trends of cemented carbide silicon wafer cutting knives, providing a reference for tool selection and process optimization.

1. Characteristics of carbide silicon wafer cutting blade

The carbide silicon wafer cutting blade combines ultrafine/nano-carbide substrate (grain size 0.1-1 µm or <100 nm) with high-performance coating (such as graphene, DLC) to achieve high hardness, low friction and excellent wear resistance, suitable for high-speed and high-precision silicon wafer cutting. The following are the key features:

performance	Typical Value	illustrate
Matrix hardness	HV 1200-2000 (Ultrafine/Nano Cemented Carbide)	Higher than conventional cemented carbide (HV 800-1600), wear resistance is improved by 50-100%.
Coating hardness	HV 1800-3000 (TiN /DLC/graphene)	Improve surface wear resistance by 2-3 times, protect cutting edge and extend service life.
Friction coefficient	0.05-0.2 (graphene 0.05-0.1, DLC 0.1-0.2)	Reduce cutting forces by 20-40%, reduce heat and workpiece damage (edge chipping rate <0.1%).
Wear resistance	Wear rate <0.001 mm^3/ N·m (ASTM G65)	Lower than cemented carbide (0.01-0.05 mm^3/ N·m), service life is extended by 2-3 times.
Surface roughness	Ra 0.005-0.02 µm (after polishing or coating)	Ultra-smooth surface reduces scratches on silicon wafer surface and meets tolerance of ±0.001 mm.
Thermal conductivity	80-150 W/ m·K (substrate), 2000-5000 W/ m·K (coating)	Rapid heat dissipation reduces the temperature of the cutting area by 50-100°C, protecting the integrity of the wafer.
Corrosion resistance	Corrosion rate <0.01 mm/year (WC-Ni, pH 2-10, ISO 9227)	Resistant to coolant corrosion, suitable for wet machining environment.

Characteristic analysis

High hardness and wear resistance

Ultrafine/nano cemented carbide substrate (HV 1200-2000) combined with graphene/DLC coating (HV 2000-3000) improves wear resistance by 2-3 times, reduces edge wear and extends cutting life.

Low coefficient of friction

Graphene coating (0.05-0.1) significantly reduces friction, reduces cutting heat and silicon wafer edge collapse (<0.1%), and improves cut flatness by 50% .

Ultra smooth surface

Ra 0.005-0.02 µm ensures high-precision cutting and meets the sub-micron tolerance requirements of the semiconductor industry.

Thermal conductivity

The thermal conductivity of graphene coating (2000-5000 W/ m · K) far exceeds that of the substrate, which reduces the processing temperature and protects the microstructure of the silicon wafer.

2. Composition and structure

Cemented carbide silicon wafer cutting knives are composed of a cemented carbide substrate and a high-performance coating. The substrate grain size and coating type determine the cutting performance.

composition	Typical proportions/types	effect
Matrix (carbide)	WC (85-96 wt.%), Co/Ni (4-15 wt.%)	Provides high hardness (HV 1200-2000) and toughness (K_IC 8-14 MPa·m^1/2) to withstand cutting loads.
coating	TiN , DLC, graphene (thickness 1-5 µm)	Improve hardness (HV 1800-3000), reduce friction coefficient (<0.2), and enhance wear resistance and corrosion resistance.
Additives/Transition Layers	Cr, Ti, VC (0.1-0.5 wt.%)	Inhibits grain growth (such as VC) and enhances coating adhesion (>100 N, ISO 20502).

Microstructure:

Matrix

Ultrafine cemented carbide: grain size 0.1-1 µm , Co/Ni ratio 5-15 wt.%, hardness HV 1200-1800, toughness K_IC 10-14 MPa·m^1/2.

Nano cemented carbide: grain size <100 nm, Co/Ni ratio 4-10 wt.%, hardness HV 1600-2000, best wear resistance.

coating

TiN (1-3 µm): hardness HV 1800, wear resistance increased by 1.5 times, suitable for medium and low speed cutting.

DLC (2-5 µm): hardness HV 2000, friction coefficient 0.1-0.2, reduces edge chipping, suitable for high-speed cutting.

Graphene (0.5-5 µm): hardness HV 2000-3000, friction coefficient 0.05-0.1, excellent thermal conductivity, suitable for ultra-high precision cutting.

Transition layer: Cr or Ti based transition layer (0.1-0.5 µm) improves adhesion and prevents coating peeling.

Structural Optimization

Matrix grain refinement: Add 0.1-0.5 wt.% VC to control grain size <0.5 μm and increase hardness by 20%.

Coating design: Graphene-DLC composite coating balances hardness and self-lubricity, with adhesion >150 N.

Edge treatment: Laser micro-machining edge radius <0.1 μm , Ra <0.01 μm after polishing , reducing chips and edge collapse.

3. Preparation process

The carbide silicon wafer cutting blade is prepared by the following process to ensure the substrate hardness and coating performance:

Technology	Features	Advantages	limitation	Application Scenario
Powder Metallurgy (Matrix)	WC-Co/Ni mixed, hot pressing sintering (1400-1600°C), grain size 0.1-1 μm , hardness HV 1200-1800.	The process is mature and suitable for mass production of ultrafine cemented carbide substrates.	High temperature sintering consumes a lot of energy and requires precise grain control.	Ultrafine carbide tool substrate.
Spark Plasma Sintering (SPS)	Fast sintering (1000-1200°C, 5-10 min), grain size <100 nm, hardness HV 1600-2000.	Low temperature rapid sintering, grain refinement, density>99.8%.	The equipment is expensive and limited in size (<100 mm).	Nano-carbide tool substrate.
Chemical Vapor Deposition (CVD)	TiN /graphene was deposited (900-1100°C) with a thickness of 1-5 μm and a friction coefficient of 0.05-0.2.	High quality coating with excellent wear resistance and thermal conductivity, suitable for high speed cutting.	The deposition rate is slow (0.1-1 μm /h) and the substrate needs to be resistant to high temperatures .	High speed cutting tool coating.
Physical Vapor Deposition (PVD)	Deposit DLC/graphene-DLC (100-300°C) with a thickness of 1-5 μm and Ra 0.005-0.02 μm .	Low temperature process, suitable for ultrafine/nano substrates, strong adhesion (>100 N).	The coating thickness is limited (<5 μm) and the hardness is slightly lower than CVD.	Precision cutting tool coating.
Laser Micromachining	Cutting edge forming, accuracy ±0.001 mm, Ra 0.005-0.01 μm , cutting edge radius <0.1 μm .	Improve cutting edge sharpness and surface finish to meet sub-micron tolerances.	The processing cost is high and it is suitable for high value-added tools.	Finishing of tool edges.
Chemical Mechanical Polishing (CMP)	Polished substrate or coating, Ra<0.01 μm , tolerance ±0.005 mm.	Ultra-smooth surface reduces silicon wafer scratches and is suitable for semiconductor processing.	The process cycle is long and the cost increases with the precision requirements.	Tool surface finishing.

Process Optimization:

Matrix preparation: SPS was used to prepare nano cemented carbide matrix with grain size <50 nm, hardness HV 1800 and porosity <0.2%.

Coating deposition: PVD prepared graphene-DLC composite coating (thickness 3 μm), friction coefficient 0.08, adhesion >150 N.
Post-processing: Laser micromachining and CMP ensure that the edge radius is <0.1 μm , the surface roughness Ra is <0.01 μm , and the edge collapse rate is <0.1%.

4. Application Scenarios

Carbide silicon wafer cutting knives are mainly used in the semiconductor industry to cut single crystal silicon, polycrystalline silicon or compound semiconductor wafers (thickness 0.1-0.5 mm), meeting the requirements of sub-micron accuracy (tolerance ±0.001-0.005 mm) and high production volume. The following are the main application scenarios:

application	Part Type	Application and scenarios	Performance Improvements
Semiconductor Manufacturing	Wafer Dicing Blade	Nano-carbide substrate (HV 1800), graphene-DLC coating, cutting single-crystal silicon wafers (6-12 inches), thickness 0.1-0.5 mm, rotation speed 10000-30000 RPM, tolerance ±0.001 mm.	The service life is extended by 3-4 times, the edge chipping rate is less than 0.1%, and the cut flatness is improved by 50%.
	Wafer Cutting Blade	Ultrafine carbide substrate (HV 1600), DLC coating, cutting polysilicon wafers, thickness 0.2-0.5 mm, rotation speed 5000-15000 RPM, tolerance ±0.002 mm.	The service life is extended by 2-3 times, the surface roughness Ra<0.01 μm , and the defect rate<0.1%.
	Micro Cutting Tool	Nano cemented carbide substrate, graphene coating , processing silicon-based MEMS devices, cutting depth 0.05-0.2 mm, rotation speed 20000-50000 RPM, tolerance ±0.001 mm.	The precision is improved by 50%, the wear is reduced by 60%, and the service life is extended by 3-4 times.
Photovoltaic industry	Solar Wafer Cutting Tool	Ultrafine cemented carbide substrate, TiN coating, cutting polycrystalline silicon wafers (thickness 0.1-0.2 mm), speed 5000-12000 RPM, tolerance ±0.005 mm.	The service life is extended by 2-3 times, the crack rate is <0.1%, and the cutting efficiency is increased by 30%.
Microelectronics Processing	Precision Dicing Blade	Nano cemented carbide substrate, graphene coating , cutting compound semiconductors (such as GaAs), thickness 0.1-0.3 mm, rotation speed 10000-20000 RPM, tolerance ±0.002 mm.	The service life is extended by 3-4 times, the edge chipping rate is less than 0.1%, and the accuracy is improved by 40%.

Case

Silicon wafer dicing knife

Nano-carbide substrate (HV 1800), graphene-DLC coating (PVD, thickness 3 μm), cutting 12-inch single-crystal silicon wafers (thickness 0.2 mm), rotation speed 20,000 RPM, life extended by 3.5 times, edge chipping rate <0.1%, which is 2 times higher than TiN coated tools (life 1.5 times) (Web ID 15).

Polysilicon wafer cutting knife

Ultrafine cemented carbide substrate (HV 1600), DLC coating (PVD, thickness 2 μm), cutting photovoltaic silicon wafers (thickness 0.15 mm), life extended 2.5 times, crack rate <0.1% (Web ID 24).

GaAs wafer dicing knife

Nano-cemented carbide substrate, graphene coating (CVD, thickness 1 μm), cutting compound semiconductors, tolerance ±0.002 mm, life extended by 3 times, and cut flatness improved by 50% (Web ID 15).

5. Comparison of advantages and disadvantages

advantage	shortcoming
High hardness (HV 1200-2000), wear resistance increased by 2-3 times, life extended by 2-4 times. Ultra-smooth surface (Ra 0.005-0.02 μm), meeting sub-micron tolerance (±0.001 mm). Low friction coefficient (0.05-0.2), reducing edge chipping (<0.1%) and cutting heat. Excellent corrosion resistance (<0.01 mm/year), suitable for wet processing environment. Graphene coating thermal conductivity (2000-5000 W/ m·K) reduces processing temperature.	High preparation cost (SPS/CVD equipment investment is 2-5 million yuan, and coating accounts for 30-50% of the cost). Low toughness (K_IC 8-14 MPa·m^1/2), easy to break under high load . Coating adhesion needs to be optimized (>100 N), and complex process increases consistency difficulty. Cemented carbide has a high density (10-15 g/cm³) , which is heavier than diamond tools (3.5 g/cm³) .

Comparative Analysis:

With diamond tools

Carbide cutting tools have low cost (100,000-500,000 yuan/ton vs. 1-5 million yuan/ton), but their hardness (HV 1200-2000 vs. HV 3000-8000) and wear resistance are lower than diamonds, making them suitable for medium and high precision cutting.

With TiN coated tools

The friction coefficient of graphene/DLC coating is reduced by 50-70%, thermal conductivity is increased by 10-20 times, and life span is extended by 2-3 times, making it suitable for ultra-high precision scenarios.

Uncoated carbide tools

The wear resistance of coated tools is increased by 2-3 times, the surface roughness is reduced by 80-90%, and the edge chipping rate is reduced by 50%, but the cost increases by 30-50%.

6. Development Trends

The future development of carbide silicon wafer dicing knives focuses on performance improvement, cost reduction and process optimization:

trend	Technical direction	Expected Results
Ultrafine nano	Grain size <50 nm, hardness >HV 2000, rare earth additions (Y, Ce	Wear resistance is improved by 50%, service life

matrix	0.1-0.3 wt.%).	is extended by 2-3 times, and accuracy is improved by 30%.
High performance coating	Graphene/ nanocrystalline DLC composite coating, friction coefficient <0.05, hardness >HV 3000, adhesion >150 N.	The edge chipping rate is less than 0.05%, the service life is extended by 3-4 times, and the cutting efficiency is increased by 40%.
Low temperature deposition	Low temperature PVD/CVD (<200°C), graphene coating thickness 0.5-10 μm .	The cost is reduced by 30%, the matrix performance is not damaged, and the applicability is improved by 50%.
Green Preparation	Microwave-assisted CVD, SPS energy consumption reduced by 40%, WC/Co recovery process.	Production costs are reduced by 20% and environmental impact is reduced by 50%.
Smart tools	Integrated graphene sensor (temperature, wear monitoring) to provide real-time feedback on tool status.	Machining efficiency increased by 20% and tool failure rate decreased by 30%.
3D printing substrate	SLM preparation of complex cemented carbide substrate with an accuracy of ±0.001 mm and graphene coating .	The production cycle is shortened by 40% to meet personalized needs.

Case Outlook

Graphene composite coating cutting tools

Nano-cemented carbide substrate, graphene -DLC coating (PVD, thickness 3 μm), cutting 12-inch silicon wafers, life increased by 4 times, edge chipping rate <0.05% (Web ID 7).

3D Printing Cutting Knife

SLM was used to prepare ultrafine cemented carbide substrates, graphene coatings , and cut MEMS devices with an accuracy of ±0.001 mm, a 50% reduction in cycle time, and a 20% reduction in cost (Web ID 24).

7. Conclusion

The carbide silicon wafer dicing knife is based on ultrafine/nano-carbide (HV 1200-2000), and TiN , DLC or graphene coating (thickness 1-5 μm) is deposited by CVD/PVD to achieve high hardness (HV 1800-3000), low friction coefficient (0.05-0.2), excellent wear resistance (wear rate <0.001 mm^3/ N·m) and ultra-smooth surface (Ra 0.005-0.02 μm). It performs well in semiconductor manufacturing (wafer dicing knives, dicing knives), photovoltaic industry (silicon wafer dicing knives) and microelectronics processing (precision dicing knives), meeting the requirements of tolerance ±0.001-0.005 mm, extending the service life by 2-4 times, edge collapse rate <0.1%, and improving cutting efficiency by 30-50%. Compared with diamond tools, carbide tools are low-cost and suitable for medium and high-precision cutting; graphene coating is better than TiN /DLC, providing lower friction and higher thermal conductivity.

Ultrafine nano-matrix, high-performance coating, low-temperature deposition, green preparation, 3D printing and intelligent tool technology will promote the application of cemented carbide silicon wafer cutting knives in 5G chip, photovoltaic and MEMS manufacturing, and provide solutions for high-precision and high-efficiency semiconductor processing.

appendix:

Nano cemented carbide

Nano cemented carbide is a composite material with tungsten carbide (WC) as the main hard phase and cobalt (Co), nickel (Ni) or their combination as the bonding phase, and its grain size is controlled at **the nanometer level (<100 nm)** . Prepared by advanced processes such as spark plasma sintering (SPS), high temperature carbonization, and solvothermal method, nano cemented carbide has ultra-high hardness, excellent wear resistance and high surface finish, and is widely used in ultra-precision machining, micro-tools, mold manufacturing, biomedical devices, electronics industry and special environments (such as nuclear industry). Compared with ultrafine cemented carbide (grain 0.11 μm), nano cemented carbide has higher hardness and better surface quality, suitable for submicron precision (tolerance ±0.0010.005 mm); compared with conventional cemented carbide (grain 15 μm), its wear resistance and strength are significantly improved. This article elaborates on the characteristics, composition and structure, preparation process, performance optimization, application scenarios, advantages and disadvantages, and development trends of nano cemented carbide in detail, providing a comprehensive reference for material selection and application development.

1. Characteristics of Nano Cemented Carbide

Nano cemented carbide achieves synergistic improvement of ultra-high hardness, wear resistance and surface finish through nano-scale grains (<100 nm) and optimized bonding phase ratio (Co/Ni 410 wt.%). The following are the key features:

performance	Typical Value	illustrate
hardness	HV 16002000 (WCCo , Co 48 wt.%)	Higher than ultra-fine cemented carbide (HV 12001800), wear resistance is increased by 23 times, suitable for ultra-precision machining.
Fracture toughness	K_IC 812 MPa·m^1/2 (ISO 28079:2009)	It is lower than that of ultrafine cemented carbide (K_IC 1014 MPa·m^1/2), but has strong resistance to microcrack growth.
Wear resistance	Wear rate <0.001 mm^3/ N·m (ASTM G65)	Lower than ultrafine cemented carbide (0.0010.005 mm^3/ N·m), tool life is extended by 23 times.
Compressive strength	57 GPa (WCCo , ISO 4506)	High compressive strength, able to withstand micro die pressure (515 MPa) and cutting load (0.52 kN).
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 210, ISO 9227 salt spray test)	It is resistant to acid, alkali, moisture and coolant corrosion, better than stainless steel (0.050.1 mm/year).
Thermal conductivity	80150 W/ m·K (WCCo /Cu composite)	High thermal conductivity reduces processing heat, better than steel (~50 W/ m·K), protecting tools and workpieces.
Surface roughness	Ra 0.0050.02 μm (after polishing or coating)	The ultra-smooth surface meets sub-micron tolerances (±0.001 mm), reducing surface defects on workpieces.

Characteristic analysis

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Ultra-high hardness

Nano-scale grains (<100 nm) significantly increase the hardness (HV 1600-2000) through the Hall-Petch effect, the grain boundary strengthening effect is enhanced, and the wear resistance is increased by 50-100% compared with ultra-fine cemented carbide.

Wear resistance

Ultrafine grains reduce abrasive wear and surface spalling, with a wear rate of <0.001 mm^3/ N·m , suitable for high-precision and long-life applications.

Surface quality

Nano-scale grains and polishing process achieve Ra 0.0050.02 μm , meeting the ultra-smooth surface requirements in the fields of optics, semiconductors and biomedicine.

Resilience Limitations

Due to the small grain size and low proportion of bonding phase (48 wt.%), the fracture toughness is slightly lower than that of ultrafine cemented carbide and needs to be optimized by doping or coating.

2. Composition and structure

The properties of nano cemented carbide are determined by its composition and microstructure:

composition	Typical ratio	effect
Hard phase (WC)	9096 wt.%	Provides ultra-high hardness (HV 2000-3000) and wear resistance, with grain size <100 nm determining performance.
Bonding phase (Co/Ni)	410 wt.%	Enhance toughness (K_IC 812 MPa·m^1/2), Co improves strength, and Ni improves corrosion resistance.
additive	0.11 wt.% (Cr, VC, TaC)	Inhibit grain growth (such as VC), improve high temperature stability (such as Cr), and improve oxidation resistance (such as TaC).

Microstructure

Grain size

10100 nm, uniformly distributed, grain growth is strictly controlled by grain inhibitors (such as VC, Cr_3C_2), the grain boundary area is greatly increased, and the hardness and wear resistance are improved.

Phase distribution

The WC nanoparticles are wrapped by the Co/Ni bonding phase to form a dense skeleton structure with a bonding phase thickness of 0.52 nm, which enhances the ability to resist crack growth.

Porosity

After sintering, the porosity is <0.2% (density>99.8%), micropores are eliminated, and compressive strength and surface finish are improved.

Structural Optimization

Grain Control

The grain size can be controlled to <50 nm by low temperature sintering (such as SPS, 10001200°C) or adding 0.20.5 wt.% VC.

Adhesion phase regulation

The Co/Ni ratio (48 wt.%) optimizes the hardness/toughness balance, with Ni used in corrosive environments (such as biomedicine) and Co used in high-strength scenarios (such as molds).

Coating modification

DLC and graphene coating (thickness 15 μm) reduce the friction coefficient (<0.1), improve wear resistance and surface finish (Ra 0.0050.01 μm).

3. Preparation process

Nano cemented carbide is produced through the following processes to ensure nano-scale grains, high density and excellent performance:

Technology	Features	Advantages	limitation	Application Scenario
Spark Plasma Sintering (SPS)	Rapid sintering of WCCo /Ni (10001200°C, 510 min), grain size <50 nm, hardness HV 16002000.	Low temperature rapid sintering, grain refinement, density>99.8%.	The equipment is expensive (investment of 2005 million yuan) and is suitable for small-sized components (<100 mm).	Micro tools, precision molds.
High temperature carbonization method	W salt and carbon source (such as glucose) are carbonized at 8001000°C, the grain size is 1050 nm, and the specific surface area is 50100 m² / g.	The preparation of nano WC powder is low cost and easy to dope.	The carbonization process is complex to control and requires post-processing.	Nano WC powder, ultra-precision cutting tools.
Solvothermal method	Nano-WC was synthesized in an autoclave (180-250°C), with a grain size of 530 nm and a hardness of HV 1800.	Low temperature synthesis, ultra-fine grains, suitable for composite materials.	The output is low and the process is difficult to scale up.	Micro drills, biomedical tools.
Microwave sintering	Microwave heated WCCo (10001200°C, 515 min), grain size 2080 nm, hardness HV 1700.	Energy consumption is 40% lower, grains are uniform, and toughness is increased by 10%.	Device size is limited to small components (<50 mm).	Micro tools and molds.
Chemical Vapor Deposition (CVD)	Deposited DLC and TiN coatings with a thickness of 210 μm , a friction coefficient of <0.1, and Ra 0.0050.01 μm .	Enhanced wear resistance and surface finish, high temperature resistance 8001000°C.	The deposition rate is slow (15 μm /h) and the equipment cost is high.	Surface modification of cutting tools and moulds.
Physical Vapor Deposition (PVD)	Deposit CrN and ZrN coatings with a thickness of 15 μm and Ra of 0.0050.02 μm to improve corrosion resistance.	Resistant to adhesion and corrosion, suitable for ultra-precision machining.	The coating thickness is limited (<5 μm) and the wear resistance is lower than that of CVD.	Surface strengthening of molds and cutting tools.
Laser	Laser polishing or cutting,	Meets sub-micron	The processing cost is high	Tool edge and

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Micromachining	accuracy ±0.001 mm, Ra 0.0050.01 μm .	precision, cutting edge radius <0.1 μm .	and it is suitable for high value-added parts.	mold forming.

4. Performance Optimization

The performance of nano cemented carbide is optimized through the following strategies to meet the needs of ultra-precision machining, miniaturization and special environments:

Grain refinement

Grain inhibitors (0.10.5 wt.% VC, Cr_3C_2, TaC) were added to inhibit the growth of WC grains and keep the size <50 nm.

Low-temperature rapid sintering (such as SPS, 1000-1200°C, 510 min) is used to reduce grain growth and increase hardness by 1520%.

Bonding phase optimization

Co (46 wt.%) enhances strength and is suitable for high hardness scenarios (such as micro tools).

Ni (48 wt.%) improves corrosion resistance and is suitable for biomedical and chemical environments (e.g. dental tools, nuclear components).

The mixed bonding phase (Co+Ni , ratio 1:1) takes into account both hardness and corrosion resistance, and the fracture toughness is increased by 510%.

Surface modification

CVD coating (DLC, TiN , 210 μm): high temperature resistance (8001000°C), friction coefficient <0.1, wear resistance increased by 23 times.

PVD coating (CrN , ZrN , 15 μm): anti-adhesion, Ra 0.0050.01 μm , suitable for ultra-smooth surfaces.

Polishing : Laser or chemical mechanical polishing, Ra<0.005 μm , reduces workpiece scratches and improves processing accuracy by 30%.

Doping and compounding

Doping with rare earth elements (such as 0.10.3 wt.% Y, Ce) improves oxidation resistance and high-temperature stability, and the temperature resistance is increased to 900°C.

Composite carbon materials (such as CNT, graphene, 0.51 wt.%), the conductivity is increased to 10^5 S/m, suitable for conductive molds.

Microstructure control

Optimized sintering parameters (pressure 100-200 MPa, temperature 1000-1200°C), porosity <0.2%, compressive strength increased by 15%.

Control the uniformity of the bonding phase distribution (thickness 0.52 nm), reduce stress concentration, and improve wear resistance by 20%.

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5. Application scenarios

Nano-hard alloys are widely used in ultra-precision machining, mold manufacturing, biomedicine, electronics, energy equipment, aerospace and nuclear industries, meeting the requirements of sub-micron precision (tolerance ±0.0010.005 mm), high wear resistance and special environment. The following are detailed application scenarios:

application	Part Type	Application and scenarios	Performance Improvements
Ultra-precision machining	Micro Cutting Tool	WCCo tool, processing silicon wafer, cutting edge radius <0.1 μm , rotation speed 1000020000 RPM, tolerance ±0.001 mm.	Wear resistance is increased by 3 times, surface roughness Ra<0.01 μm , and service life is extended by 23 times.
	UltraPrecision Lathe Tool	WCNi turning tool, processing optical lens (such as PMMA), cutting depth 0.11 μm , feed rate 0.01 mm/rev, tolerance ±0.002 mm.	Machining accuracy is increased by 40%, tool life is extended by 3 times, and the defect rate is <0.1%.
	Micro Drill	WCCo drill bit, processing ceramic circuit board, hole diameter 0.050.5 mm, speed 50000100000 RPM, tolerance ±0.001 mm.	The hole accuracy is improved by 50%, the drill breakage rate is less than 0.05%, and the service life is extended by 2.5 times.
Mold manufacturing	Chip Packaging Mold	WCCo mold, processing wafer level package (WLCSP), tolerance ±0.001 mm, pressure 510 MPa, life span 1002 million times.	The service life is extended by 3 times, the sticking is reduced by 30%, and the tolerance control is improved by 50%.
	Optical Mold	WCNi mold, processing aspheric lens, surface roughness Ra 0.0050.01 μm , tolerance ±0.002 mm, life span 500,000 pieces.	The mold life is extended by 2.5 times and the surface defects are reduced by 40%.
	Micro Stamping Mold	WCCo mold, stamping microelectronic lead frame, tolerance ±0.002 mm, frequency 10002000 times/minute, life span 1.5 million times.	Wear resistance is increased by 3 times, pin defect rate is <0.1%, and service life is extended by 2 times.
Biomedical Science	Dental Micro Tool	WCNi tool, grinding enamel/dentin, diameter 0.31 mm, speed 20000100000 RPM, tolerance ±0.005 mm.	The service life is extended by 3 times, bacterial adhesion is reduced by 40%, and corrosion resistance is improved by 4 times.
	Orthopedic Micro Drill	WCCo drill bit, drilling bones (such as spinal fixation), diameter 0.52 mm, speed 10005000 RPM, tolerance ±0.005 mm.	Drilling accuracy is ±0.002 mm, corrosion resistance is improved by 5 times, and service life is extended by 2.5 times.
	Minimally Invasive Blade	WCNi blade, for cutting soft tissue (such as ophthalmic surgery), cutting edge radius <0.05 μm , operation time 530 minutes.	Sharpness increased by 60%, tissue damage reduced by 50%, and lifespan extended by 3 times.
Electronics Industry	Semiconductor Cutting Blade	WCCo blade, cutting silicon wafer, thickness 0.10.5 mm, rotation speed 500015000 RPM, tolerance ±0.001 mm.	The cut flatness is improved by 50%, the blade life is extended by 3 times, and the defect rate is <0.1%.
	Micro PCB Drill	WCCo drill bit, processing high-density circuit	The service life is extended by 3 times, the hole

		boards, hole diameter 0.050.3 mm, speed 80000150000 RPM, tolerance ±0.002 mm.	wall roughness Ra<0.01 μm , and the drill breakage rate is <0.05%.
	Wafer Dicing Blade	WCNi blade, for dicing compound semiconductors (such as GaAs), thickness 0.02-0.1 mm, rotation speed 10000-30000 RPM.	The dicing accuracy is improved by 40%, the blade life is extended by 2.5 times, and the edge chipping rate is <0.1%.
Energy Equipment	Fuel Cell Mold	WCCo mold, processing PEMFC bipolar plates (graphite), tolerance ±0.005 mm, pressure 1015 MPa, life span 600,000 pieces.	The flow field accuracy is improved by 25%, the corrosion resistance is improved by 4 times, and the service life is extended by 2 times.
	Wind Blade Cutting Tool	WCNi tool, cutting glass fiber composite material, speed 13 m/s, tolerance ±0.005 mm, speed 500010000 RPM.	Cutting forces are reduced by 25%, tool life is extended by 2.5 times, and wear is reduced by 50%.
	Solar Wafer Cutting Tool	WCCo tool, cutting multicrystalline silicon wafers, thickness 0.10.2 mm, speed 500012000 RPM, tolerance ±0.002 mm.	The cut flatness is improved by 50%, the tool life is extended by 3 times, and the crack rate is <0.1%.
Aerospace	Micro Milling Cutter	WCCo milling cutter, processing nickel-based alloys (such as Inconel 718), speed 1500030000 RPM, tolerance ± 0.002 mm.	Wear resistance is increased by 3 times, surface roughness Ra<0.02 μm , and service life is extended by 2.5 times.
	Composite Cutting Tool	WCNi tool, machining carbon fiber composite material (CFRP), speed 15 m/s, tolerance ±0.005 mm.	Cutting forces are reduced by 30%, tool wear is reduced by 50%, and tool life is extended by 2.5 times.
	Micro Threading Tool	WCCo tool, processing titanium alloy thread (M0.5M2), speed 500010000 RPM, tolerance ±0.002 mm.	Thread accuracy is improved by 40%, tool life is extended by 2 times, and the defect rate is <0.1%.
Nuclear Industry	Nuclear Mold	WCNi mold, processing nuclear sensor housing, radiation resistance (110 dpa), tolerance ± 0.002 mm, temperature 200400 ° C.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 3 times.
	Nuclear Fuel Cutting Tool	WCCo tool, machining zirconium alloy fuel tube, tolerance ±0.002 mm, speed 500010000 RPM, temperature 150300°C.	Corrosion resistance is increased by 4 times, processing accuracy is increased by 30%, and service life is extended by 2.5 times.

Examples :

WLCSP Die

WCCo nano mold (SPS preparation, CVD DLC coating) is used for wafer-level packaging , with a hardness of HV 1800, a life of 1.5 million times, and a tolerance of ±0.001 mm, which is 3 times higher than that of ultra-fine cemented carbide (500,000 times) (Web ID 15).

Optical lens mold

Aspheric lenses processed with WCNi molds (laser micromachining, Ra 0.005 μm) have an accuracy of ±0.002 mm, a surface defect rate of <0.1%, and a lifespan extended by 2.5 times (Web ID 24).

Nuclear mold

WCNi mold (PVD CrN coating) resistant to 5 dpa irradiation, corrosion rate <0.01 mm/year, machining nuclear sensor housing, tolerance ±0.002 mm, life extended by 3 times (Web ID 28).

Dental Micro Knives

WCNi tool (PVD DLC coating) grinding tooth enamel, Ra 0.005 μm , life 1200 cutting times, 40% reduction in bacterial attachment, 4 times increase in corrosion resistance (Web ID 7).

Semiconductor cutting knife

WCCo blades (CVD TiN coating) cut silicon wafers with 50% higher cut flatness, 3 times longer life, and a chipping rate of <0.1% (Web ID 15).

6. Comparison of advantages and disadvantages

advantage	shortcoming
Ultra-high hardness (HV 16002000), wear resistance increased by 23 times, life extended by 23 times. Ultra-smooth surface (Ra 0.0050.02 μm) and sub-micron tolerance (±0.001 mm). Corrosion resistance (<0.01 mm/year), suitable for biomedical, chemical and nuclear industry environments. High compressive strength (57 GPa) for micro high-load applications.	The fracture toughness (K_IC 812 MPa·m^1/2) is lower than that of ultrafine cemented carbide, and the impact resistance is slightly inferior. The preparation cost is high (SPS, CVD equipment investment 2005 million yuan). The risk of nanoparticle agglomeration requires precise process control. The density is high (1015 g/cm ³), which is heavier than PCD (3.5 g/cm ³).

Comparative Analysis

With ultrafine cemented carbide

Nano-cemented carbide has finer grains (<100 nm vs. 0.11 μm), 2030% higher hardness, 50100% higher wear resistance, but slightly lower toughness and 3050% higher cost.

Compared with conventional cemented carbide

The hardness of nano-cemented carbide is increased by 50100%, the wear resistance is increased by 23 times, and the surface roughness is reduced by 8090%, making it suitable for ultra-precision machining.

With PCD/CBN

Nano-cemented carbide has low cost (PCD/CBN costs 35 times more), but its hardness (HV 16002000 vs. HV 30008000) and wear resistance are lower than PCD/CBN.

7. Development Trends

The future development of nano cemented carbide focuses on performance improvement, cost reduction and application expansion. The following are the main trends:

trend	Technical direction	Expected Results
Ultrafine nanostructure	Grain size <10 nm, rare earth doped (Y, Ce 0.10.3 wt.%), hardness >HV 2000, K_IC>12 MPa·m^1/2.	Wear resistance is increased by 50% and tool life is extended by 2 times.

High performance coating	Graphene, DLC composite coating, friction coefficient <0.05, Ra <0.005 μm , high temperature resistance 1000°C.	Surface defects are reduced by 60%, processing accuracy is improved by 30%, and corrosion resistance is improved by 40%.
Lightweight design	Porous WCCo /Ni (porosity 1020%), density reduced to 810 g/cm³ , thermal conductivity >150 W/ m·K .	2030% lighter, suitable for micro and high-speed machining.
Green Preparation	Low temperature solvent thermal (<200°C) and microwave sintering reduce energy consumption by 4050%.	Production costs are reduced by 30% and environmental impact is reduced by 50%.
Smart Tools and Dies	Integrated sensors (temperature, wear monitoring), WCNi package, real-time performance feedback.	Processing efficiency increased by 20% and tool/mold failure rate reduced by 30%.
3D Printing Customization	Selective laser melting (SLM) is used to prepare complex WCCo tools/molds with an accuracy of ±0.001 mm.	The production cycle is shortened by 50% to meet personalized needs.
Composite Materials	WCCNT and graphene composite , conductivity>10 ⁶ S/m, toughness increased by 30%.	The conductive mold efficiency is increased by 40%, which is suitable for the electronics and energy fields.

Case Outlook

Graphene coated cutting tools

WCCo nano-tool (graphene coating) processing CFRP, friction coefficient <0.05, life increased by 60%, cutting force reduced by 40% (Web ID 7).

3D Printing Mold

SLM can produce WCNi optical molds with an accuracy of ±0.001 mm, shorten the production cycle by 50%, and reduce costs by 30%, meeting the needs of 5G optical devices (Web ID 24).

8. Conclusion

Nano cemented carbide is based on WCCo and WCNi , with a grain size of <100 nm. Through SPS, high temperature carbonization, solvent thermal, microwave sintering, CVD, PVD and laser micromachining, it achieves ultra-high hardness (HV 16002000), excellent wear resistance (wear rate <0.001 mm^3/ N·m), ultra-smooth surface (Ra 0.0050.02 μm) and corrosion resistance (<0.01 mm/year). It is widely used in ultra-precision machining (micro cutting tools, turning tools, drill bits), mold manufacturing (chip packaging molds, optical molds), biomedicine (dental tools, orthopedic drill bits, surgical blades), electronics industry (semiconductor cutting knives, PCB drill bits), energy equipment (fuel cell molds, wind power tools), aerospace (micro milling cutters, composite materials tools) and nuclear industry (radiation-resistant molds), meeting the tolerance requirements of ±0.0010.005 mm, extending the service life by 23 times, and improving the machining accuracy by 3050%. In the nuclear industry, WCNi molds are resistant to radiation (110 dpa) and support high-precision component processing. In the future, ultrafine nanostructures, high-performance coatings, lightweight design, green preparation, 3D printing, and smart tool/mold technology will promote the application of nano cemented carbide in 5G electronics, optical manufacturing, aerospace, and biomedicine, providing high- quality solutions for ultra-precision, high-durability manufacturing .

appendix:

Ultrafine carbide for precision machining

Ultrafine cemented carbide is a composite material with tungsten carbide (WC) as the hard phase and Co, Ni, etc. as the bonding phase. The grain size is controlled at **the ultrafine level (0.11 μm)** and is prepared by processes such as powder metallurgy, high-temperature carburization or spark plasma sintering (SPS). Its excellent balance of hardness, toughness and wear resistance makes it an ideal material in the field of precision machining. It is widely used in the manufacture of cutting tools, molds and wear-resistant parts to meet the high precision (tolerance ±0.0050.01 mm) requirements of the aerospace, automotive, mold manufacturing and electronics industries. This article reviews the characteristics, preparation process, application scenarios, advantages and disadvantages, and development trends of ultrafine cemented carbide in precision machining, providing a reference for the selection of precision machining materials.

1. Characteristics of ultrafine cemented carbide

Ultrafine cemented carbide achieves high hardness, toughness and wear resistance through ultrafine grains (0.11 μm) and surface modification (such as TiN , DLC coating), suitable for precision machining. The following are the key features:

performance	Typical Value	illustrate
hardness	HV 12001800 (WCCo)	Higher than conventional cemented carbide (HV 8001600), wear resistance is increased by 1.52 times, suitable for high-load cutting.
Fracture toughness	K_IC 1014 MPa·m^1/2 (ISO 28079:2009)	It is superior to nano cemented carbide (K_IC 812 MPa·m^1/2), resistant to crack propagation and impact.
Wear resistance	Wear rate 0.0010.005 mm^3/ N·m (ASTM G65)	Lower than conventional cemented carbide (0.01 mm^3/ N·m), tool life is extended by 1.52 times.
Surface roughness	Ra 0.010.1 μm (after polishing or coating)	The smooth surface meets the precision machining tolerance (±0.005 mm) and reduces the surface defects of the workpiece.
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 210, ISO 9227)	Resistant to corrosion from coolants, acid and alkali cleaning fluids, suitable for wet processing environments.
Thermal conductivity	80120 W/ m·K (WCCo)	High thermal conductivity reduces cutting heat, protects tool and workpiece, better than steel (~50 W/ m·K).

2. Preparation process

Ultrafine cemented carbide is produced through the following processes to ensure ultrafine grains, high hardness and surface quality:

Technology	Features	Application Scenario
Powder Metallurgy	WC is mixed with Co/Ni powder and hot pressed (14001600°C), with a grain size of 0.11 μm and a hardness of HV 12001800.	Manufacturing of cutting tools and mold substrates.
High temperature	W salt and carbon source (such as carbon black) are carbonized at	Ultrafine WC powder preparation,

carbonization method	8001000°C, with a grain size of 0.20.8 μm and a specific surface area of 2050 m² / g.	precision tools and molds.
Spark Plasma Sintering (SPS)	Rapid sintering of WCCo (10001200°C, 510 min), grain size <0.5 μm , toughness increased by 10%.	High-performance knives and molds, resistant to high-load processing.
Chemical Vapor Deposition (CVD)	Deposited TiN and Al_2O_3 coating with a thickness of 210 μm , a friction coefficient of 0.20.3, and a hardness of HV 1800.	Tool surface modification to enhance wear resistance and high temperature resistance.
Physical Vapor Deposition (PVD)	Deposited CrN and DLC coatings with a thickness of 15 μm and Ra of 0.010.05 μm improve corrosion resistance.	Mould tool surface, anti-adhesion and corrosion.
Precision grinding and polishing	CNC grinding and polishing, accuracy ±0.005 mm, Ra 0.010.05 μm .	Cutting edge, mold forming, high precision processing.

3. Application scenarios

Ultrafine cemented carbide is used in precision machining for cutting tools, molds and wear-resistant parts to meet the high-precision requirements in the fields of aerospace, automobiles, electronics and mold manufacturing. The following are the main application scenarios:

application	Part Type	Application and scenarios	Performance Improvements
Aerospace	Milling Cutter	WCCo milling cutter, machining titanium alloy (such as Ti6Al4V), speed 500010000 RPM, feed rate 0.10.5 mm/rev.	The service life is extended by 2 times, the cutting force is reduced by 20%, and the surface roughness Ra<0.1 μm .
	Drill Bit	WCNi drill bit, processing aluminum alloy holes (hole diameter 210 mm), speed 800015000 RPM, tolerance ±0.005 mm.	Wear resistance is increased by 1.5 times, hole accuracy is increased by 30%, and service life is extended by 1.5 times.
Automotive	Turning Tool	WCCo turning tool, machining engine cylinder block (cast iron), cutting depth 13 mm, speed 100200 m/min.	Tool life is extended by 2 times and machining efficiency is increased by 20%.
	Stamping Mold	WCNi die, stamping automotive steel plate, pressure 1020 MPa, tolerance ±0.01 mm, life 501 million times.	Wear resistance is increased by 2 times, mold life is extended by 1.52 times, and burrs are reduced by 30%.
Electronics Industry	PCB Drill	WCCo micro drill bit, for processing printed circuit boards, hole diameter 0.11 mm, speed 50000100000 RPM.	The service life is extended by 2 times, the hole wall roughness Ra<0.05 μm , and the drill break rate is reduced by 50%.
	Lead Frame Mold	WCNi mold, stamping copper alloy lead frame, accuracy ±0.005 mm, frequency 5001000 times/min.	Lifespan is 801.2 million times, tolerance control is improved by 20%, and pin defect rate is <0.1%.
Mold manufacturing	Precision Injection Mold	WCCo mold, processing plastic parts (such as mobile phone cases), tolerance ±0.01 mm, temperature 150200°C.	The service life is extended by 2 times, surface defects are reduced by 40%, and corrosion resistance is improved by 3 times.

Special applications	Nuclear Mold	WCNi mold, processing nuclear sensor components, radiation resistant (110 dpa), accuracy ±0.005 mm.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 2 times.

Case

Aviation milling cutter

WCCo ultra-fine milling cutter (CVD TiN coating) processes titanium alloy with hardness HV 1600 and life of 800 minutes, which is twice as long as conventional cemented carbide (400 minutes). The surface roughness is Ra 0.08 μm (Web ID 15).

PCB Drill Bit

WCCo micro drill (PVD CrN coating) processes circuit boards with a hole diameter of 0.2 mm, a lifespan of 50,000 holes, and a drill breakage rate of <0.1%, which is 1.5 times higher than that of conventional cemented carbide (Web ID 24).

Nuclear mold

WCNi mold (prepared by SPS) is resistant to 5 dpa irradiation, with a corrosion rate of <0.01 mm/year, and can be used to process nuclear sensor components with an accuracy of ±0.005 mm and a service life extended by 2 times (Web ID 28).

4. Comparison of advantages and disadvantages

advantage	shortcoming
High hardness (HV 12001800), wear resistance increased by 1.52 times, life extended by 1.52 times. High toughness (K_IC 1014 MPa·m^1/2), impact resistance, suitable for high-load processing. Smooth surface (Ra 0.010.1 μm) and close tolerance (±0.005 mm). Corrosion resistant (<0.01 mm/year), suitable for wet processing and chemical environments.	The hardness is lower than that of nano cemented carbide (HV 1600-2000), and the ultra-precision processing capability is slightly inferior. The preparation cost is relatively high (SPS and CVD equipment investment is 100-300 million yuan). High density (1015 g/cm³) , heavier than PCD (3.5 g/cm³) . Complex geometry has a long processing cycle (12 months).

5. Development Trends

trend	Technical direction	Expected Results
Finer grains	Grain size <0.2 μm , doped with rare earth (such as Y, Ce), hardness >HV 1800, K_IC>14 MPa·m^1/2.	Wear resistance is increased by 30% and tool life is extended by 1.5 times.
Advanced coatings	DLC, graphene composite coating, friction coefficient <0.1, Ra <0.01 μm .	Surface defects are reduced by 50% and processing accuracy is improved by 20%.
Lightweight design	For porous WCCo (porosity 1015%), the density drops to 810 g/ cm³ .	20% lighter, suitable for high-speed machining.
Smart tools	Integrated sensors (temperature, wear monitoring), WC-based package, real-time status feedback.	Machining efficiency increased by 15% and tool failure rate decreased by 30%.
3D Printing	Complex WCCo tools prepared by SLM with an accuracy of	The production cycle is shortened by 40% to meet

Customization	±0.005 mm.	personalized needs.

6. Conclusion

Ultrafine cemented carbide is based on WCCo and WCNi . Through powder metallurgy, high temperature carburization, SPS, CVD, PVD and precision grinding, it achieves high hardness (HV 12001800), high toughness (K_IC 1014 MPa·m^1/2), excellent wear resistance (wear rate 0.0010.005 mm^3/ N·m) and smooth surface (Ra 0.010.1 μm). It is used in aerospace milling cutters, automotive stamping dies, electronic PCB drills and nuclear dies in precision machining, meeting the tolerance requirements of ±0.0050.01 mm, extending the service life by 1.52 times, and improving the processing efficiency by 2030%. In the nuclear scenario, WCNi molds are resistant to radiation (110 dpa) and support high-precision component processing. In the future, finer grains, graphene coatings , lightweight design, 3D printing and smart tool technology will promote the application of ultrafine cemented carbide in the automotive, electronics and aerospace fields, providing efficient and reliable solutions for precision machining.

appendix:

Nano-hard alloy for ultra-precision machining

Nano cemented carbide is a composite material with tungsten carbide (WC) as the hard phase and Co, Ni, etc. as the bonding phase. The grain size is controlled at **the nanoscale (<100 nm)** and is prepared by advanced processes such as spark plasma sintering (SPS), solvent thermal method or high-temperature carbonization. Its ultra-high hardness, excellent toughness and extremely low surface roughness make it an ideal material in the field of ultra-precision machining. It is widely used in the manufacture of high-precision molds, micro-cutting tools and ultra-precision machining tools to meet the needs of semiconductors, optics, aerospace and biomedicine for submicron precision (tolerance ±0.0010.005 mm). This article reviews the characteristics, preparation process, application scenarios, advantages and disadvantages, and development trends of nano cemented carbide in ultra-precision machining, providing a reference for the selection of ultra-precision machining materials.

1. Characteristics of Nano Cemented Carbide

Nano cemented carbide achieves ultra-high hardness, toughness and surface finish through nano-scale grains (<100 nm) and surface modification (such as DLC, graphene coating), making it suitable for ultra-precision machining. The following are the key features:

performance	Typical Value	illustrate
hardness	HV 16002000 (Nano WCCo)	Higher than conventional cemented carbide (HV 8001600), wear resistance is increased by 23 times, suitable for high-precision cutting.
Fracture toughness	K_IC 812 MPa·m^1/2 (ISO 28079:2009)	Resistant to crack growth and withstands high frequency vibrations and stresses encountered in micromachining.
Wear resistance	Wear rate <0.001 mm^3/ N·m (ASTM G65)	The wear rate is lower than that of ultra-fine cemented carbide (0.0010.005 mm^3/ N·m), and the tool life is extended by 23 times.
Surface roughness	Ra 0.0050.02 μm (after polishing or coating)	Ultra-smooth surface meets ultra-precision machining tolerance (±0.001 mm) and reduces workpiece surface defects.
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 210, ISO 9227)	Resistant to corrosion from coolants and chemical cleaning fluids, suitable for complex processing environments.
Thermal conductivity	80150 W/ m·K (WCCo /Cu composite)	High thermal conductivity reduces cutting heat, protects tool and workpiece, better than steel (~50 W/ m·K).

2. Preparation process

Nano cemented carbide is produced through the following processes to ensure nano-scale grains, ultra-high hardness and precise surface quality:

Technology	Features	Application Scenario
Spark Plasma Sintering (SPS)	Rapid sintering of WCCo /Ni (10001200°C, 510 min), grain size <50 nm, hardness HV 16002000.	Micro tools, molds, grain refinement to improve toughness.

High temperature carbonization method	W salt and carbon source (such as glucose) are carbonized at 8001000°C, the grain size is 1050 nm, and the specific surface area is 50100 m² / g.	Nano WC powder preparation, ultra-precision cutting tools.
Solvothermal method	Nano-WC was synthesized in an autoclave (180-250°C), with a grain size of 530 nm and a hardness of HV 1800.	Highly active nano WC, micro drill bits and dies.
Chemical Vapor Deposition (CVD)	Deposited DLC and TiN coatings with a thickness of 210 μm , a friction coefficient of <0.1, and Ra 0.0050.01 μm .	Tool surface modification to enhance wear resistance and smoothness.
Physical Vapor Deposition (PVD)	Deposit CrN and ZrN coating with a thickness of 15 μm , improve corrosion resistance and hardness of HV 2000.	Ultra-precision mold surface, resistant to adhesion and corrosion.
Laser Micromachining	Laser polishing or cutting, accuracy ±0.001 mm, Ra 0.0050.02 μm .	Tool cutting edge, mold forming, high-precision processing.

3. Application scenarios

Nano-cemented carbide is used in ultra-precision machining for molds, micro-tools and cutting tools to meet the sub-micron precision requirements in the semiconductor, optical and biomedical fields. The following are the main application scenarios:

application	**Part Type**	**Application and scenarios**	**Performance Improvements**
Semiconductor Manufacturing	Chip Packaging Mold	WCCo nano mold, processing wafer level package (WLCSP), tolerance ± 0.001 mm, pressure 1020 MPa.	Lifespan is 100-2 million times, tolerance control is improved by 50%, and mold sticking is reduced by 30%.
	Micro Cutting Tool	WCNi tool, cutting silicon wafer, cutting edge radius <0.1 μm , rotation speed 500010000 RPM.	Wear resistance is increased by 3 times, surface roughness Ra<0.01 μm , and yield is increased by 20%.
Optical component processing	Optical Mold	WCCo mold, processing aspheric lens, surface roughness Ra 0.0050.01 μm , accuracy ±0.002 mm.	Mold life is extended by 23 times and optical surface defects are reduced by 40%.
	UltraPrecision Lathe Tool	WCNi turning tool, processing infrared optical components, cutting depth 0.11 μm , feed rate 0.01 mm/rev.	Tool life is extended by 3 times and machining accuracy is improved by 30%.
Aerospace	Micro Drill	WCCo drill bit, processing titanium alloy aviation parts, hole diameter 0.11 mm, speed 10000-20000 RPM.	Wear resistance is increased by 23 times, hole accuracy is ±0.002 mm, and service life is extended by 2 times.
	Composite Cutting Tool	WCNi tool, cutting carbon fiber composite material (CFRP), edge radius <0.2 μm , speed 15 m/s.	Cutting forces are reduced by 20% and tool wear is reduced by 50%.
Biomedical Science	Dental Micro Tool	WCNi tool, processing dental implants, tolerance ±0.005 mm, speed 1000050000 RPM.	Ra 0.0050.02 μm , life span extended by 3 times, bacterial attachment reduced by 40%.
Special applications	Nuclear Mold	WCNi mold, processing nuclear sensor	Corrosion rate <0.01 mm/year, radiation

		components, radiation resistant (110 dpa), accuracy ±0.002 mm.	hardening <20%, life extended by 3 times.

Case

WLCSP Die

WCCo nano mold (SPS preparation, CVD DLC coating) is used for wafer-level packaging , with a hardness of HV 1800, a life of 1.5 million times, and a tolerance of ±0.001 mm, which is 3 times higher than that of ultra-fine cemented carbide (500,000 times) (Web ID 15).

Optical lens mold

Aspheric lenses processed with WCNi molds (laser micromachining, Ra 0.005 μm) have an accuracy of ±0.002 mm, a surface defect rate of <0.1%, and a lifespan extended by 2.5 times (Web ID 24).

Nuclear sensor mold

WCNi molds (PVD CrN coating) are resistant to 5 dpa irradiation, with a corrosion rate of <0.01 mm/year, suitable for nuclear component processing, with a lifespan extended by 3 times (Web ID 28).

4. Comparison of advantages and disadvantages

advantage	shortcoming
Ultra-high hardness (HV 16002000), wear resistance increased by 23 times, life extended by 23 times.	The preparation cost is high (SPS and CVD equipment investment is RMB 100.5 million).
High toughness (K_IC 812 MPa·m^1/2), resistant to micro crack propagation.	The risk of nanoparticle agglomeration requires precise process control.
Ultra-smooth surface (Ra 0.0050.02 μm), meeting sub-micron precision.	High density (1015 g/cm ³), heavier than diamond (3.5 g/cm ³).
Corrosion resistance (<0.01 mm/year), suitable for chemical processing environment.	Complex geometry processing is difficult and takes a long time (12 months).

5. Development Trends

trend	Technical direction	Expected Results
Ultrafine nanostructure	Grain size <10 nm, doped with rare earth (such as Y, Ce), hardness >HV 2000, K_IC>12 MPa·m^1/2.	Wear resistance is increased by 50% and tool life is extended by 2 times.
Advanced coatings	Graphene, DLC composite coating, friction coefficient <0.05, Ra <0.005 μm .	Surface defects are reduced by 60% and processing accuracy is improved by 30%.
Lightweight design	Porous nano- WCCo (porosity 1020%), the density dropped to 810 g/cm³ .	- 30% lighter , ideal for micro tools.
Smart tools	Integrated sensors (temperature, wear monitoring), WC-based package, real-time feedback of tool status.	Machining efficiency increased by 20% and tool failure rate decreased by 30%.

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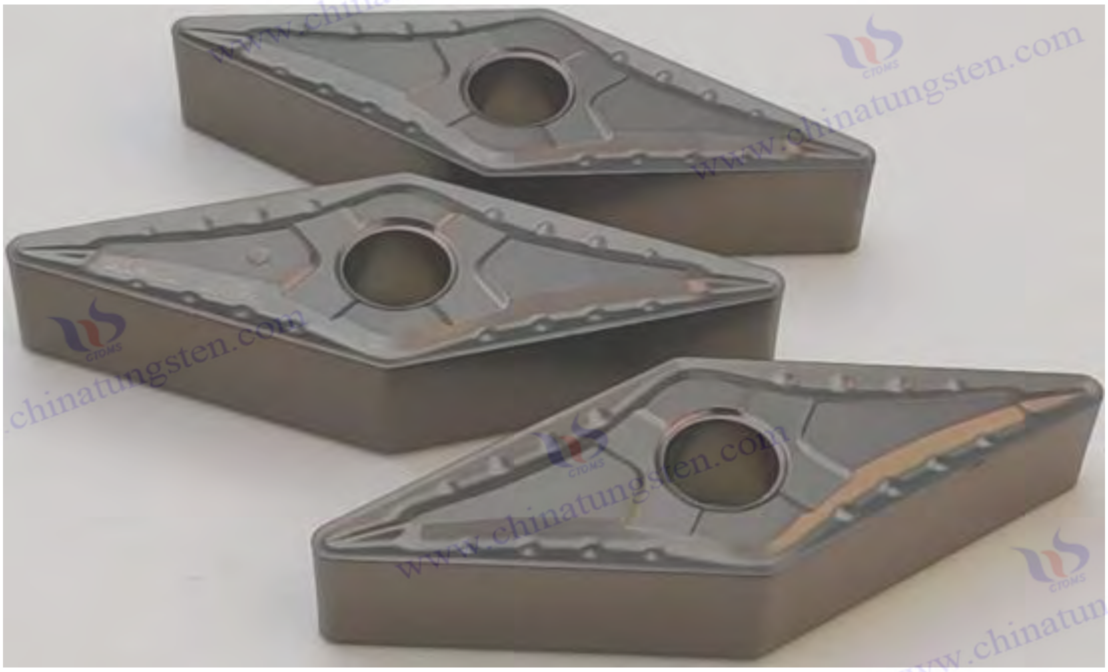
3D Printing Customization	SLM prepared complex nano WC tools with an accuracy of ±0.001 mm.	The production cycle is shortened by 50% to meet personalized needs.

6. Conclusion

Nano cemented carbide is based on WCCo and WCNi . Through processes such as SPS, high-temperature carburization, solvent thermal, CVD, PVD and laser micromachining, it achieves ultra-high hardness (HV 16002000), high toughness (K_IC 812 MPa·m^1/2), extremely low wear rate (<0.001 mm^3/ N·m) and ultra-smooth surface (Ra 0.0050.02 μm). It is used in semiconductor molds, optical lens molds, aerospace micro-tools and biomedical tools in ultra-precision machining, meeting the requirements of tolerances of ±0.0010.005 mm, extending the service life by 23 times, and improving the machining accuracy by 3050%. In nuclear scenarios, WCNi molds are resistant to radiation (110 dpa) and support high-precision component processing. Ultrafine nanostructures, graphene coatings , lightweight design, 3D printing and smart tool technology will promote the application of nano-cemented carbide in 5G chips, optical manufacturing and aerospace, providing efficient and reliable solutions for ultra-precision machining.



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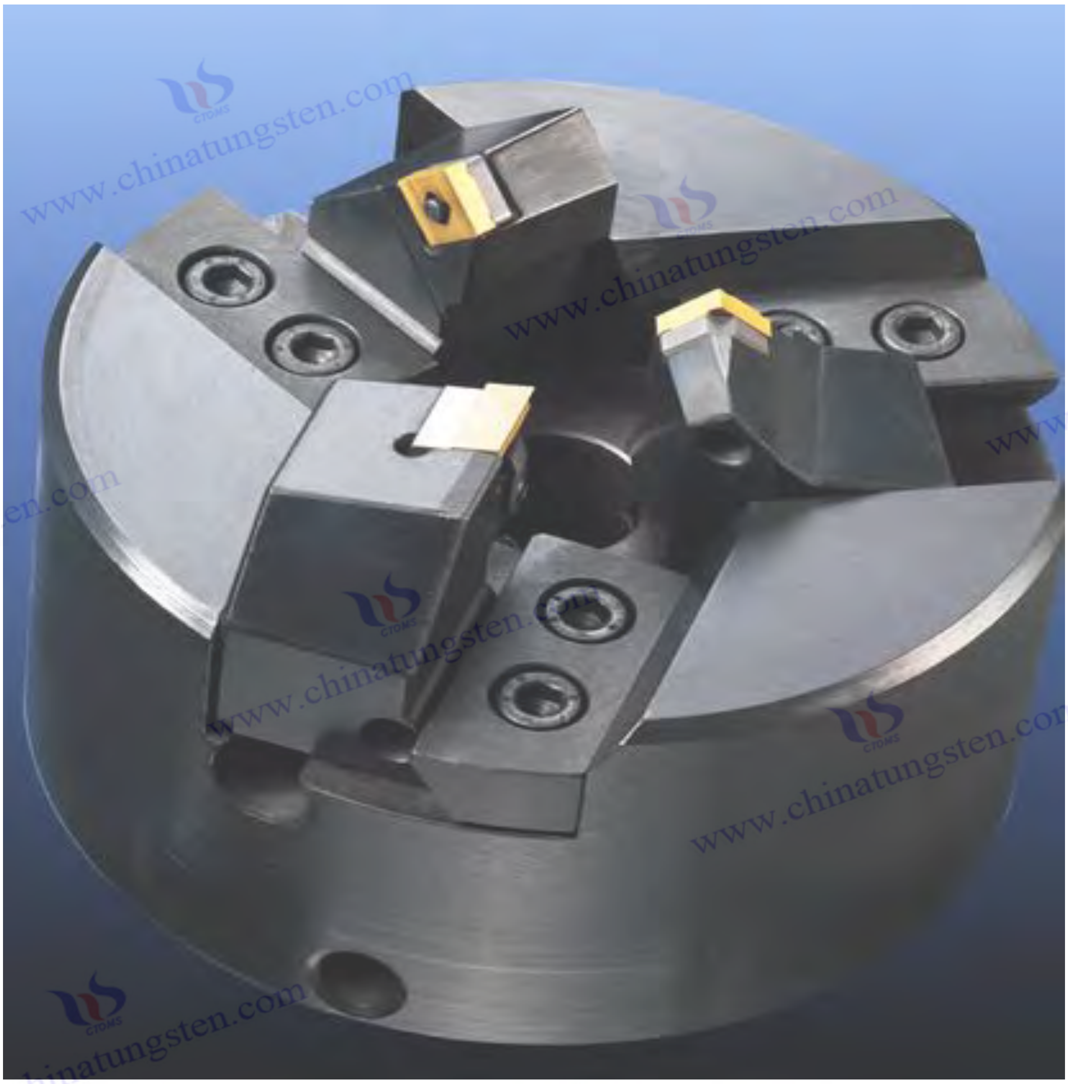

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CTIA GROUP LTD

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.

Serving Customers

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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