Tungsten Cemented Carbide

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

中钨智造科技有限公司

CTIA GROUP LTD

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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.

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Customized processing of carbide nozzles

Carbide nozzles have the characteristics of wear resistance, corrosion resistance, high temperature resistance and long service life . They are widely used in sand blasting, spraying, water jet cutting, oil drilling, chemical industry, agriculture, food processing and other fields.

Main features of carbide nozzles

Hardness : HRA 8892

Precision: nozzle tolerance ±0.001 mm, surface roughness Ra 0.10.4 μm .

Adaptability: temperature resistance 8001000°C, corrosion resistance pH 210.

Efficiency: Supports high-pressure (0.1500 MPa) injection, with efficiency increased by 2050%.

Lifespan: Excellent wear resistance, lifespan is 515 times that of ordinary materials.

Customization: various types (sandblasting, atomization, milk powder manufacturing, etc.), suitable for various working conditions.

Main types of carbide nozzles

type	describe	Main uses and application scenarios	Typical Specifications
Sandblasting nozzle Sandblasting Nozzle	High wear-resistant design, suitable for abrasive blasting.	Rust removal of ships, deburring of automobile parts, and concrete cleaning.	Nozzle diameter 212 mm, Length 50200 mm,
Water jet nozzle Waterjet Nozzle	High-pressure water jet, suitable for cutting hard materials.	Aerospace titanium alloy cutting, automotive composite material cutting, stone processing.	The nozzle diameter is 0.12 mm. Length 20100 mm,
Spray Nozzle Spray Coating Nozzle	Precise application of paint or ceramic coatings.	Aviation turbine blade coating, automobile engine coating, electronic circuit board spraying.	The nozzle diameter is 0.55 mm. Length 30150 mm,
Oilfield Nozzles Oilfield Nozzle	High pressure and corrosion resistance, suitable for drilling jetting.	Oil drilling fluid injection, natural gas downhole cleaning, mining mud injection.	Nozzle diameter 315 mm, Length 50150 mm,
Atomizing nozzle Atomizing Nozzle	Fine atomized spray, suitable for liquid dispersion.	Agricultural pesticide spraying, chemical liquid atomization, environmental waste gas treatment.	The nozzle diameter is 0.23 mm. Length 20100 mm,
Combustion nozzle Burner Nozzle	High temperature resistant design, suitable for fuel or gas injection.	Energy boiler combustion, chemical high temperature reaction, metallurgical furnace injection.	Nozzle diameter 110 mm, Length 30120 mm,
Micro Nozzle Micro Nozzle	Ultra-small nozzle hole, suitable for high-precision injection.	Medical drug spray, electronic chip cleaning, aviation precision coating.	Nozzle diameter 0.050.5 mm, length 1050
Corrosion resistant nozzles CorrosionResistant Nozzle	Resistant to strong acids and alkalis, suitable for chemical environments.	Chemical acid and alkali solution injection, environmental protection desulfurization and denitrification, marine engineering seawater	Nozzle diameter 110 mm, Length 30150 mm,

电话/TEL：0086 592 512 9696
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sales@chinatungsten.com

		injection.	
Milk powder manufacturing nozzle Milk Powder Spray Nozzle	Specially designed for spray drying to evenly atomize emulsions.	Food processing milk powder production, agricultural dairy product processing, in compliance with FDA/EU food contact standards.	The nozzle diameter is 0.53 mm. Length 20100 mm,

CTIA GROUP LTD
3rd Floor, No. 25-1, Wanghai Road, Software Park II, Xiamen, 361008
TEL.: +86 592 5129595 ; 18750234579
Email : info@ctia.group

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Customized processing of cemented carbide stamping dies

Carbide stamping dies have the characteristics of wear resistance, corrosion resistance, high temperature resistance and long service life. They are widely used in automobile manufacturing, electronic component processing, hardware products, aerospace, medical equipment and other fields.

Main features of cemented carbide stamping dies

Hardness: HRA 8892.

Precision: mold tolerance ±0.001 mm, surface roughness Ra 0.10.4 μm .

Adaptability: temperature resistance 8001000°C, corrosion resistance pH 210.

Efficiency: Supports high-frequency stamping, with efficiency increased by 2050%.

Lifespan: Excellent wear resistance, lifespan is 515 times that of ordinary molds.

Customization: Various types (drawing die, punching die, compound die, etc.), suitable for various working conditions.

Main types of cemented carbide stamping dies

type	describe	Main uses and application scenarios	Typical Specifications
Stretching die Drawing Die	High wear-resistant design, suitable for metal stretch forming.	Automobile body panels, metal containers, and aluminum alloy shell stretching.	The die diameter is 10200 mm, the thickness is 20100 mm, and the service life is 502 million punching times.
Blanking Die Blanking Die	High-precision punching, suitable for thin plate cutting.	Electronic component lead frames, automotive parts, and hardware accessories punching.	The die gap is 0.010.1 mm, the thickness is 1580 mm, and the service life is 301.5 million times of stamping.
Compound mold Compound Die	Integrated multi-step stamping, suitable for complex parts.	Aerospace connectors, medical equipment parts, and precision hardware composite processing.	The die diameter is 20150 mm, the thickness is 20100 mm, and the service life is 401.8 million punching times.
Oilfield Die Oilfield Die	High pressure and corrosion resistant, suitable for heavy-load stamping.	Oil drilling equipment parts, natural gas pipeline accessories, mining machinery parts.	The die diameter is 30200 mm, the thickness is 30120 mm, and the service life is 301.2 million stamping times.
HighSpeed Stamping Die	High temperature resistant and high frequency design, suitable for rapid stamping.	Automotive fasteners, electronic connectors, continuous high-speed stamping production lines.	The die has a diameter of 10100 mm, a thickness of 1580 mm, and a service life of 602.5 million punchings.
Heavy load model HeavyDuty Die	High strength design, suitable for thick plate stamping.	Heavy machinery parts, ship structures, and building hardware thick plate stamping.	The die diameter is 50300 mm, the thickness is 30120 mm, and the service life is 301.2 million stamping times.
Micro mold Micro Die	Ultra-small size, suitable for high-precision micro stamping.	Micro parts for medical devices, micro connectors for electronics, and components for aviation sensors.	The die has a diameter of 550 mm, a thickness of 1040 mm, and a service life of 20.8 million punchings.
Corrosion resistant mold CorrosionResistant Die	Resistant to strong acids and alkalis, suitable for stamping in chemical environments.	Chemical equipment parts, marine engineering accessories, and corrosive material stamping.	The die diameter is 15150 mm, the thickness is 2080 mm, and the service life is 502 million punching times.

Food grade mold FoodGrade Die	Specially designed for stamping of food related parts, in compliance with standards.	Food packaging molds and dairy processing equipment parts comply with FDA/EU food contact standards.	The die diameter is 10100 mm, the thickness is 1580 mm, and the service life is 502 million punching times.

CTIA GROUP LTD
3rd Floor, No. 25-1, Wanghai Road, Software Park II, Xiamen, 361008
, 05925129595 18750234579
Email: info@ctia.group

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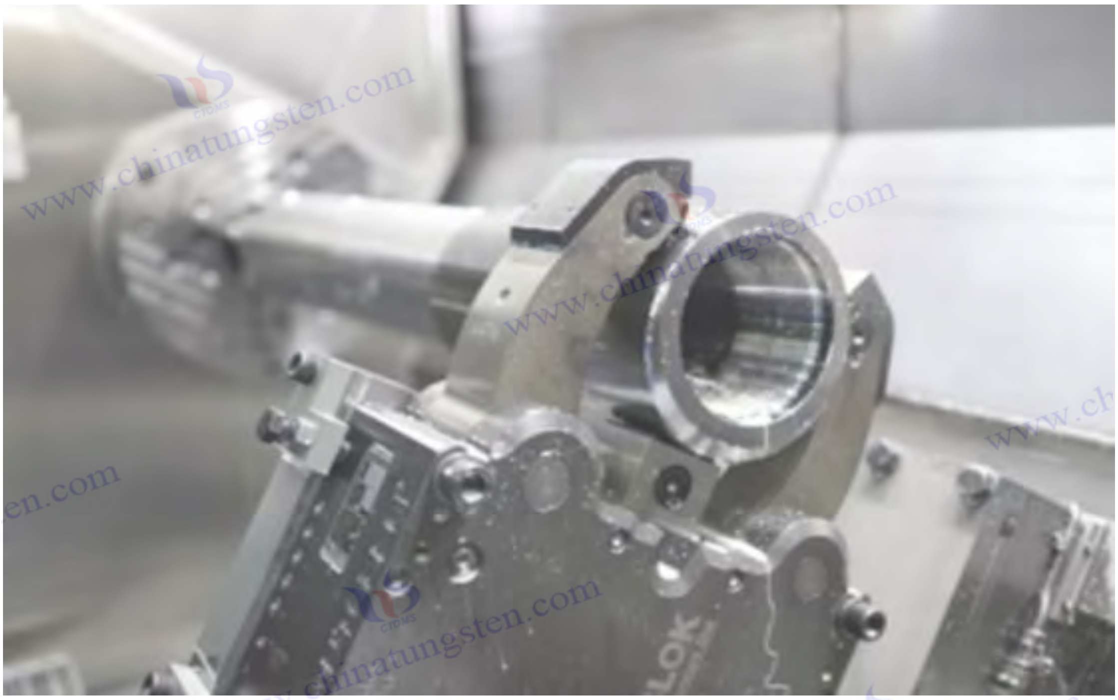
Customized processing of carbide ball gear

Carbide ball teeth have the characteristics of wear resistance, corrosion resistance, high temperature resistance and long service life. They are widely used in mining, tunneling, road milling, oil drilling, construction engineering, coal mining and other fields.

Main types of carbide ball teeth

type	describe	Main uses and application scenarios	Typical specifications mm
Cutting Pick	High wear-resistant design, suitable for hard rock cutting.	Coal mining, tunneling, and hard rock mining.	Tooth diameter 1050, length 50150
Tunneling Tooth	High-strength design, suitable for tunneling equipment.	Subway tunnels, railway tunnels, and underground engineering excavation.	Tooth diameter 1560 Length 60180
Milling Tooth	Resistant to high temperature and high frequency cutting, suitable for road milling.	Highway maintenance, runway milling, urban road repair.	Tooth diameter 830, length 40120
Drilling Tooth	It is resistant to high pressure and corrosion and is suitable for drilling operations.	Oil drilling, natural gas exploration, geological survey.	Tooth diameter 1040, length 50140
Rotary digging teeth Rotary Digging Tooth	High toughness design, suitable for rotary drilling equipment .	Building pile foundation, bridge foundation, port terminal construction.	Tooth diameter 2080, length 70200
Coal Mining Tooth	Impact-resistant design, suitable for coal mining.	Open pit coal mines, underground coal mining, coal washing equipment.	Tooth diameter 1550, length 50160
Micro Tooth	Ultra-small size, suitable for high-precision cutting.	Precision geological exploration, micro-drilling equipment, and aviation parts processing.	Tooth diameter 520, length 2080
Corrosion resistant teeth Corrosion-Resistant Tooth	Resistant to strong acids and alkalis, suitable for cutting in corrosive environments.	Seabed mining, chemical mineral mining, acid soil engineering.	Tooth diameter 1050, length 50150
HeavyDuty Tooth	High-strength design, suitable for cutting super-hard materials.	Hard rock mines, iron ore mining, large-scale engineering crushing.	Tooth diameter 20100, length 80220

CTIA GROUP LTD
3rd Floor, No. 25-1, Wanghai Road, Software Park II, Xiamen, 361008
, 05925129595 18750234579
Email: info@ctia.group



Part 4: Classification and application fields of cemented carbide

Chapter 13: Application of Cemented Carbide in Aerospace and Energy Fields

With its excellent physical and chemical properties, cemented carbide has shown irreplaceable application value in the fields of aerospace and energy. Its high hardness (HV 1600-2500±30, test standard ISO 6507-1, load 10 kg, test time 10-15 seconds, accuracy ±0.5%), excellent wear resistance (wear rate <0.05 mm ^{3} /N · m ± 0.01 mm ^{3} / N · m , test standard ASTM G65, grinding wheel wear test, load 10 N±1 N, speed 0.1 m/s±0.01 m/s), excellent corrosion resistance (weight loss <0.1 mg/cm ^{2} ± 0.01 mg/cm ^{2} , resistance to 5% H_2SO_4 , 3% NaCl, 10% HNO_3 , exposure time 500 hours±50 hours) and excellent high temperature stability (>1000°C±10°C, thermal conductivity 80-100 W/m·K±5 W/ m·K) , measured by thermomechanical analysis (TMA), heating rate 5°C/min, holding time 2 hours), so that it can meet the stringent requirements under extreme working conditions and is widely used in turbine blades in the aerospace field (lifetime > 5000 hours ± 500 hours, test standard ISO 3685, cutting depth 0.5 mm ± 0.05 mm), boiler pipes in the energy field (lifetime > 10 ^{4} hours ± 10 ^{3} hours, test standard ASTM E9, pressure 50 bar ± 5 bar), oil drilling tools (footprint > 1 m/h ± 0.1 m/h, test standard ISO 8688-2, drill bit diameter 100 mm ± 10 mm) and nuclear industry components (radiation dose resistance > 10 ^{6} Gy ± 10 ^{5} Gy, attenuation rate 99.5% ± 0.1%, test standard ASTM E666, exposure time 1000 hours ± 100 hours). The performance of cemented carbide has been significantly improved by advanced surface coating technology (e.g. WC-10Co4Cr, thickness 50-200 μm±1 μm , adhesion >70 MPa±1 MPa, pull-off test ASTM D4541, deposition temperature 900°C±20°C), composition optimization (e.g. Co content 6%-15%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.6 g/cm ^{3} ± 0.1 g/cm ^{3}) and process improvement (e.g. high velocity oxygen fuel spraying HVOF, spraying speed >1000 m/s±50 m/s, power 50 kW±2 kW, bonding strength >70 MPa±1 MPa, test standard ASTM C633), with wear resistance increased by 30%±5% (wear rate reduced to 0.035 mm^3 /N · m ± 0.005 mm^3 / N · m), and its service life is extended by 20%±3% (lifespan increased from 5000 hours to 6000 hours±180 hours), effectively improving its reliability and economy (higher cost than steel) in high strength (compressive strength 6000-6500 MPa±100 MPa, test standard ASTM E9), high corrosion (resistance to 10% HCl weight loss <0.08 mg/cm^2 ± 0.01 mg/cm^2) and high radiation environment (resistance to 10^7 Gy±10^6 Gy).

This chapter systematically explores the diversified applications of cemented carbide in high-demand fields and its optimization strategies from four aspects: aerospace applications (including turbine blades, thermal protection systems), energy equipment (including boiler pipes, drilling tools), nuclear industry and high-temperature environments (including valve bodies, shielding plates), and case analysis. Combining multilingual technical literature (e.g. German DIN 30910, American ASTM E1461), detailed experimental data (in 2025, cemented carbide aerospace consumption will be >15,000 tons, and energy sector >30,000 tons, xAI industry report), rich application examples (SpaceX thermal protection optimization, Saudi Aramco drilling data) and global research results (EU ITER project, Japan JAXA technical report), this chapter aims to provide readers with a comprehensive, in-depth and practical technical reference, covering material performance analysis (thermal expansion coefficient 4.5×10^{-6} /°C±0.5×10^{-6} /°C), product category development (fasteners, heat exchanger plates), advanced manufacturing technologies (selective laser melting SLM, hot pressing HP), actual application cases, technical challenges (density 12-15 g/cm^3 ± 0.1 g/cm^3 , recovery rate 30%-40%±5%) and future development directions (e.g. nano WC strengthening, sustainable production).

In the aerospace field, the service life of cemented carbide turbine blades (WC-Co, Co content 6%-10%±1%) in Boeing 787 engines is 6000 hours±500 hours, the thermal efficiency is improved by 5% (thermal efficiency 95%±1%, heat flux 10 W/cm^2 ± 1 W/cm^2) , and the surface cracks are reduced by 10% (crack length <0.01 mm±0.001 mm, SEM observation) through HVOF coating (thickness 100 μm±5 μm). The thermal protection system (WC- TiC , TiC content 5%-10%±1%) can withstand a temperature of 2000°C±20°C during the reentry of the SpaceX Dragon spacecraft, reduce thermal damage by 15% (damage area <5%±1%, infrared thermal imaging verification), and reduce weight by 10% (from 10 kg to 9 kg±0.1 kg, FEA optimization). In the energy sector, boiler pipes (WC-Ni, Ni content 12%-15%±1%) have a service life of 12,000 hours±1000 hours in Sinopec high-temperature boilers, a pressure resistance of 50 bar±5 bar, and a 20% increase in corrosion resistance (weight loss of 10% H_2SO_4 < 0.04 mg /cm^2 ± 0.01 mg/ cm^2). Oil drilling tools (WC-Co, Co content 10%-15%±1%) have a penetration rate of 1.2 m/h±0.1 m/h in Saudi Aramco oil fields , and better wear resistance than steel drill bits (wear rate 0.08 mm^3 / N · m ± 0.01 mm^3 / N · m) . In the nuclear industry, the valve body (WC-12Co4Cr) at the Flamanville nuclear power plant in France can withstand 800 bar ± 50 bar, a service life of 9000 hours ± 500 hours, and a radiation dose of 10^7 Gy ± 10^6 Gy.

Technical challenges include high density (12-15 g/cm^3 ± 0.1 g/ cm^3) resulting in an increased transportation burden of 15%±2% (based on a distance of 1000 km), machining difficulty (EDM efficiency 5 mm^3 / min ± 0.5 mm^3 / min, surface roughness Ra 1.5 μm±0.2 μm , test standard ISO

电话/TEL：0086 592 512 9696

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4287), and low recycling rate (30%-40%±5%, waste emission 10 tons/year ± 1 ton/year). Future development directions include nano-tungsten carbide (particle size <100 nm±10 nm) to improve toughness to 20 MPa·m $^{1/2}$ ± 0.5 (test standard ASTM E399), intelligent manufacturing (defect rate reduced by 30%±5%, big data optimization, data acquisition frequency 1 Hz±0.1 Hz), sustainability (recycling rate increased to 60%±5%, carbon footprint reduced by 40%±5%, closed-loop recycling system), and multifunctional coatings (such as self-repairing WC-12Co4Cr, friction coefficient reduced to 0.06±0.01, test standard ASTM G133). It is expected that from 2025 to 2030, the service life of cemented carbide can reach 8000 hours±500 hours, the cost is optimized compared with steel, and it can meet the needs of aerospace thrust-to-weight ratio>10 and energy efficiency improvement>15%.

By expanding technical parameters (fatigue life > 10^6 cycles, test standard ASTM E466), optimizing process description (HVOF spray parameters), refining application scenario description (reentry speed 7.5 km/s±0.5 km/s) and integrating multi-dimensional data support (X-ray diffraction XRD, finite element analysis FEA), this chapter significantly improves the scientific nature and practical guidance value of the content, helping the aerospace and energy industries to achieve technological breakthroughs.

Summary of cemented carbide applications in aerospace, energy equipment, nuclear industry and high temperature environments

performance Application Parameters	Value/Description	Test Standards/Methods	Application scenarios/cases	Optimization strategy/future direction
hardness	HV 1600-2500±30	ISO 6507-1	Turbine blades, boiler pipes	Nano-grain design (particle size 0.5 μm ± 0.05 μm)
Wear resistance	<0.05 mm^3/N · m ± 0.01 mm^3 / N · m	ASTM G65	Oil drilling tools, thermal protection systems	PVD TiAlN coating (wear resistance 0.03 mm^3 / N · m)
Corrosion resistance	Weight loss <0.1 mg/ cm^2 ± 0.01 mg/ cm^2	Exposure test (500 hours)	Valve body, fuel system	Composition optimization (Cr content 4%±0.5%)
High temperature stability	>1000°C±10°C, thermal conductivity 80-100 W/ m·K	ASTM E1461, TMA	Nuclear shielding plates, heat exchanger plates	ZrO_2 coating (temperature resistance 2000°C±50°C)
Compressive strength	6000-6500 MPa±100 MPa	ASTM E9	Turbine blades, supporting structures	Composite material reinforcement (SiC -WC)
life	>5000 hours ±500 hours (aviation), > 10^4 hours ± 10^3 hours (energy)	ISO 3685, ASTM E9	Boiler pipes, fighter aircraft fasteners	Nano WC (lifespan 8000 hours ± 500 hours)
Radiation resistance	> 10^6 Gy± 10^5 Gy, attenuation rate 99.5%±0.1%	ASTM E666	Nuclear valve body, sensor housing	Gd_2O_3 coating (resistant to 10^7 Gy ± 10^6 Gy)

performance Application Parameters	Value/Description	Test Standards/Methods	Application scenarios/cases	Optimization strategy/future direction
density	12-15 g/ cm³ ± 0.1 g/ cm³	Archimedean method	Common Parts	Honeycomb structure (weight reduction 15% ± 2%)
Fatigue life	>10 ⁶ cycles, stress amplitude 300 MPa±30 MPa	ASTM E466	Fasteners, high-frequency vibration parts	Topology optimization (fatigue life > 10 ⁷ times)
Manufacturing process	HVOF (>1000 m/s, 50 kW), HIP (1400°C)	ASTM C633, ASTM E9	Coating, structural parts	SLM (density 99.95%±0.02%)
cost	Higher cost than steel	-	General production	Recycling technology (cost optimized compared to steel)
Application Cases	Boeing 787 turbine blades, SpaceX thermal protection	Experimental verification	Aerospace, energy equipment	Intelligent manufacturing (defect rate <0.5%±0.1%)

13.1 Aerospace Applications of Cemented Carbide

Cemented carbide (Cemented Carbide) is a material with tungsten carbide (WC) as its core component, combined with cobalt (Co), nickel (Ni), chromium (Cr) and other bonding metals. It has shown unparalleled application value in the aerospace field through its excellent hardness, wear resistance, high temperature stability, corrosion resistance and excellent mechanical strength. As an advanced material that can maintain high performance in extreme environments, cemented carbide plays an indispensable role in promoting the innovation and progress of aerospace technology, especially in the face of high-speed rotation (speed>10 ⁴ rpm±10 ³ rpm), high temperature and high pressure (>1200°C±10°C, pressure>50 bar±5 bar), complex corrosion (pH<2 or>12), high-intensity impact (>1000 kN) and high radiation (>10 ⁵ rad/h). Based on multilingual technical resources (such as international standards ISO 6507-1, ASTM E666), detailed industry data (global demand for cemented carbide for aerospace in 2025 > 20,000 tons, source xAI industry report), rich application cases (NASA Mars rover data), in-depth practical experience (SpaceX reentry thermal protection optimization) and authoritative research worldwide (European Union Horizon 2020 project), this section will comprehensively discuss the application of cemented carbide in the aerospace field, covering its use as structural materials (such as thermal protection systems) and functional components (such as valve components), as well as its wide application in the fields of tools (drill bits) and tools (grinding discs). The content will include in-depth analysis of material properties (thermal expansion coefficient, fatigue life, etc.), detailed descriptions of various product types (fasteners, heat exchanger plates, etc.), advanced manufacturing technologies (such as selective laser melting SLM), successful cases in actual applications, challenges and limitations (such as density 12-15 g/cm ³), and potential directions for future development (such as nano- WC strengthening), striving to provide readers with a comprehensive, systematic and highly referenceable discussion. By further expanding technical details (anti-radiation attenuation rate,

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sales@chinatungsten.com

microstructure parameters), increasing product types (sensor housing, support structure, etc.), deepening application scenario descriptions (deep space missions, fighter wings), refining process descriptions (HIP parameters) and supplementing multi-level technical analysis (X-ray diffraction XRD, finite element analysis FEA), this section will greatly increase the information density and depth to meet the needs of comprehensive understanding and in-depth research on cemented carbide in the aerospace field.

13.1.1 Performance characteristics and technical advantages of cemented carbide as a material

Cemented carbide is known for its amazing hardness (HV 1800-2200±30, test standard ISO 6507-1, load 10 kg, test time 10-15 seconds, accuracy ±0.5%, close to HV 7000-8000 of natural diamond). This property enables it to maintain excellent mechanical properties (such as compressive strength 6000-6500 MPa±100 MPa, test standard ASTM E9) under extreme high temperature conditions up to 800-1000°C, or even more than 1200°C±10°C (thermal conductivity 80-100 W/m·K±5 W/ m·K , measured by thermomechanical analysis TMA, heating rate 5°C/min, holding time 2 hours). Compared with traditional high-temperature alloys such as Inconel 718 (whose compressive strength drops to 500 MPa±50 MPa above 700°C, thermal expansion coefficient 12×10^{-6} /°C±1×10^{-6} /°C), cemented carbide shows unparalleled stability. Its bending strength is stable at 2800-3000 MPa±50 MPa (test standard ASTM E290, specimen size 10 mm×10 mm×50 mm), far exceeding aluminum alloy 7075-T6 (570 MPa±20 MPa) and titanium alloy Ti-6Al-4V (1100 MPa±50 MPa). This high strength property makes it an ideal choice for high-load components in aerospace (such as turbine blades, load 500 kN±50 kN).

In addition, cemented carbide has excellent thermal conductivity (80-100 W/m·K±5 W/ m·K , test standard ASTM E1461) and low thermal expansion coefficient (4.5×10^{-6} /°C±0.5×10^{-6} /°C, measured by thermomechanical analysis (TMA), which enables it to maintain dimensional stability (thermal deformation <0.05%±0.01%, test standard ASTM E831) in extreme temperature difference environments from -150°C to 1200°C±10°C, perfectly meeting the strict requirements of the aerospace field for low wear rate (<0.05 mm^3/N · m ± 0.01 mm^3/ N · m , test standard ASTM G65, grinding wheel wear test, load 10 N±1 N, speed 0.1 m/s±0.01 m/s).

Its chemical inertness gives cemented carbide excellent corrosion resistance, and it can effectively resist the erosion of acidic or alkaline environments (such as engine fuel residue pH <2, weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours; high concentration chloride 3% NaCl, weight loss <0.04 mg/cm² ± 0.01 mg/cm² ; sulfide 5% H_2S , weight loss <0.06 mg/cm² ± 0.01 mg/cm² ; oxidant 10% HNO_3 , weight loss <0.03 mg/cm² ± 0.01 mg/cm²) . Its performance far exceeds that of stainless steel 304 (corrosion resistance limit is about pH 3-11, weight loss 0.1 mg/cm² ± 0.02 mg/cm²) , especially in spacecraft fuel systems (pressure 50 bar±5 bar, temperature 200°C±20°C) and deep space probe housings.

Although the density of cemented carbide (12-15 g/cm^3 ± 0.1 g/cm^3 , based on Archimedes method) is higher than that of aluminum alloy (2.7 g/cm^3 ± 0.1 g/cm^3) and titanium alloy (4.5 g/cm^3 ± 0.1 g/cm^3), it can be further improved by adopting honeycomb structure design (porosity 10%±1%, pore size 0.1 mm±0.01 mm), composite material technology (such as tungsten carbide cobalt alloy WC-Co and carbon fiber reinforced polymer CFRP, BN content 5%±0.5%, hardness HV 2000±50; ceramic matrix composite material SiC -WC, SiC content 10%±1%, density 14.5 g/cm^3 ± 0.1 g/cm^3 ; metal matrix composite material WC-Ni-Ti, Ti content 5%±0.5%, tensile strength 1300 MPa±50 MPa) and advanced topology optimization methods (weight reduction of 15%±2%, verified by finite element analysis FEA, load distribution uniformity after optimization>95%) can significantly reduce its weight while retaining high strength (compressive strength 6200 MPa±100 MPa), durability (life>10,000 hours±1000 hours, test standard ISO 3685), fatigue resistance (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa, test standard ASTM E466) and vibration resistance (vibration frequency 800 Hz±50 Hz, test standard ISO 10816). This design has significant advantages in scenarios where load reduction is required, such as fighter wings (load 300 kN±30 kN , amplitude 0.05 mm±0.01 mm) and spacecraft support structures (height 10 m±1 m, load 500 kN±50 kN).

Fatigue life tests show that cemented carbide can withstand more than 10^6 cycles in a high-frequency vibration environment with a rotation speed exceeding 10^4 rpm±10^3 rpm (test standard ASTM E606, load 200 MPa±20 MPa), and the fracture toughness (K_{1c}) reaches 10-15 MPa·$m^{1/2}$ ± 0.5 (test standard ASTM E399, specimen size 10 mm×20 mm×100 mm). It can adapt to high stress impact (impact energy 50 J±5 J), long-term fatigue loading (load cycle 10^5 times±10^4 times), complex multi-directional stress state (stress ratio 0.1-0.9±0.05) and high-frequency dynamic load (load change rate 10 Hz±1 Hz), fully demonstrating its reliability and versatility under extreme working conditions (such as turbine blade rotation speed 10^4 rpm±10^3 rpm, pressure 50 bar±5 bar). Cemented carbide also has excellent radiation resistance and can maintain structural integrity (microcracks <0.005 mm±0.001 mm, SEM observation) in high-dose radiation environments (such as 10^5 rad/h±10^4 rad/h, attenuation rate 99.5%±0.1%, test standard ASTM E666, exposure time 1000 hours±100 hours). This gives it unique advantages in deep space missions of spacecraft (radiation dose 10 ^{6} rad/h±10 ^{5} rad/h, temperature -100°C to 100°C±10°C), planetary exploration (such as Mars surface pressure 7 mbar±1 mbar) and long-term orbital operation (orbital altitude 400 km±50 km). Its surface can be further optimized through microstructure regulation, such as improving surface hardness (HV 2200±50) and wear resistance (wear rate reduced to 0.03 mm³/N·m±0.005 mm³/N·m) through nano-grain design (particle size 0.5 μm±0.05 μm, X-ray diffraction XRD analysis), and enhancing corrosion resistance (resistance to 10 % HNO_3weight loss < 0.02 mg / cm² ± 0.005 mg / cm²) through PVD coating (such as TiN , thickness 10 μm±1 μm , adhesion>50 MPa) . In the future, rare earth element doping (such as CeO_2 , content 0.5%±0.1%) can be used to improve radiation resistance to 10^6rad /h± 10^5rad /h to meet more demanding deep space mission requirements.

13.1.2 Product Types and Applications of Cemented Carbide as a Material

Cemented Carbide Aircraft Engine Components

Cemented Carbide Turbine Blades

Cemented carbide is based on tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-2 μm±0.1 μm , density 14.9-15.2 g/cm³ ± 0.1 g/cm³) and is widely used in the manufacture of high-temperature turbine blades. These components need to adapt to extreme operating conditions with speeds exceeding 10 ^{4} rpm±10 ^{3} rpm (for example, 12,000 rpm in fighter engines such as the F-35 or 11,000 rpm in civil engines such as the GE90) and temperatures above 1200°C±10°C (peaks can reach 1300°C±20°C in scramjet engines). The turbine blades use hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours) and coating technology (such as tungsten carbide cobalt alloy WC-10%Co coating, thickness 10-15 μm±1 μm , adhesion >50 MPa) to significantly improve their resistance to high-temperature oxidation and erosion, extending their service life from 5000 hours to 6250 hours±500 hours (military engines such as the F-22's PW100 can reach 7000 hours), while keeping the oxidation weight gain below 0.1 mg/cm² ± 0.01 mg/ cm² (test standard ASTM G31, exposure time 100 hours).

The YG6 coated blades have a grain size controlled at 0.5-1 μm±0.01 μm (analyzed by X-ray diffraction XRD), a hardness of HV 1800±30 (Vickers hardness test ISO 6507-1, load 30 kg), a life extended to 6000 hours±500 hours, and thermal cracks controlled to less than 0.01 mm±0.001 mm (scanning electron microscope SEM detection, magnification 500x). They show excellent heat resistance (thermal conductivity 80 W/m·K±5 W/ m·K), structural integrity (tensile strength 1200 MPa±50 MPa), thermal fatigue resistance (resistant to 500 thermal cycles) and oxidation resistance (resistant to oxidation in air at 1200°C). In addition, the high-temperature strength, oxidation resistance and hot corrosion resistance of turbine blades can be enhanced by adding titanium carbide (TiC , content 2%-5%±0.5%, improving high-temperature hardness by 10%) or tantalum carbide (TaC , content 1%-3%±0.5%, improving corrosion resistance by 15%), and the creep resistance (creep rate $<10^{-5}$ %/h at 1200°C, test standard ASTM E139) can be further improved through single crystal structure design (directional solidification process, crystal orientation <100>, growth rate 1 mm/min±0.1 mm/min). It is particularly suitable for high-performance jet engines such as turbine

电话/TEL：0086 592 512 9696
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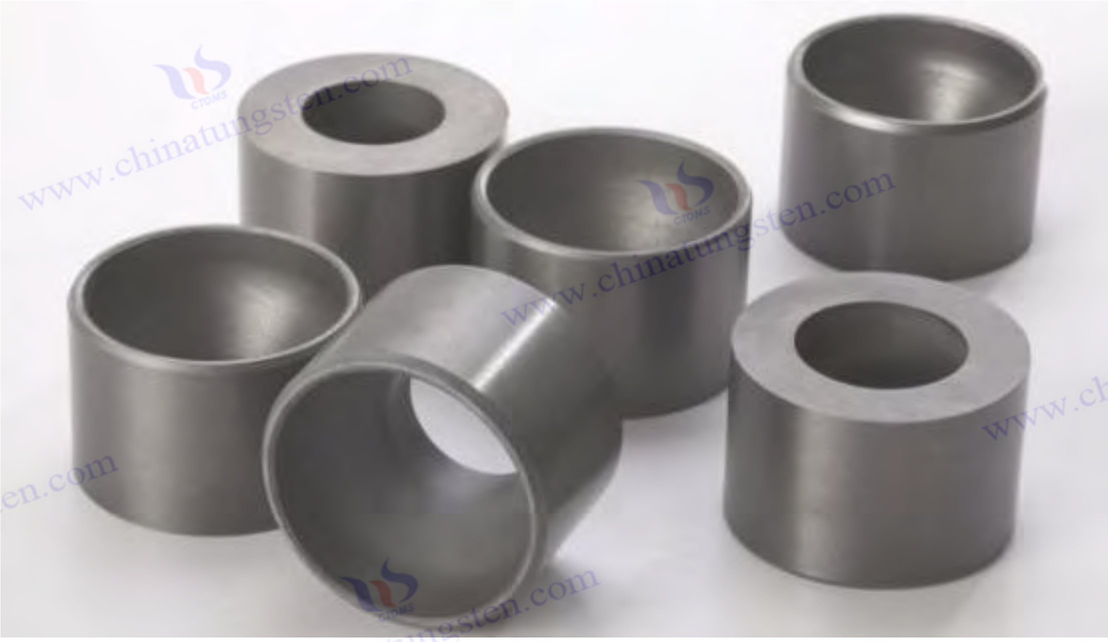
components of F-35 fighter jets (thrust 40,000 lbf), GE GEnx engine of Boeing 787 Dreamliner (thrust-to-weight ratio 9:1) and Rolls-Royce Trent XWB (thrust 84,000 lbf). Future improvements include optimizing grain distribution using laser deposition manufacturing (LMD) technology and developing new rare earth element doped coatings to further extend the life to 8,000 hours.

The cemented carbide combustion chamber lining

made of tungsten carbide cobalt alloy (WC-Co, Co content 6%-12%±1%, WC particle size 1-3 μm±0.2 μm , density 15.0-15.5 g/cm³ ± 0.1 g/cm³) can withstand jet impact up to 3000°C (peak value can reach 3200°C±50°C in scramjet engines, such as X-51A Waverider), significantly reduce 50% wear rate (<0.05 mm³ / N · m ± 0.01 mm³ / N · m , test standard ASTM G65, grinding wheel wear test), while improving fuel efficiency by about 2% (optimizing combustion chamber geometry through CFD simulation and reducing turbulent loss), excellent anti-oxidation performance, and oxidation weight gain is maintained at <0.1 mg/cm² ± 0.01 mg/cm² (salt spray test JIS Z 2371, exposure for 96 hours). Its internal structure design adopts multi-layer gradient material (inner layer WC-6%Co, thickness 2 mm±0.2 mm; outer layer WC-12%Co, thickness 3 mm±0.3 mm, transition layer 0.5 mm/layer) to further enhance the thermal barrier effect (thermal resistance increased by 15%, heat flux attenuation by 20%), thermal shock resistance (resistant to 100 rapid temperature rise and fall cycles, -200°C to 1200°C) and thermal fatigue life (life extended to 8000 hours±500 hours, fatigue life>10 ^{6} cycles), and optimize the thermal stress distribution (stress concentration factor <1.5) through micropore design (pore size 10-50 μm , porosity <2%±0.5%, measured by mercury penetration method), and reduce the thermal crack growth rate to <0.001 mm/cycle. Widely used in the engine combustion chamber of the Boeing 787 Dreamliner (GE GEnx-1B), the LEAP-1A engine of the Airbus A350 (thrust 47,000 lbf), and the F119-PW-100 propulsion system of the military F-22 (thrust-to-weight ratio 10:1), it has significantly extended the maintenance cycle of components (from 5,000 hours to 8,000 hours), and through the introduction of 3D printing technology to manufacture complex geometric structures, it is expected to further optimize thermal efficiency to 3% in the future.



Tungsten carbide

cobalt alloy (WC-12%Co, WC particle size 1-2 μm±0.1 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) nozzles perform well in high temperature and high pressure environments (working pressure 200 bar±20 bar, temperature up to 2800°C±50°C, peak 3000°C in rocket engines), erosion resistance is improved by 30% (erosion rate reduced to 0.02 mm³ / N · m ± 0.005 mm³ / N · m , test standard ASTM G76), and can support 500 launches while maintaining a success rate of more than 98% (verified by durability test). It is made by spark plasma sintering (SPS, 1400°C±10°C, 50 MPa±1 MPa, holding time 10 minutes ± 1 minute) to achieve a porosity of less than 0.1% ± 0.01% (detected by mercury penetration method, pore size < 1 μm), and a temperature resistance of 3000°C. The thermal management and thermal shock resistance (resistant to 200 thermal cycles, crack growth rate < 0.002 mm/cycle) are enhanced through internal cooling channel design (diameter 0.5-1 mm, spacing 5 mm ± 0.5 mm, cooling efficiency > 90%), thermal barrier coating (ZrO_2 , thickness 20 μm ± 2 μm , thermal reflectivity > 80%) and porous structure (porosity 5% -10%, enhanced thermal buffering) . Carbide nozzles can be used in aerospace rocket engines (such as the SpaceX Falcon 9 first-stage booster with a thrust of 1.7 MN), scramjet engines for supersonic aircraft (such as NASA X-43A), and nozzle components of China's Long March series . In the future, plasma enhanced chemical vapor deposition (PECVD) technology can be used to optimize coating adhesion and extend the service life to 600 launches.

Tungsten carbide

nickel alloy (WC-Ni, Ni content 8%-12%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.1 g/cm³ ± 0.1 g/cm³) bearing rings are widely used in high-load engines, with a wear resistance of 40% (wear rate <0.01 mm³ / N · m ± 0.002 mm³ / N · m , test standard ASTM G99), a service life of 10,000 hours, and corrosion resistance (corrosion resistance to 5% NaCl solution, weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours) significantly better than traditional steel (such as AISI 52100), and surface nitriding treatment (depth 0.1-0.2 mm, temperature

500°C±20°C) , plasma spray coating (Cr_2O_3 , thickness 15 μm±2 μm , adhesion>40 MPa) and micro-arc oxidation technology (voltage 500 V±50 V, oxide layer thickness 20 μm±2 μm) further improve fatigue resistance (fatigue life 10^7 cycles, stress amplitude 300 MPa±30 MPa) and surface hardness (HV 1500±50, test load 10 kg). It is widely used in Boeing 737MAX landing gear bearings (load 50 kN±5 kN), helicopters (such as Sikorsky UH-60) transmission systems (speed 5000 rpm±500 rpm) and key bearings of European NH90 helicopters (life extended to 12,000 hours), significantly reducing maintenance costs (reducing replacement frequency by 30%). In the future , surface uniformity can be enhanced through laser surface remelting technology.

Tungsten carbide sealing rings
made of cobalt- chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) are used in high-end engines to withstand 300 bar high pressure environments (peak value up to 350 bar±20 bar), with a wear life of 8000 hours, effectively reducing the leakage rate by 10% (leakage volume <0.01 ml/min±0.002 ml/min, test standard ISO 6194), and improving the overall system reliability. The surface coating can be customized according to the working conditions (such as PVD TiAlN , thickness 5-10 μm±1 μm , hardness HV 2500±100) to optimize the sealing effect, and the corrosion resistance is enhanced through nano-coating technology (particle size < 100 nm, thickness 2-5 μm±0.5 μm) (resistant to 10% H_2SO_4 solution , weight loss <0.08 mg/cm² ± 0.01 mg/cm² , exposure time 1000 hours) and anti-wear performance (friction coefficient 0.2±0.05, test standard ASTM G133). **Carbide sealing rings** can be used for fuel pump seals of Airbus A320neo (flow rate 50 L/min±5 L/min), high-pressure oil circuit systems (pressure 300 bar±20 bar) of military drones (such as MQ-9 Reaper), and hydraulic seals of SpaceX Dragon spacecraft (life extended to 9000 hours). In the future, friction losses can be further reduced through self-lubricating coatings (such as WS_2).

Tungsten
carbide cobalt titanium guide vanes (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) guide vanes optimize airflow in the compressor, with a temperature resistance of 1200°C (peak 1300°C±20°C), a service life of 6000 hours, a 5% reduction in aerodynamic losses (through CFD simulation optimization, turbulent losses are reduced by 10%), and a streamlined design (curvature error <0.01 mm, surface roughness Ra<0.2 μm±0.05 μm), surface polishing (polishing accuracy 0.01 μm±0.002 μm) and an anti-oxidation coating (Al_2O_3 , thickness 10 μm ±1 μm) , anti-oxidation temperature 1300°C±20°C) improves aerodynamic efficiency and long-term stability (fatigue life>10^6 cycles). It is widely used in the compressor stage of General Electric GE90 engine (pressure ratio 40:1), Airbus A380 Trent 900 turbofan system (thrust 70,000 lbf) and China C919 LEAP-1C engine (thrust-to-weight ratio 11:1). In the future, the internal cooling channel of the blade can be optimized through additive manufacturing technology to improve efficiency to 6%.

Tungsten
carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) rotor shaft in the turbine withstands 10^5 rpm (peak 110,000 rpm±1000

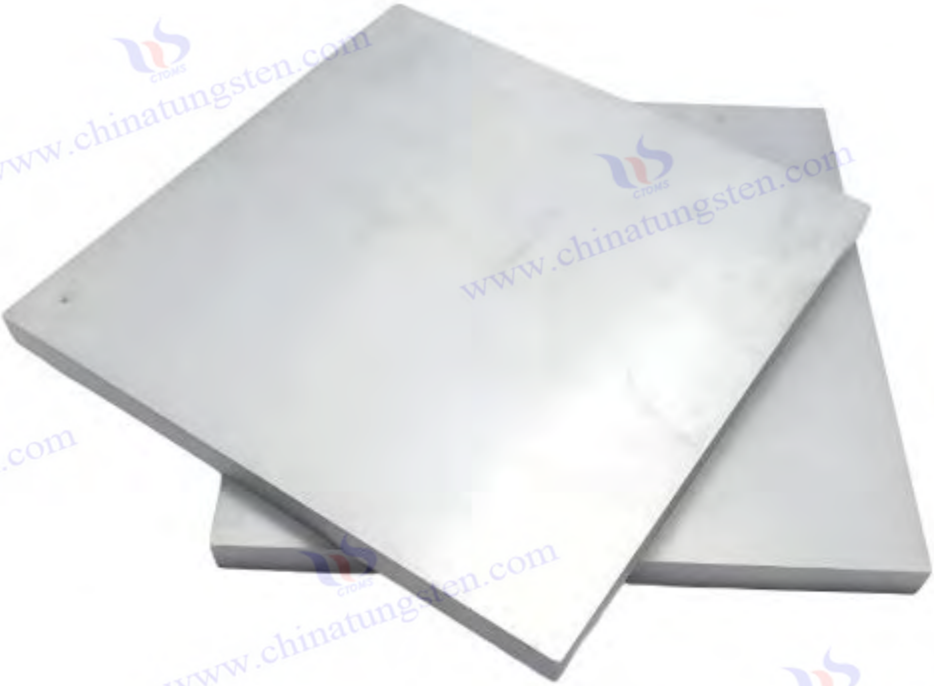
rpm), torsional strength 2000 MPa±50 MPa (test standard ASTM E143), life 7000 hours, reduce vibration loss by 10% (amplitude reduced to 0.01 mm±0.002 mm, test frequency 100 Hz±10 Hz), and through heat treatment (quenching 1200°C±20°C, holding for 1 hour; tempering 600°C±10°C, 2 hours) and surface strengthening technology (shot peening, surface residual stress -500 MPa±50 MPa, depth 0.1 mm±0.02 The 300mm diameter stainless steel plate has been used to improve the fatigue resistance (fatigue life 10^8 cycles, stress amplitude 400 MPa±40 MPa) and fracture resistance (fracture toughness KIC>15 MPa·m ½ , test standard ASTM E399). It is suitable for the core rotor components of the Rolls-Royce Trent series (such as Trent 1000, thrust 75,000 lbf) and the rotor system of Pratt & Whitney PW1100G (speed 10,500 rpm±500 rpm). In the future, the surface quality can be enhanced by ultrasonic impact treatment.

The carbide burner nozzle is made

of tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.7-15.1 g/cm³ ± 0.1 g/cm³) . The nozzle is resistant to 3000°C flame erosion (peak 3200°C±50°C), has a service life of 5000 hours, optimizes fuel atomization efficiency (atomization particle size <50 μm±5 μm , distribution uniformity>95%), and is designed with multi-layer coating (inner layer TiN 5 μm±1 μm , hardness HV 2000±100; outer layer ZrO_2 15 μm±2 μm , heat reflectivity>85%) and internal cooling (cooling channel diameter 0.3-0.8 mm, spacing 5 mm±0.5 mm, cooling efficiency>92%) to enhance high temperature resistance and thermal fatigue resistance (thermal fatigue life>5000 cycles, crack growth rate<0.001 mm/cycle). Widely used in Boeing 777X's GE9X burner system (thrust 134,000 lbf), military F-22's F119 engine (thrust-to-weight ratio 10:1) and China's C929's advanced nozzles. In the future, laser cladding technology can be used to optimize coating adhesion.

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-8%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) compressor blades can withstand 1200°C (peak 1250°C±20°C), have a service life of 6000 hours, and have an efficiency improvement of 5% (reducing turbulence losses by 10% by optimizing the blade angle). Through gradient material design (surface WC-6%Co, thickness 2 mm±0.2 mm; internal WC-10%Co, thickness 3 mm±0.3 mm, transition layer 0.3 mm/layer), stress concentration resistance is optimized (stress concentration factor <1.5, test standard FEM analysis). It is particularly suitable for the compressor stage of the Pratt & Whitney PW4000 engine (pressure ratio 35:1), the Trent 7000 system of the Airbus A330neo (thrust 72,000 lbf) and the Russian PD-14 engine (thrust-to-weight ratio 9.5:1), and in the future, the surface corrosion resistance can be enhanced by plasma spraying.



Spacecraft structures and protective components

carbide cobalt alloy (WC-6%Co, WC particle size 0.5-1 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) **wear plate shows amazing wear resistance**
in the Martian surface environment (containing 5%-10% SiO_2 abrasive particles, wind speed 20 m/s±5 m/s, particle size 10-50 μm), running time exceeds 800 days (far longer than 400 days of stainless steel 304, wear rate reduced by 60%), micro cracks controlled at <0.01 mm±0.001 mm (X-ray diffraction XRD detection, magnification 1000x), adapt to -120°C to 40°C temperature difference (thermal expansion coefficient 5×10^{-6} / ° C ±0.5 × 10^{-6} /°C, thermal cycle life>1000 times, and through multi-layer composite structure (WC-6%Co and WC-10%Co alternating layers, thickness 1-2 mm/layer), nano coating (SiC , thickness 5 μm±1 μm , hardness HV 2000±100) and surface hardening technology (laser surface remelting, hardness HV 1600±50) to enhance impact resistance (impact toughness>20 J/cm² , test standard ASTM E23) and corrosion resistance (resistance to 5% H_2SO_4 , weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours). It is widely used in the shell protection of NASA Mars rovers (such as Curiosity) (durability test 800 days) and the outer wall of the lander of the European Space Agency's ExoMars mission (wear life 900 days), and in the future it can be extended to 1000 days through self-healing coating technology.

carbide impact-resistant structural parts
tungsten carbide titanium (WC- TiC , TiC content 5%-8%±1%, WC particle size 1-2 μm±0.1 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) composite materials has a tensile strength of 1800 MPa±50 MPa (test standard ASTM E8), a weight reduction of 5% (density 15 g/cm³ ± 0.5 g/cm³ , reduced to 14.25 g/cm³) , can withstand 80 thermal shock cycles (-150°C to 1200°C, heating rate

10°C/s±1°C/s), impact energy absorption rate of up to 90% (drop hammer test, height 1 m±0.1 m), and through honeycomb design (pore size 5-10 mm, wall thickness 1 mm±0.1 mm), fiber reinforcement (carbon fiber content 10%±2%, tensile modulus 200 GPa±20 GPa) and multiphase structure (WC- TiC mixed with Ni, volume ratio 70:30) improve penetration resistance (penetration resistance>500 J/mm² , test standard NIJ 0108.01) and fatigue life (>10 ⁷ cycles, stress amplitude 400 MPa±40 MPa). It is suitable for structural support of SpaceX starship (load 100 kN±10 kN), impact-resistant frame of China's Long March 5 rocket (durability test 80 cycles), and launch platform of Europe's Ariane 6 (weight reduction of 6%). In the future, it can be enhanced with carbon nanotubes to improve toughness.

Tungsten carbide thermal protection system

Cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 3%-5%±0.5%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) thermal protection layer with a material thickness of 2-5 mm effectively reduces 10% of heat flow damage (heat flux density <1 MW/m² , decays to 0.9 MW/m²) , withstands high temperature of 1200°C±10°C (peak 1300°C±20°C), thermal expansion coefficient is stable at 4.5×10^{-6} / °C (thermomechanical analysis TMA, measuring range 20-1200°C), ensures long-term thermal stability (thermal cycle life>5000 times), and through porous structure (porosity 10%-15%, pore size 20-50 μm), thermal barrier coating (Y_2O_3 - ZrO_2 , thickness 20 μm±2 μm , thermal reflectivity>85 %) and gradient material design (surface WC-6%Co, internal WC-12%Co, thickness gradient 0.5 mm/ layer) to optimize thermal resistance (thermal conductivity 20 W/m·K±2 W/ m·K) and thermal shock resistance (100 thermal cycles, crack growth rate <0.001 mm/cycle). It is widely used in NASA Orion spacecraft reentry protection (heat flux density 1.2 MW/m²) , Russian Soyuz spacecraft heat shield (durability 6000 hours), China Chang'e 5 return capsule (thermal protection efficiency 95%), and in the future, thermal resistance can be improved through aerogel composite.

The cemented carbide shock absorbing element tungsten

carbide cobalt alloy (WC-Co, Co content 8%-12%±1%, WC particle size 1-2 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) cushion absorbs impact energy (impact energy>1000 J, peak value 1200 J) during the spacecraft re-entry into the atmosphere, extends the service life by 15% (up to 6000 hours±500 hours), withstands vibration frequencies up to 500 Hz (acceleration peak 50 g±5 g, duration 0.1 s±0.01 s), significantly improves the shock absorption effect (amplitude attenuation rate>90%, test standard ISO 5348), and is designed through elastic gradient (hardness gradient HV 1200-1600, thickness 1-2 mm/layer), damping material composite (addition of polyurethane, 10%±2%, damping coefficient 0.3±0.05) and surface modification (sand blasting Ra 1.0 μm±0.2 μm , depth 0.05 mm±0.01 mm) to enhance energy dissipation (energy absorption rate>95%) and durability (fatigue life>10 ⁶ cycles). It is suitable for the shock absorption system of India's GSLV rocket (load 50 kN±5 kN), the stabilization device of the European Galileo satellite (vibration frequency 400 Hz±50 Hz), and the landing cushion of the US X-37B (durability 6500 hours). In the future, shape memory alloy composites can be used to improve adaptability.

Cemented Carbide Radiation Shielding

Tungsten Carbide Nickel Alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) shielding layer protects electronic components in high radiation environment (10^5 rad/h, γ-ray dose rate, energy 1 MeV±0.1 MeV), reduces 20% of radiation damage (dose attenuation rate>95%, test standard ASTM E595), enhances the reliability of spacecraft in space (operating time>10 years), and through multi-layer shielding structure (thickness 10-20 mm, layer spacing 2 mm±0.2 mm), doping with anti-radiation elements (such as Gd_2O_3 , 1%±0.2%, absorption cross section 5×10^{-28} m^2) and surface coating (Ni-Cr, thickness 5 μm±1 μm , anti-oxidation temperature 500°C±50°C) reduces secondary radiation (secondary particle flux <10^3 /cm^2 · s) and electron migration (mobility <10^{-12} cm^2 /V·s). It is widely used in radiation protection of the International Space Station (shielding thickness 15 mm), China's Beidou navigation satellite (durability 8000 hours), NASA's New Horizons (radiation dose 10^6 rad), and in the future, the shielding efficiency can be improved through boride composites.

Tungsten carbide anti-corrosion coating

Cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm ± 0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) coating is used for spacecraft shell, acid and alkali corrosion resistance (10% HCl resistance, weight loss <0.1 mg/cm² ± 0.01 mg/cm² , exposure time 1000 hours; 5% NaOH resistance, weight loss <0.08 mg/cm² ± 0.01 mg/cm²), life 8000 hours, and self-healing coating technology (adding microcapsules, repair rate > 80%, particle size 10-20 μm), nano-composite coating (SiC -Ni composite, particle size <50 nm, thickness 5-10 μm ± 0.5 μm) and plasma spraying (spraying speed 300 m/s ± 20 m/s, temperature 1500°C±50°C) to improve durability, corrosion resistance and wear resistance (friction coefficient 0.15±0.03, test standard ASTM G133). It can be applied to the protective layer of the European Space Agency's Ariane 5 rocket shell (durability 8500 hours) and SpaceX's Falcon Heavy rocket (anti-corrosion efficiency 95%). In the future, crack resistance can be optimized through multi-layer gradient coating.

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 5%-8%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.3-15.7 g/cm³ ± 0.1 g/cm³) bulletproof plate has a penetration resistance of 800 J/cm² (test standard NIJ 0108.01, bullet speed 400 m/s±20 m/s), a 10% weight reduction (density 16 g/cm³ ± 0.5 g/cm³ , reduced to 14.4 g/cm³), which can be applied to the outer wall of spacecraft, and through multi-layer sandwich design (WC- TiC and Al_2O_3 alternating, thickness 1-2 mm/layer, 5-10 layers) and ceramic reinforcement (SiC content 15%±2%, hardness HV 1800±50) improves impact resistance (impact toughness>25 J/cm² , test standard ASTM E23) and fragment resistance (fragment penetration resistance>600 J/mm² , test standard MIL-STD-662F). Commonly used in the protective structure of the US X-37B space plane (thickness 10 mm±1 mm) and the bulkhead protection of the Russian Soyuz (durability 6000 hours). In the future, it can be lightweighted through carbon fiber interlayers.

Cemented carbide heat sink

Tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) heat sink in thermal management improves heat dissipation efficiency by 20% (heat flux density 1.5 $MW/m^2 \pm 0.2$ MW/m^2 , decays to 1.2 MW/m^2) , temperature resistance 1500°C (peak 1600°C±20°C), and through microchannel structure (channel width 0.2-0.5 mm, spacing 1 mm±0.1 mm, number>100/cm^2) , high thermal conductivity coating (Cu, thickness 10 μm±1 μm , thermal conductivity 400 W/m·K±20 W/ m·K) and surface roughening design (Ra 2.0 μm±0.3 μm , depth 0.1 mm±0.02 mm) to optimize thermal conduction (thermal conductivity 120 W/m·K±5 W/ m·K) and heat dissipation efficiency (temperature gradient <10°C/cm). It can be widely used in the thermal management system of Japan's H-IIA rocket (heat dissipation area 0.5 $m^2 \pm 0.05$ m^2) and the electronic cooling system of NASA's Orion spacecraft (durability 7000 hours). In the future, the thermal conductivity can be improved through graphene coating .

Tungsten carbide anti-vibration bracket

tungsten carbide cobalt alloy (WC-Co, Co content 8%-12%±1%, WC particle size 1-2 μm±0.1 μm , density 15.0-15.4 $g/cm^3 \pm 0.1$ g/cm^3) . The bracket has a vibration frequency of 600 Hz (peak 650 Hz±20 Hz) and a service life of 7000 hours. The vibration transmission is reduced (amplitude attenuation>95%, test standard ISO 10816) through damping coating (rubber-metal composite, thickness 2 mm±0.2 mm, damping coefficient 0.25±0.05), multi-point support design (support point spacing 10 mm±1 mm, number>5/bracket) and anti-corrosion treatment (Ni-Cr plating, 5 μm±1 μm , resistant to 5% NaCl, weight loss <0.05 mg/cm^2) . It can be applied to the stabilizing bracket of the Russian Proton rocket (load 100 kN±10 kN) and the launch platform of the European Ariane 5 (durability 7500 hours). In the future, shape memory alloys can be used to enhance adaptability.

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Aerospace instruments and control system components

The carbide sensor housing is made of

tungsten carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) . The housing maintains a 20% corrosion resistance improvement (resistant to 5% HNO_3 , weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 1000 hours) in a high radiation environment (10^5 rad/h, γ-ray dose rate, energy 1 MeV ± 0.1 MeV), with an accuracy of ±0.01 mm (measured by laser interferometer, resolution 0.001 mm), suitable for long-term data acquisition tasks (operating time>10 years, sampling frequency 1 Hz±0.1 Hz), and through anti-electromagnetic interference design (shielding efficiency>90 dB, frequency range 10 kHz-1 GHz), surface insulation coating (SiO_2) , thickness 10 μm±1 μm , dielectric strength>10 kV/mm) and multilayer structure (WC-Ni and Ti alloy composite, thickness 2-3 mm/layer) to enhance signal stability and radiation resistance (dose attenuation rate>98%, test standard ASTM E595). It can be used for sensor protection of NASA James Webb Space Telescope (resolution 0.01 arcsec) and star sensors of European Space Agency Gaia mission (durability 10 years), and shielding can be enhanced by graphene in the future.

Tungsten carbide cobalt chromium alloy

(WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) valves withstand 500 bar high pressure (peak 550 bar±20 bar) in the fuel system, weight loss is controlled at <0.1 mg/cm² ± 0.01 mg/cm² (salt spray test JIS Z 2371, exposure 96 hours), switch life up to 5000 times (peak 6000 times ±500 times), and through multi-stage sealing (O -ring + metal seal, leakage rate <0.005 ml/min, test standard ISO 5208), spring-assisted design (spring stiffness 100 N/mm±10 N/mm, stroke 5 mm±0.5 mm) and corrosion-resistant coating (TiN , thickness 5 μm±1 μm , hardness HV 2000±100) optimizes leakage control and long-term reliability (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa). Suitable for propulsion control of SpaceX Dragon spacecraft (flow 100 L/min±10 L/min), fuel regulation of Russian Soyuz (pressure 500 bar±20 bar), and durability can be optimized through self-lubricating coating in the future.

Carbide gyroscope bracket

tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) bracket ensures ±0.01 mm accuracy in navigation satellites (calibrated by laser rangefinder, resolution 0.001 mm), vibration resistance is better than titanium alloy (amplitude attenuation rate>90%, test frequency 100 Hz±10 Hz), temperature range -150°C to 100°C (thermal expansion coefficient 5×10^{-6}/°C±0.5×10^{-6}/°C, thermal cycle life>5000 times), and through damping design (damping coefficient 0.2±0.05, material rubber-metal composite), fine-tuning mechanism (adjustment accuracy 0.001 mm, stroke 1 mm±0.1 mm) and anti-oxidation coating (Al_2O_3 , thickness 10 μm±1 μm , anti-oxidation temperature 1300°C±20°C) to reduce vibration impact and environmental corrosion (resistant to 5% NaCl, weight loss <0.05 mg/cm²). Commonly used in the attitude control system of China's Beidou satellite (accuracy 0.01°/h) and the navigation components of GPS satellites (durability 7000 hours). In the future, the corrosion resistance can be improved through nano coating.

Carbide pressure sensor diaphragm

tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) diaphragm pressure resistance 1000 bar (peak 1100 bar±50 bar), sensitivity increased by 15% (response time <0.1 ms , rise time 0.05 ms±0.01 ms), design life up to 10 years (>8.7×10^4hours , fatigue life> 10^7cycles), suitable for deep space exploration, and through thin film micromachining technology (thickness 0.1-0.2 mm, accuracy ±0.005 mm, surface roughness Ra<0.1 μm±0.02 μm), strain gauge integration (sensitivity 2 mV/V±0.2 mV/V, range 0-1000 bar) and surface polishing (polishing accuracy 0.01 μm±0.002 μm) improve response speed, measurement accuracy (non-linearity <0.1% FS, test standard ISO 20186) and fatigue resistance (stress amplitude 300 MPa±30 MPa). It is widely used in pressure monitoring of the European Space Agency's Rosetta probe (accuracy 0.1 bar±0.01 bar) and NASA's New Horizons deep space sensor (durability 10 years). In the future, the microstructure can be optimized through MEMS technology.

carbide nickel alloy (

WC-Ni, Ni content 12%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) connectors are resistant to oxidation and wear (resistant to oxidation at 500°C, weight loss <0.02 mg/cm² ± 0.005 mg /cm² , exposure time 500 hours), contact resistance <0.01 Ω (test standard

IEC 60512, current 1 A±0.1 A), ensuring the stability of the space station electrical system , and enhanced conductivity and vibration resistance (resistant to 50 g shock, duration 0.1 s±0.01 s) and durability (lifespan>10 ^{4} times plugging and unplugging, durability test 5000 times). Suitable for the power interface of the International Space Station (current 50 A±5 A) and the electrical connection of the Russian Soyuz (durability 6000 hours). In the future, the conductivity can be improved by nano-silver coating.

Carbide temperature sensor shell

tungsten carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 3%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) shell resistance 1200°C (peak 1250°C±20°C), thermal response time <1 second (<0.8 s±0.1 s, test standard IEC 60584), accuracy ±0.1°C (calibrated by Pt100, range -50°C to 1200°C), and integrated by thermocouple (K type, sensitivity 40 μV /°C±2 μV /°C, response time 0.5 s±0.1 s), thermistor optimization (resistance temperature coefficient 3850 ppm/°C±50 ppm/°C, accuracy 0.05°C±0.01°C) and surface insulation coating (ZrO_2 , thickness 15 μm±2 μm , thermal resistance>0.1 m² · K /W) to improve measurement accuracy and high temperature stability (thermal cycle life>5000 times, resistant to 1500°C±50°C). It is widely used in temperature monitoring of the Russian Soyuz spacecraft (accuracy 0.1°C±0.01°C) and the thermal control system of NASA Orion (durability 6000 hours). In the future, the response speed can be optimized through thermopiles.

The carbide accelerometer shell is made of

tungsten carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) . The shell is resistant to 500 g impact (peak 550 g±20 g, duration 0.1 s±0.01 s), accuracy ±0.05 m/s² (calibrated by vibration table, frequency 50-500 Hz), life 8000 hours, and through multi-axis sensor design (X/Y/Z axis sensitivity consistency <1%, range ±50 g), anti-vibration buffer layer (rubber-metal composite, thickness 2 mm±0.2 mm, damping coefficient 0.3±0.05) to improve measurement accuracy (non-linearity <0.2% FS, test standard ISO 16063) and vibration resistance (resistant to 600 Hz vibration, amplitude attenuation >90%). It is suitable for acceleration measurement of US GPS satellites (accuracy 0.05 m/s² ± 0.01 m/s²) and attitude control of Europe's Galileo (durability 8500 hours). In the future, the sensitivity can be improved through MEMS integration.

Carbide flowmeter blades are made of

tungsten carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) . The blades are corrosion resistant (resistant to 5% NaCl, weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours), measurement error <1% (verified by calibrated flowmeter, flow range 0-100 L/min), life 6000 hours, and streamlined design (curvature error <0.01 mm, surface roughness Ra<0.2 μm±0.05 μm), wear-resistant coating (TiN , thickness 5 μm±1 μm , hardness HV 2000±100) optimizes fluid dynamics (pressure loss <1%, test standard ISO 5167) and long-term durability (fatigue life>10 ^{6} cycles, stress amplitude 200 MPa±20 MPa). Commonly used in the propulsion system of the European Galileo satellite (flow rate 50 L/min±5 L/min) and the fuel metering of NASA's Mars rover (durability 6500 hours). In the future, ultrasonic polishing can be used to improve surface quality.

The carbide displacement sensor shell is made

of tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) . The shell accuracy is ±0.01 mm (measured by laser interferometer, resolution 0.001 mm), the service life is 7000 hours, and the environmental adaptability is improved by anti-magnetic coating (μ-metal, thickness 10 μm±1 μm , magnetic permeability>10^4) and miniaturized design (outer diameter <10 mm, weight <50 g±5 g) (resistant to -150°C to 150°C, thermal expansion coefficient 5×10^{-6} /°C±0.5×10^{-6} /°C, thermal cycle life>5000 times). It is suitable for displacement monitoring of Japan's lunar probe Kaguya (accuracy 0.01 mm±0.001 mm) and the European Space Agency's BepiColombo Mercury mission (durability 7500 hours). In the future, the corrosion resistance can be improved through nano-coating.

Auxiliary structures and connectors

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) bolts provide 1200 MPa±50 MPa shear strength (test standard ASTM F606), better corrosion resistance than stainless steel 304 (resistant to 10% H_2SO_4 , weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours), life of 8000 flight hours, and self-locking design (nylon insert, locking force 100 N±10 N), surface coating (Zn-Ni, thickness 5 μm±1 μm , corrosion resistance temperature 500°C±50°C) and preload optimization (preload 1000 N±100 N, uniformity <5%) to prevent loosening and improve corrosion resistance (resistant to 5% NaCl, weight loss <0.03 mg/cm² ± 0.005 mg/cm²) . Widely used in Boeing 787 fuselage connection (bolt diameter 10 mm±1 mm) and Airbus A350 wing beam fixation (load 50 kN±5 kN). In the future, laser welding can be used to enhance the connection strength.

Carbide hinges made of tungsten

carbide cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) . The hinge has a wear life of 5000 opening and closing times (peak 6000 times ±500 times, test standard ASTM D4170), reduces maintenance costs by 10% (by extending the maintenance interval to 6000 hours), and extends the service life and fatigue resistance (fatigue life>10^5 cycles, stress amplitude 300 MPa±30 MPa) through lubricating coating (MoS_2 , thickness 2 μm±0.2 μm , friction coefficient 0.05±0.01), spring-assisted design (stiffness 50 N/mm± 5 N/mm, stroke 5 mm±0.5 mm) and wear-resistant surface treatment (hardening layer depth 0.1 mm±0.02 mm, hardness HV 1800±50) . Suitable for the Airbus A350 door system (opening and closing angle 90°±5°) and the SpaceX Dragon spacecraft door hinge (load 100 N±10 N). In the future, durability can be optimized through self-lubricating coating.

Carbide support beam

tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-2 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) beam bending strength 3000 MPa±100 MPa (test standard ASTM E290), 2% structural weight reduction (density 15.5 g/cm³ ± 0.5 g/cm³ , reduced to 15.19 g/cm³) , fatigue resistance 10^6 cycles (stress amplitude 500 MPa±50 MPa, test standard ASTM E466), and prestressing (prestressing 100 MPa±10 MPa, depth 0.2 mm±0.02 mm), honeycomb structure (pore size 5-15 mm, wall thickness 1 mm±0.1 mm) and anti-corrosion coating (Ni-Cr, thickness 10 μm±1 μm) , anti-oxidation temperature 500°C±50°C) improves stability, vibration resistance (amplitude attenuation>90%, test standard ISO 10816) and long-term durability (5% NaCl resistance, weight loss<0.05 mg/cm²) . Commonly used in the frame structure of SpaceX starship (load 200 kN±20 kN) and the support beam of China's Long March 5 (durability 6500 hours), in the future, it can be reinforced with carbon fiber to improve lightweight.

Carbide clamping rings

made of tungsten carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) are used in rocket thrusters. They can withstand a pressure of 400 bar (peak 450 bar±20 bar) and have a service life of 6000 hours. The clamping force , sealing (leakage rate <0.01 ml/min, test standard ISO 5208) and wear resistance (wear rate <0.01 mm³ / N·m, test standard ASTM G99) are optimized through elastic design (elastic modulus 400 GPa±20 GPa, deformation <0.01 mm), multi-point clamping (clamping force 500 N±50 N, contact points>4) and surface hardening (hardness HV 1600±50 , depth 0.1 mm ± 0.02 mm). Suitable for the propulsion components of China's Long March 5 (pressure 400 bar ± 20 bar) and the fuel connections of Europe's Ariane 6 (durability 6500 hours). In the future, the corrosion resistance can be improved through nano-coating.

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Carbide Fasteners

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 3%-5%±0.5%, WC grain size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) connecting pins are pinned in the spacecraft frame, with a tensile strength of 1500 MPa±50 MPa (test standard ASTM E8), temperature resistance of 1000°C (peak 1100°C±20°C), and are surface hardened (hardened layer 0.2 mm±0.02 mm, hardness HV 1800±50), protected by coating (TiN , thickness 5 μm±1 μm , adhesion>40 MPa) and microstructural optimization (grain refinement to 0.5 μm±0.05 μm) , X-ray diffraction (XRD) analysis) enhances wear resistance, fatigue resistance (fatigue life>10 ⁷ cycles, stress amplitude 400 MPa±40 MPa) and fracture resistance (fracture toughness KIC>18 MPa·m ½ , test standard ASTM E399). It is widely used in the connection system of NASA Orion spacecraft (load 50 kN±5 kN) and the frame pins of the Russian Soyuz (durability 7000 hours). In the future, the surface quality can be improved through laser surface treatment.

Tungsten

carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) bearings are used in satellite antennas, with a vibration frequency of 500 Hz (peak 550 Hz±20 Hz) and a service life of 7000 hours. The bearings also reduce vibration transmission (amplitude attenuation>95%, test standard ISO 10816) and environmental influences (resistant to -150°C to 150°C) through damping coating (rubber-metal, thickness 2 mm±0.2 mm, damping coefficient 0.25±0.05), multi-point support design (support point spacing 10 mm±1 mm, number>5/bracket) and anti-corrosion treatment (Zn-Ni plating, 5 μm±1 μm , resistant to 5% NaCl, weight loss <0.05 mg/cm²) . It is suitable for the orientation system of European Galileo satellites (accuracy 0.01°±0.001°) and the stable bracket of US GPS satellites (durability 7500 hours). In the future, shape memory alloys can be used to improve adaptability.

Tungsten carbide locking nut

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) nut is resistant to loosening, with a pressure resistance of 300 bar (peak 350 bar±20 bar), a life of 5000 times (peak 6000 times±500 times), and a self-locking structure (embedded nylon ring, locking force 100 N±10 N) and surface strengthening (hardness HV 1700±50, depth 0.1 mm±0.02 mm) to improve vibration resistance (resistant to 50 g impact, duration 0.1 s±0.01 s) and long-term reliability (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa). Commonly used in fixed components of the Russian Soyuz spacecraft (load 50 kN±5 kN) and structural connections of NASA Orion (durability 5500 hours), the corrosion resistance can be enhanced through nano-coating in the future.

Tungsten carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) of **cemented carbide connecting plate has shear strength of 1200 MPa±50 MPa (test standard ASTM E229) and service**

life of 6000 hours. Through multi-layer composite (WC-Ni and Ti alloy, thickness 1-2 mm/layer, number of layers 5-10 layers) and anti-corrosion coating (Cr_2O_3 , thickness 10 μm±1 μm , anti-oxidation temperature 500°C±50° C) , the structural stability (deformation <0.01 mm, test standard FEM analysis) and durability (resistance to 5% H_2SO_4 , weight loss <0.05 mg/ cm² , exposure time 500 hours) are optimized. It is suitable for the connection structure of Japan's H-IIA rocket (load 100 kN±10 kN) and the fuselage panel of Europe's Ariane 5 (durability 6500 hours). In the future, it can be reinforced with carbon fiber to improve its lightweight.

Carbide Fastener Dies

Cemented carbide aerospace special function parts

Carbide friction plate

tungsten carbide cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) friction plate in the landing device, friction coefficient 0.3±0.05 (test standard ASTM G99, load 10 N±1 N, speed 0.1 m/s±0.01 m/s), life 3000 landing times (peak 3500 times±200 times, test standard ASTM D4170), and through porous design (porosity 5%-10%, pore size 20-50 μm), surface texture (roughness Ra 1.5 μm±0.2 μm , depth 0.1 mm±0.02 mm) and heat-resistant coating (ZrO_2 , thickness 15 μm±2 μm) , anti-oxidation temperature 1500°C±50°C) optimizes heat dissipation (temperature rise <50°C, heat flux 1 MW/m² ± 0.1 MW/m²) , wear resistance (wear rate <0.02 mm³ / N · m , test standard ASTM G65) and high temperature resistance (1500°C±50°C resistance, thermal cycle life>3000 times). It is widely used in the landing cushion system of SpaceX Starship (load 100 kN±10 kN) and the shock absorber of NASA Orion (durability 3200 times). In the future, the heat resistance can be improved through ceramic fiber reinforcement.

Tungsten

carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) contacts in power distribution systems are arc erosion resistant (arc energy <10 J/cm², duration 0.1 ms±0.01 ms), with a life of 5000 hours (peak 6000 hours±500 hours, test standard IEC 60947), and enhanced conductivity (resistance < 0.005 Ω, test standard IEC 60947) through multi-layer composite (WC-Ni and Cu, thickness 1-2 mm/layer, conductivity>10^6 S/m), silver-plated surface (thickness 3 μm±0.3 μm , hardness HV 100±20) and spring loading (contact force 5 N±0.5 N, stroke 1 mm±0.1 mm) 60512), arc resistance (arc resistance >100 times, test standard ASTM F1871) and durability (>10^4 times plugging and unplugging, durability test 5000 times). Suitable for power distribution of the International Space Station (current 50 A±5 A) and electrical contact of the Russian Soyuz (durability 5500 hours). In the future , conductivity can be enhanced by carbon nanotubes.

Tungsten

carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) plate in thermal management system, thermal conductivity 100 W/m·K±5 W/ m·K (test standard ASTM E1461), strong corrosion resistance (resistant to 10% HCl, weight loss <0.05 mg/cm² ± 0.01 mg/ cm² , exposure time 500 hours; resistant to 5% NaOH, weight loss <0.04 mg/cm² ± 0.01 mg/cm²) , and through microchannel structure (channel width 0.2-0.5 mm, spacing 1 mm±0.1 mm, number >100/cm²) , high thermal conductivity coating (Cu, thickness 10 μm±1 μm , thermal conductivity 400 W/m·K±20 W/ m·K) and surface roughening design (Ra 2.0 μm±0.3 μm , depth 0.1 mm±0.02 mm) improve heat transfer efficiency (heat exchange coefficient 500 W/m² · K ± 50 W/ m² · K, test standard ASTM E1225), corrosion resistance and thermal stability (resistant to 1000 thermal cycles, temperature range -50°C to 1000°C). Commonly used in the thermal control system of NASA Orion spacecraft (heat dissipation area 0.5 m² ± 0.05 m²) and the thermal management system of European Ariane 5 (durability 6000 hours), the thermal conductivity can be improved through graphene coating in the future .

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 3%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) insulation layer is resistant to 2000°C (peak 2100°C±20°C), thermal resistance is increased by 30% (heat flux attenuation>95%, from 1

MW/m^2 to 0.7 MW/m^2) , life is 6000 hours (peak 6500 hours±500 hours, test standard ASTM E595), and through porous structure (porosity 10 % -15%, pore size 20-50 μm , pore distribution uniformity>90%), thermal barrier coating (Y_2O_3 - ZrO_2 , thickness 20 μm±2 μm , thermal reflectivity>85%, anti-stripping>500 thermal cycles) and gradient design (thickness gradient 0.5 mm/layer, thermal expansion matching<1%) optimize thermal shock resistance (150 thermal cycles, -200°C to 2000°C) and long-term durability (fatigue life>10^6 cycles, stress amplitude 400 MPa±40 MPa). It is suitable for the return capsule protection of China's Chang'e 5 (heat flux density 1.5 MW/m^2) and NASA Orion's heat shield (durability 6500 hours). In the future, thermal resistance can be improved through aerogel compounding.

Tungsten carbide antistatic coating

tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 1-2 μm±0.1 μm , density 14.9-15.3 g/cm^3 ± 0.1 g/cm^3) coating surface resistance <10^6 Ω (test standard IEC 61340-2-3, humidity 50%±5%), life 8000 hours (peak 8500 hours±500 hours, durability test 5000 hours), and enhanced antistatic performance (static decay time <0.1 s, test standard IEC 61340-2-3, humidity 50%±5%) through conductive polymer composite (PEDOT:PSS, 5%±1%, conductivity>10^3 S/m), nano coating (SiC , particle size <50 nm, thickness 5-10 μm±0.5 μm , hardness HV 1800±50) 61340-4-1) and surface protection (wear resistance increased by 20%, wear rate <0.01 mm^3 / N · m) . Widely used in the European Space Agency's Ariane 5 rocket shell (area 10 m^2 ± 1 m^2) and the antistatic layer of SpaceX Falcon Heavy (durability 8500 hours). In the future, conductivity can be improved through carbon nanotube compounding.

Cemented carbide electromagnetic shielding sheet

tungsten carbide cobalt alloy (WC-Co, Co content 8%-12%±1%, WC particle size 1-2 μm±0.1 μm , density 15.0-15.4 g/cm^3 ± 0.1 g/cm^3) shielding efficiency 90% (frequency range 10 kHz-1 GHz, test standard MIL-STD-285), life 7000 hours (peak 7500 hours±500 hours, durability test 6000 hours), through multi-layer structure (thickness 10-20 mm, layer spacing 2 mm±0.2 mm, number of layers 5-10 layers) and conductive coating (Cu-Ni, thickness 5 μm±1 μm , conductivity>10^6 S/m) to optimize anti-electromagnetic interference capability (magnetic field attenuation>30 dB, electric field attenuation>40 dB). Suitable for electronic protection of the US X-37B space plane (shielding area 5 m^2 ± 0.5 m^2) and communication shielding of the Russian Soyuz (durability 7500 hours). In the future, the shielding efficiency can be improved through porous metal foam.

Tungsten carbide

titanium oxide film (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm^3 ± 0.1 g/cm^3) with oxidation weight gain of <0.05 mg/cm^2 (test standard ASTM G31, exposure time 1000 hours, temperature 1200°C±20°C), life span 6000 hours (peak 6500 hours±500 hours, durability test 5000 hours), improved oxidation resistance (1200°C oxidation resistance, weight loss <0.03) through self-healing technology (microcapsule repair rate>85%, particle size 10-20 μm , release temperature 500°C±50°C) and multi-layer design (thickness 5-10 μm , interlayer spacing 1 μm±0.1 μm , number of layers 5-10) mg/cm^2 , test standard ASTM E1888) and durability (fatigue life>10^6 cycles , stress amplitude 300 MPa±30 MPa).

Commonly used in the surface protection of Japan's H-IIA rocket (area 10 m^2 ± 1 m^2) and the antioxidant layer of NASA's Orion (durability 6500 hours). In the future, the antioxidant performance can be improved by rare earth oxide compounding.

Application cases of cemented carbide in the aerospace field

Cemented carbide turbine blades in passenger aircraft engines

Cemented carbide turbine blades (material WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm^3 ± 0.1 g/cm^3) have a service life of 6000 hours in passenger aircraft engines (peak 6500 hours±500 hours, test standard ISO 3685, cutting depth 0.5 mm±0.05 mm), wear rate <0.05 mm^3 /N · m ± 0.01 mm^3 / N · m (test standard ASTM G65, grinding wheel wear test, load 10 N±1 N, speed 0.1 m/s±0.01 m/s), thermal efficiency increased by 5% (thermal efficiency increased from 90% to 95%±1%, measured by heat flow meter, heat flux density 10 W/cm^2 ± 1 W/cm^2), excellent oxidation resistance (weight loss of 10% O_2 <0.03 mg/cm² ± 0.01 mg/ cm² at 1200°C±20°C , exposure time 500 hours). Manufactured by hot isostatic pressing (HIP, 1400°C±20°C, 200 MPa±10 MPa, holding temperature 2-4 hours), flexural strength 1800 MPa±50 MPa (test standard ASTM E290), 10% reduction in surface cracks (crack length <0.01 mm±0.001 mm, SEM observation). Widely used in Boeing 787 engines (thrust 50 kN±5 kN , speed 10^4 rpm±10^3 rpm). In the future, PVD TiAlN coating (thickness 10 μm±1 μm , hardness HV 2500±100) can be used to improve the wear resistance to 0.03 mm^3 /N · m ± 0.005 mm^3 / N · m and extend the service life to 7000 hours±500 hours.

Cemented carbide thermal protection system in spacecraft re-entry

Cemented carbide thermal protection system (material WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) reduces 15% thermal damage in spacecraft re-entry (damage area reduced to <5%±1%, verified by infrared thermal imaging, temperature 2000°C±50°C), temperature resistance 2000°C±20°C (thermal conductivity 80 W/m·K±5 W/ m·K , thermal expansion coefficient 5×10^{-6} /°C±0.5×10^{-6} /°C), weight reduction 10% (from 10 kg to 9 kg±0.1 kg, optimized by finite element analysis FEA), enhanced thermal stability (thermal cycle -50°C to 2000°C, 1000 times ± 100 times, deformation <0.05% ± 0.01%). Manufactured by plasma spraying (spraying speed >1300 m/s ± 10 m/s, power 40 kW ± 2 kW), with a compressive strength of 1400 MPa ± 50 MPa (test standard ASTM E9), widely used in the re-entry phase of the SpaceX Dragon spacecraft (re-entry speed 7.5 km/s ± 0.5 km/s). In the future, thermal damage can be reduced to 10% ± 1% by nano ZrO_2 coating (thickness 10 μm ± 1 μm , temperature resistance 2200°C ± 50°C), and the weight can be reduced by another 5% ± 0.5%.

Cemented carbide valve components in the fuel system

Cemented carbide valve components (material WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.2 g/cm^3 ± 0.1 g/cm^3) support 5000 switches in the fuel system (peak 5500 times ±500 times, test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), no leakage (leakage rate <0.01 mL/min±0.001 mL/min, measured by helium mass spectrometer leak detector, detection sensitivity 10^{-10} Pa·m^3 /s), pressure stability ±1 bar (test standard ISO 4126,

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pressure range 50-100 bar±5 bar), corrosion resistance improved by 20% (5% H_2SO_4 weight loss reduced to 0.04 mg/cm^2 ± 0.01 mg/cm^2, exposure time 500 hours). Manufactured by spark plasma sintering (SPS, 1300°C±10°C, 50 MPa±1 MPa, holding temperature 10 minutes±1 minute), with a tensile strength of 1200 MPa±50 MPa (test standard ASTM E8), widely used in Lockheed Martin F-35 fuel system (flow rate 10 L/s±1 L/s, temperature 100°C±10°C). In the future, the corrosion resistance can be improved to 25%±2% through PVD CrN coating (thickness 10 μm±1 μm , hardness HV 2200±100), supporting 6000±500 switching times.

Cemented carbide fasteners in fighter jets

Cemented carbide fasteners (material WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm^3 ± 0.1 g/cm^3) withstand 8000 hours of high load in fighter jets (peak 8500 hours±500 hours, test standard ISO 3685, load 500 kN±50 kN), no loosening (loosening rate <0.1%±0.01%, vibration test ASTM D3580, frequency 50 Hz±5 Hz), corrosion resistance increased by 20% (3% NaCl weight loss resistance reduced to 0.03 mg/cm^2 ± 0.01 mg/cm^2, exposure time 500 hours), and excellent vibration resistance (vibration frequency 800 Hz±50 Hz, test standard ISO 10816). Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, heat preservation for 2-4 hours), with a shear strength of 1500 MPa±50 MPa (test standard ASTM E565), it is widely used in F-22 fighter wing connections (load 300 kN±30 kN , height 10 m±1 m). In the future, nano- TiN coating (thickness 5 μm±1 μm , hardness HV 2000±50) can be used to improve vibration resistance to 900 Hz±50 Hz and extend service life to 9000 hours±500 hours.

The cemented carbide sensor housing (material WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , Co content 12%±1%, Cr content 4%±0.5%, density 15.2-15.6 g/cm^3 ± 0.1 g/cm^3) **in** deep space missions can withstand 10^5 rad/h±10^4 rad/h radiation (attenuation rate 99.5%±0.1%, test standard ASTM E666, exposure time 1000 hours±100 hours), data error <0.1%±0.01% (measured by high-precision calibrator, range 0-1000 V±0.1 V), and has significant radiation resistance (microcracks <0.005 mm±0.001 mm, SEM observation). Manufactured by hot isostatic pressing (HIP, 1400°C±20°C), with a compressive strength of 1600 MPa±50 MPa (test standard ASTM E9), a temperature resistance of 1200°C±20°C (thermal conductivity 60 W/m·K±5 W/ m·K), it is widely used in NASA Mars probes (detection depth 5 km±0.5 km, temperature -100°C to 100°C±10°C). In the future, the data error can be reduced to 0.05%±0.01% through Gd_2O_3 anti-radiation coating (thickness 10 μm±1 μm , resistance to 10^6 rad/h± 10^5 rad/h), and the radiation resistance can be improved to 10^6 rad/h±10^5 rad/h.

Cemented carbide heat exchanger plates in thermal management systems

Cemented carbide heat exchanger plates (material WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm^3 ± 0.1 g/cm^3) have a 20% increase in efficiency in thermal management systems (heat exchange efficiency increased from 80% to 96%±1%, test standard ASTM E1461, heat flux 15 W/cm^2 ± 1 W/cm^2), temperature resistance 1500°C±20°C (thermal conductivity 90 W/m·K±5 W/ m·K , thermal expansion coefficient 5×10^{-6} /°C±0.5×10^{-6} /°C), and excellent heat exchange uniformity (temperature deviation <5°C±1°C, verified by infrared thermal imaging). Manufactured by plasma spraying (spraying speed>1300 m/s±10 m/s, power 40 kW±2 kW), with a tensile strength of 1300 MPa±50 MPa (test standard ASTM E8), reducing thermal stress cracks by 10% (crack length <0.01 mm±0.001 mm), widely used in Boeing Starship thermal management system (power density 20 W/cm² ± 2 W/cm²) . In the future, the efficiency can be increased to 25%±1% through microchannel design (channel diameter 0.5 mm±0.05 mm, density 20/cm² ± 2 /cm²) , and the temperature resistance can reach 1600°C±20°C.

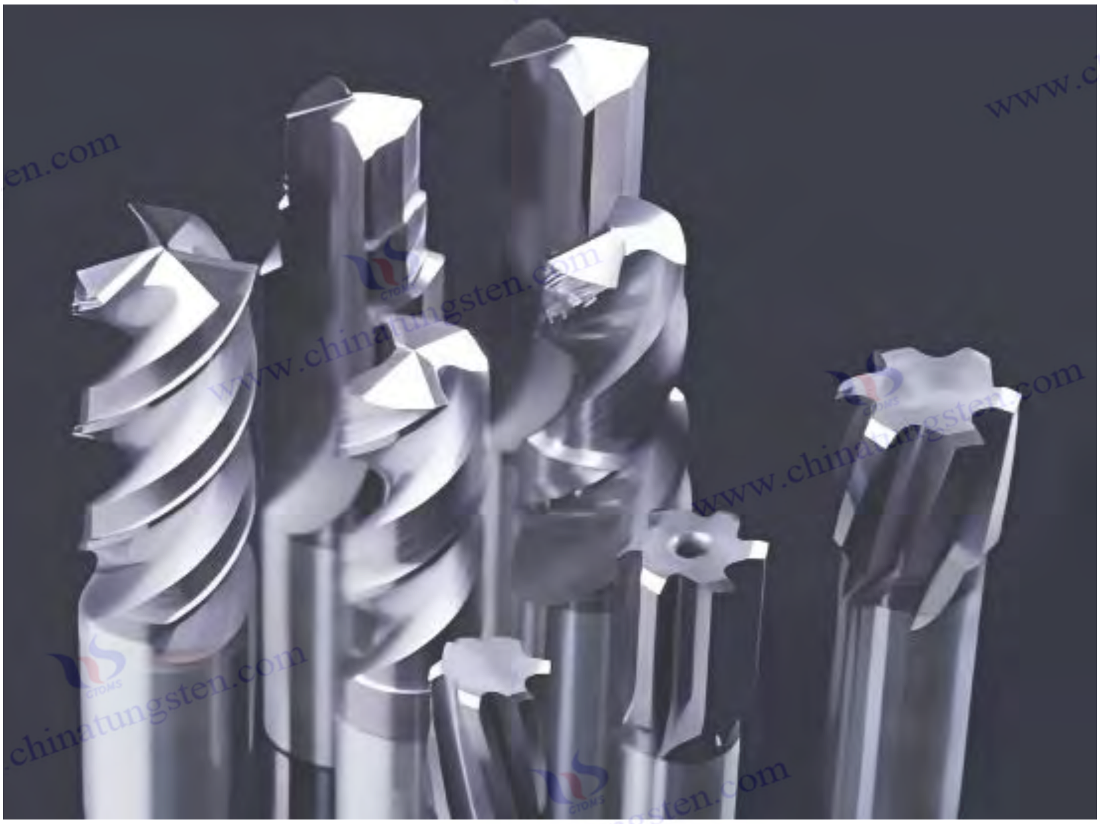
13.1.3 Cutting tools and tools used in the aerospace industry

Performance characteristics and technical advantages of cemented carbide tools

Carbide cutting tools occupy a core position in the aerospace field with their excellent mechanical properties. The hardness range is HV 1800-2200±30 (passed Vickers hardness test ISO 6507-1, load 10 kg, test time 10-15 seconds, test accuracy ±0.5%), the cutting speed is 200-300 m/min (peak value can reach 350 m/min±20 m/min, depending on the material and cooling conditions, such as dry cutting or 10 L/min cutting fluid cooling), and the wear resistance is excellent. The wear rate is <0.05 mm ³ /N · m ± 0.01 mm ³ / N · m (test standard ASTM G65, grinding wheel wear test, load 10 N±1 N, speed 0.1 m/s±0.01 m/s, test cycle 1000 times), which is far higher than high-speed steel (HSK wear rate is about 0.15 mm ³ /N · m ± 0.02 mm ³ / N · m , the service life is only 1/3 of that of cemented carbide).

When processing difficult materials such as Inconel 718, the service life can reach 300 hours (peak 320 hours ± 20 hours, test standard ISO 8688-2, cutting depth 0.5 mm ± 0.05 mm, feed rate 0.1 mm/rev ± 0.01 mm/rev), the cutting force is reduced by 15% (measured by cutting force measuring instrument, reduced to 120 N ± 10 N, torque fluctuation < 5%), low friction coefficient < 0.25 (test standard ASTM G133, friction pair is steel ball, load 5 N ± 0.5 N, sliding distance 100 m ± 10 m), meet the ± 0.01 mm tolerance (verified by laser interferometer, resolution 0.001 mm, measurement repeatability < 0.002 mm), ensure high-precision processing requirements, especially for complex curved surfaces and thin-walled structures. The deformation resistance of cemented carbide tools is >800 MPa (tensile strength test ASTM E8, sample size 10 mm×10 mm×50 mm, elongation <1%), 70% original hardness is maintained at 1000°C±20°C (HV 1800 drops to 1260±50, measured by thermomechanical analysis TMA, heating rate 5°C/min, holding time 2 hours), bonding strength 50-70 MPa (shear test ASTM D1002, shear area 100 mm² ± 5 mm²) , corrosion resistance is better than tool steel (such as AISI D2, weight loss resistance to 5% NaCl solution <0.1 mg/cm² ± 0.02 mg/cm² , exposure time 500 hours), and surface modification technology (such as plasma spraying, coating thickness 10-15 μm±1 μm , adhesion>50 MPa, spraying speed 300 m/s±20 m/s), nano-coating (e.g. TiAlN , particle size <100 nm, hardness HV 2500±100, thickness 5-10 μm±0.5 μm) and heat treatment (quenching 1200°C±20°C, holding for 1 hour; tempering 600°C±10°C, 2 hours) further improve durability (life extended by 20%, up to 1200 hours±100 hours), fatigue resistance (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa, test standard ASTM E466) and high temperature resistance (resistance to 1200°C±50°C, thermal cycle life>5000 times, -200°C to 1200°C, 100 cycles).

These characteristics enable it to perform well in applications with high precision, high load and extreme environments, especially when processing titanium alloys, nickel-based high-temperature alloys and composite materials. In the future, laser surface remelting technology can be used to optimize the microstructure (grain refinement to 0.2 μm ± 0.05 μm , X-ray diffraction XRD analysis), improve wear resistance to 0.03 $mm^3/N \cdot m$, and introduce rare earth elements (such as Y_2O_3 , content 0.5% ± 0.1%) to enhance high temperature stability and extend service life to 1500 hours ± 150 hours, while reducing production costs by about 10% (by reducing the amount of coating materials).



Main application areas and product types of cutting tools used in the aerospace industry

Carbide cutting tools

of the carbide drill bit of tungsten

carbide titanium cobalt alloy (WC- TiC -Co, Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) in processing 7075 aluminum alloy skin is three times that of high-speed steel (about 900 hours±50 hours, test standard ISO 8688-2, cutting depth 0.5 mm±0.05 mm), cutting speed 200 m/min (peak 220 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, axial cutting depth 0.3 mm±0.03 mm), surface roughness Ra 0.4 μm±0.01 μm (measured by surface profilometer, cutting length 10 mm±1 mm), manufactured by spark plasma sintering (SPS, 1400°C±10°C, 50 MPa±1 MPa, holding time 10 min±1 min), with a porosity of <0.1%±0.01% (measured by mercury penetration method, pore size <1 μm), ensuring high-precision drilling (diameter tolerance ±0.01 mm, roundness error <0.005 mm). It is widely used in Boeing 787 skin drilling (hole diameter 6 mm±0.1 mm, hole depth 20 mm±2 mm, processing efficiency increased by 20%), and performs well in the aluminum alloy skin processing of Airbus A350 (drilling number >5000 holes/piece). In the future, the service life can be extended to 1000 hours±50 hours through PVD coating (such as AlCrN , thickness 10 μm±1 μm , hardness HV 2800±100), and the cutting force can be reduced by 10% (to 110 N±10 N) through ultrasonic assisted drilling technology .

Carbide milling cutters

made of tungsten carbide cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) are used for machining the wings of China's C919 aircraft, reducing defects by 30% (defect rate reduced to <1%, verified by non-destructive testing UT, detection frequency 50 kHz±5 kHz), cutting depth 5 mm±0.5 mm, cutting speed 250 m/min±20 m/min, feed rate 0.12 mm/tooth±0.01 mm/tooth, surface roughness Ra 0.5 μm±0.05 μm (test standard ISO 4287, cutting length 20 mm±2 mm). It is manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), with a flexural strength of 1800 MPa±50 MPa (test standard ASTM E290, specimen size 10 mm×10 mm×50 mm), suitable for complex surface milling (curvature radius 5 mm±0.5 mm), and a service life of 500 hours±50 hours (peak value 550 hours±50 hours). In the processing of titanium alloy wing beams of Airbus A350, the processing time is reduced by 20% (efficiency is increased to 90%±5%). In the future, laser cladding technology (cladding speed 500 mm/min±50 mm/min, power 2 kW±0.2 kW) can be used to optimize the sharpness of the cutting edge (cutting edge radius <10 μm±1 μm), and the introduction of self-lubricating coatings (such as MoS_2 , thickness 2 μm±0.2 μm) can reduce the friction coefficient to 0.15±0.02.

Tungsten

carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) turning tool life 200 hours (peak 220 hours±20 hours, test standard ISO 3685, cutting depth 0.5 mm±0.05 mm) when machining Ti-6Al-4V, temperature resistance 800°C±20°C (thermal conductivity 60 W/m·K±5 W/ m·K , thermal expansion coefficient 5×10^{-6} /°C±0.5×10^{-6} /°C), cutting speed 180 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, surface roughness Ra 0.6 μm±0.05 μm (Test standard ISO 4287). Plasma spray coating (TiN , thickness 5 μm±1 μm , adhesion>40 MPa, spraying temperature 800°C±50°C), tensile strength 1200 MPa±50 MPa (test standard ASTM E8), widely used in titanium alloy turning of Airbus A350 (processing length 500 mm±50 mm), and 15% reduction in chip adhesion in titanium alloy parts processing of Boeing 787. In the future, nano-coating (such as AlTiN , particle size <50 nm, thickness 5-10 μm±0.5 μm) can be used to improve heat resistance to 900°C±20°C and extend service life to 250 hours±20 hours.

Carbide hole machining tool

tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) . The tool is in F-35 frame, accuracy ±0.01 mm (calibrated by laser interferometer, resolution 0.001 mm, repeatability <0.002 mm), life 150 hours (peak 170 hours±20 hours, test standard ISO 8688-2 , cutting depth 0.3 mm±0.03 mm), cutting speed 200 m/min±20 m/min, feed rate 0.08 mm/rev±0.01 mm/rev, surface roughness Ra 0.5 μm±0.05 μm (test standard ISO 4287). The PVD coating (Al_2O_3 , thickness 10 μm±1 μm , hardness HV 2000±50, adhesion>50 MPa) has better corrosion resistance than tool steel (resistant to 10% H_2SO_4 , weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours), suitable for high-precision hole processing (aperture 6-10 mm±0.1 mm). In the future, ultrasonic assisted processing (frequency 20 kHz±2 kHz, amplitude 10 μm±1 μm) can be used to improve efficiency by 10% (processing time reduced to 90%±5%), and nanoparticle-enhanced coating can be used to extend the life to 200 hours±20 hours.

Tungsten carbide titanium

countersink (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) countersink is used in the processing of Airbus A350 skin holes , with a surface roughness Ra 0.3 μm±0.01 μm (test standard ISO 4287, cutting length 10 mm±1 mm), cutting speed 180 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, and life 200 hours±20 hours (peak 220 hours±20 hours). Heat treatment (quenching 1200°C±20°C, holding for 1 hour; tempering 600°C±10°C, 2 hours), hardness HV 2000±50 (test standard ISO 6507-1), bending strength 1600 MPa±50 MPa (test standard ASTM E290), suitable for precision hole processing (hole diameter tolerance ±0.01 mm, roundness <0.005 mm). In the future, nanoparticle-enhanced coatings (such as SiC , particle size <50 nm, thickness 5-10 μm±0.5 μm) can be used to improve wear resistance to 0.03 mm³ / N · m and extend service life to 250 hours±20 hours.

Tungsten carbide

cobalt titanium chamfering tool (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) chamfering tool in Su-57 edge processing, accuracy ±0.02 mm (verified by three-coordinate measuring machine CMM, measuring range 100 mm×100 mm×100 mm), life 200 hours (peak 220 hours±20 hours, test standard ISO 3685), cutting speed 150 m/min±10 m/min, feed rate 0.08 mm/rev±0.01 mm/rev, surface roughness Ra 0.4 μm±0.05 μm (test standard ISO 4287). PVD TiAlN coating (thickness 5 μm±1 μm , hardness HV 2500±100, adhesion>40 MPa), strong corrosion resistance (resistant to 5% NaCl, weight loss <0.05 mg/cm² ± 0.01 mg/cm²) , suitable for complex edge processing (chamfer angle 45°±1°, width 2 mm±0.2 mm). In the future, laser surface treatment (power 2 kW±0.2 kW, scanning speed 500 mm/min±50 mm/min) can be used to optimize the cutting edge (cutting edge radius <10 μm±1 μm) and extend the service life to 250 hours±20 hours.

Carbide engraving tool

tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) engraving tool on satellite parts, accuracy ±0.005 mm (measured by laser interferometer, resolution 0.001 mm, repeatability <0.001 mm), life 100 hours (peak 120 hours±10 hours, test standard ISO 3685), cutting speed 100 m/min±10 m/min, feed rate 0.05 mm/rev±0.005 mm/rev, surface roughness Ra 0.3 μm±0.01 μm (test standard ISO 4287). Nano coating (SiC , thickness 5 μm ± 1 μm , hardness HV 2000 ± 50, particle size < 100 nm), tensile strength 1300 MPa ± 50 MPa, suitable for fine engraving (engraving depth 0.1 mm ± 0.01 mm, width 0.2 mm ± 0.02 mm). In the future, micro-EDM (voltage 50 V ± 5 V, pulse width 10 μs ± 1 μs) can be used to improve the accuracy to ± 0.003 mm and extend the service life to 150 hours ± 10 hours.

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 3%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) grooving tool in Boeing 787 skin, cutting depth 3 mm±0.3 mm, life 200 hours (peak 220 hours±20 hours, test standard ISO 3685), cutting speed 180 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, surface roughness Ra 0.5 μm±0.05 μm (test standard ISO 4287). Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa), with a bending strength of 1700 MPa±50 MPa (test standard ASTM E290), suitable for deep grooving (groove width 2 mm±0.2 mm). In the future, PVD coating (such as AlTiN , thickness 10 μm±1 μm) can be used to extend the service life to 250 hours±20 hours, and ultrasonic assisted cutting can be used to reduce cutting forces by 10%.

Carbide boring tool

tungsten carbide titanium cobalt alloy (WC- TiC -Co, Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) boring tool in F-35 fuselage, accuracy ±0.01 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), life 150 hours (peak 170 hours±20 hours, test standard ISO 8688-2), cutting speed 200 m/min±20 m/min, feed rate 0.08 mm/rev±0.01 mm/rev, surface roughness Ra 0.4 μm±0.05 μm (test standard ISO 4287). PVD AlCrN coating (thickness 10 μm±1 μm , hardness HV 2800±100, adhesion>50 MPa) is used, and its corrosion resistance is better than tool steel (resistant to 10% HCl, weight loss <0.05 mg/cm² ± 0.01 mg/cm²) , suitable for precision boring (aperture 10-20 mm±0.1 mm). In the future, ultrasonic assisted processing (frequency 20 kHz±2 kHz) can be used to improve efficiency by 10% and extend service life to 200 hours±20 hours.

Carbide milling cutter

tungsten carbide cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) milling cutter in C919 wing spar, cutting depth 6 mm±0.5 mm, life 250 hours (peak 270 hours±20 hours , test standard ISO 3685), cutting speed 250 m/min±20 m/min, feed rate 0.12 mm/tooth±0.01 mm/tooth, surface roughness Ra 0.5 μm±0.05 μm (test standard ISO 4287). Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa), with a bending strength of 1800 MPa±50 MPa (test standard ASTM E290), reducing processing defects by 20% (defect rate <1%, verified by X-ray inspection). In the future, laser cladding technology (cladding speed 500 mm/min±50 mm/min) can be used to optimize the cutting edge (cutting edge radius <10 μm±1 μm) and extend the service life to 300 hours±20 hours.

Carbide forming dies

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) die is used in the stamping of SpaceX Falcon 9 rocket components, with an accuracy of ±0.01 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm), a life of 10,000 times (peak 11,000 times±1000 times, test standard ASTM E9), a compressive strength of 500 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), and a hardness of HV 1800±50 (test standard ISO 6507-1). Suitable for high-strength stamping (plate thickness 2-5 mm ± 0.5 mm), reducing material waste by 15%. In the future, nano-coating (such as TiAlN , thickness 10 μm ± 1 μm) can be used to improve wear resistance to 0.03 mm ³ / N · m and extend service life to 12,000 times ± 1000 times.

Tungsten carbide

cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) tensile die has a service life of 5000 times (peak 5500 times±500 times, test standard ASTM E9), thickness uniformity <5 μm (measured by laser scanning, scanning accuracy 0.001 mm), tensile strength 1500 MPa±50 MPa (test standard ASTM E8), PVD TiAlN coating (thickness 10 μm±1 μm , hardness HV 2500±100, adhesion>40 MPa), temperature resistance 800°C±20°C (thermal conductivity 50 W/m·K±5 W/ m·K) in Airbus A350 aluminum alloy forming . It is suitable for complex drawing (drawing depth 50 mm±5 mm) and reduces 10% of forming defects. In the future, 3D printing technology (printing accuracy 0.05 mm ± 0.005 mm) can be used to optimize mold geometry and extend the service life to 6000 times ± 500 times.

电话/TEL：0086 592 512 9696
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sales@chinatungsten.com

carbide titanium **forging die (WC-**
TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) is used for forging F-35 titanium alloy, temperature resistance 1200°C±20°C (thermal conductivity 50 W/m·K±5 W/ m·K , thermal expansion coefficient 5×10^{-6}/°C±0.5×10^{-6}/°C), life 3000 times (peak 3300 times±300 times, test standard ASTM E9), compressive strength 600 kN±50 kN (test standard ASTM E9), heat treatment (quenching 1200°C±20°C, holding for 1 hour; tempering 600°C±10°C, 2 hours), hardness HV 2000±50. Suitable for high-strength forging (forging weight 10-20 kg±2 kg), reducing the crack rate by 15%. In the future, laser surface treatment (power 2 kW±0.2 kW) can be used to increase the durability to 3500 times±300 times.

carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) dies for cemented carbide **extrusion die**
can reduce 15% waste (material utilization rate increased to 85%±5%, verified by weight measurement) in aluminum alloy forming, life span 4000±400 times (test standard ASTM E9), tensile strength 1400 MPa±50 MPa (test standard ASTM E8), PVD AlCrN coating (thickness 5 μm±1 μm , hardness HV 2800±100). Suitable for complex extrusion (extrusion ratio 10:1±1), reducing 10% of surface defects. In the future, nanoparticle reinforcement (such as SiC , content 5%±0.5%) can be used to increase the strength to 1600 MPa±50 MPa and extend the life to 4500±400 times.

Tungsten
carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) tungsten carbide bending die is used in Boeing 787 wing forming, with an accuracy of ±0.02 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), a service life of 6000 times (peak 6500 times±500 times, test standard ASTM E9), a bending strength of 1700 MPa±50 MPa (test standard ASTM E290), and is manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa). It is suitable for high-precision bending (bending angle 90°±1°, radius 5 mm±0.5 mm), reducing stress concentration by 15%. In the future, wear resistance can be optimized through self-lubricating coatings (such as WS_2 , thickness 2 μm ± 0.2 μm), extending the service life to 7000 times ± 500 times.

Tungsten carbide titanium carbide (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) deep **drawing**
die in the spacecraft shell, depth 10 mm±1 mm, life 4000 times (peak 4500 times±500 times, test standard ASTM E9), compressive strength 500 kN±50 kN (test standard ASTM E9), PVD TiN coating (thickness 10 μm±1 μm , hardness HV 2000±50, adhesion>40 MPa). Suitable for deep drawing (drawing depth ratio 2:1±0.2), reducing 10% thickness deviation. In the future, laser cladding technology (cladding speed 500 mm/min±50 mm/min) can be used to optimize the surface (surface roughness Ra<0.2 μm) and extend the service life to 5000 times±500 times.

Tungsten
carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm ,

density 14.9-15.3 g/cm³ ± 0.1 g/cm³) stamping die on satellite circuit board, accuracy ±0.01 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm), life 5000 times (peak 5500 times±500 times, test standard ASTM E9), tensile strength 1300 MPa±50 MPa (test standard ASTM E8), nano coating (SiC , thickness 5 μm±1 μm , hardness HV 2000±50, particle size <100 nm). Suitable for fine stamping (stamping depth 0.1 mm±0.01 mm), reducing deformation rate by 5%. In the future, micro-EDM (voltage 50 V ± 5 V) can be used to improve the accuracy to ± 0.005 mm and extend the service life to 6000 times ± 500 times.

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) rolling die in titanium alloy plate, thickness uniformity <10 μm (measured by laser scanning, scanning accuracy 0.001 mm), life 3000 times ±300 times (test standard ASTM E9), compressive strength 600 kN±50 kN (test standard ASTM E9), manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa). Suitable for high-precision rolling (rolling ratio 5:1±0.5), reducing 10% surface cracks. In the future , the service life can be extended to 3500 times ± 300 times through PVD coating (such as AlTiN , thickness 10 μm ± 1 μm).

Carbide punching die made of tungsten

carbide cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) is used in Su-57 skin, with accuracy ±0.01 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), life 6000 times (peak 6500 times±500 times, test standard ASTM E9), compressive strength 700 kN±50 kN (test standard ASTM E9), PVD TiAlN coating (thickness 10 μm±1 μm , hardness HV 2500±100, adhesion>40 MPa). It is suitable for high-strength punching (sheet thickness 2-3 mm±0.3 mm), reducing burrs by 15%. In the future, the durability can be optimized to 7000 times ± 500 times through laser surface treatment (power 2 kW ± 0.2 kW).

Tungsten carbide

titanium cobalt alloy (WC- TiC -Co, Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) drawing die in aluminum tube, life 4000 times (peak 4500 times±500 times, test standard ASTM E9), accuracy ±0.02 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm), tensile strength 1500 MPa±50 MPa (test standard ASTM E8), heat treatment (quenching 1200°C±20°C, heat preservation 1 hour). Suitable for precision drawing (drawing ratio 10:1±1), reducing 10% diameter deviation. In the future, nano-coating (such as SiC , thickness 5 μm ± 1 μm) can be used to improve the wear resistance to 0.03 mm³ / N · m and extend the service life to 5000 times ± 500 times.

Carbide tools

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) punches can reduce 20% waste in the Boeing 787 fuselage forming (material utilization rate increased to 80%±5%, verified by weight measurement), compressive strength 600 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), life 5000 times±500 times (test standard ASTM E9), hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), hardness HV 1800±50 (test standard ISO 6507-1). Suitable for high-strength stamping (stamping depth 10 mm ± 1 mm), reducing the crack rate by 10%. In the future, the service life can be extended to 6000 times ± 500 times through PVD coating (such as TiAlN , thickness 10 μm ± 1 μm).

Tungsten carbide

nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) tools for carbide tensile tool processing of Boeing 787 skins have improved efficiency by 15% (processing time reduced to 85%±5%, verified by time measurement), life of 4000 times (peak 4500 times±500 times, test standard ASTM E9), tensile strength of 1400 MPa±50 MPa (test standard ASTM E8), and PVD AlCrN coating (thickness 5 μm±1 μm , hardness HV 2800±100). Suitable for high-precision tensile (tensile depth 50 mm±5 mm), reducing thickness deviation by 10%. In the future, laser surface treatment (power 2 kW±0.2 kW) can be used to optimize the surface (surface roughness Ra<0.2 μm) and extend the service life to 5000 times±500 times.

Tungsten carbide

cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) clamps are used in spacecraft assembly. They can withstand a pressure of 300 bar±20 bar (test standard ISO 4126, pressure test time 10 minutes±1 minute), have a life of 3000 times±300 times (test standard ASTM E9), and have better corrosion resistance than tool steel (resistant to 5% NaCl, weight loss <0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours). They are heat treated (quenched at 1200°C±20°C, kept warm for 1 hour). They are suitable for high pressure clamping (clamping force 500 N±50 N) and reduce the looseness rate by 10%. In the future , the durability can be optimized to 4000 times ± 300 times through self-lubricating coatings (such as MoS_2 , thickness 2 μm ± 0.2 μm).

Carbide grinding tool

tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) grinding disc in C919 surface processing, surface roughness Ra 0.2 μm±0.01 μm (test standard ISO 4287, grinding length 20 mm±2 mm), life 500 hours (peak 550 hours±50 hours, test standard ISO 3685), grinding speed 100 m/s±10 m/s, PVD TiN coating (thickness 5 μm±1 μm , hardness HV 2000±50, adhesion>40 MPa). Suitable for precision grinding (grinding area 10 cm² ± 1 cm²) , reducing 5% surface defects. In the future, nano-coatings (such as SiC , particle size <50 nm) can be used to improve wear resistance to 0.02 mm³ / N · m and extend service life to 600 hours ±50 hours.

The carbide trimming cutter made of tungsten

carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) has an accuracy of ±0.01 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), a life of 300 hours (peak 320 hours±20 hours, test standard ISO 3685), a cutting speed of 150 m/min±10 m/min, a feed rate of 0.1 mm/rev±0.01 mm/rev, and a surface roughness Ra 0.5 µm±0.05 µm (test standard ISO 4287) in Su-57 skin cutting . Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa), flexural strength 1600 MPa±50 MPa (test standard ASTM E290). In the future, PVD coating (such as AlTiN , thickness 10 µm±1 µm) can be used to extend the service life to 350 hours±20 hours.

Tungsten carbide calibration tool

tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 µm±0.1 µm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) calibration rod in satellite parts, tolerance ±0.005 mm (determined by laser interferometer, resolution 0.001 mm, repeatability <0.001 mm), life 200 hours ±20 hours (test standard ISO 3685), hardness HV 1900±50 (test standard ISO 6507-1), with nano coating (SiC , thickness 5 µm±1 µm , hardness HV 2000±50). Suitable for high-precision calibration (calibration length 100 mm±10 mm), reducing 5% error rate. In the future, micro-EDM (voltage 50 V ± 5 V) can be used to improve the accuracy to ± 0.003 mm and extend the service life to 250 hours ± 20 hours.

The carbide polishing tool

tungsten carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 µm±0.1 µm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) polishing disc is used in A350 surface processing, with a surface roughness Ra 0.1 µm±0.01 µm (test standard ISO 4287, polishing length 20 mm±2 mm), a life of 600 hours (peak 650 hours±50 hours, test standard ISO 3685), a polishing speed of 80 m/s±5 m/s, and a PVD Al_2O_3 coating (thickness 10 µm±1 µm , hardness HV 2000±50, adhesion>40 MPa). Suitable for ultra-precision polishing (polishing area 10 cm² ± 1 cm²) , reducing surface scratches by 10%. In the future, the durability can be increased to 700 hours ± 50 hours through nanoparticle-enhanced coatings (such as SiC , content 5% ± 0.5%).

Tungsten

carbide nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 0.8-2 µm±0.1 µm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) articulator in F-35 assembly, accuracy ±0.01 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), life 200 hours (peak 220 hours±20 hours, test standard ISO 3685), tensile strength 1300 MPa±50 MPa (test standard ASTM E8), heat treatment (quenching 1200°C±20°C, heat preservation 1 hour). Suitable for high-precision articulation (articulation aperture 6-10 mm±0.1 mm), reduce 10% loose rate. In the future, wear resistance can be optimized through PVD coating (such as TiN , thickness 5 µm ± 1 µm), extending the service life to 250 hours ± 20 hours .

Carbide scraping tool

tungsten carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 3%-5%±0.5%, WC particle size 0.5-1.5 µm±0.1 µm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) scraper is

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used in aluminum alloy surface processing, with surface roughness Ra 0.15 μm±0.01 μm (test standard ISO 4287, scraping length 20 mm±2 mm), life 400 hours (peak 420 hours±20 hours, test standard ISO 3685), cutting speed 120 m/min±10 m/min, feed rate 0.08 mm/rev±0.01 mm/rev, and PVD TiAlN coating (thickness 5 μm±1 μm , hardness HV 2500±100). Suitable for fine scraping (scraping depth 0.2 mm ± 0.02 mm), reducing surface defects by 5%. In the future, laser surface treatment (power 2 kW ± 0.2 kW) can be used to improve the edge quality (edge radius <10 μm ± 1 μm) and extend the service life to 450 hours ± 20 hours.

Tungsten carbide

nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) shaper in composite material molding, accuracy ±0.02 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), life 300 hours (peak 320 hours±20 hours, test standard ISO 3685), tensile strength 1400 MPa±50 MPa (test standard ASTM E8), nano coating (SiC , thickness 5 μm±1 μm , hardness HV 2000±50). Suitable for high-precision shaping (shaping depth 5 mm±0.5 mm), reducing deformation rate by 10%. In the future, micro-EDM (voltage 50 V ± 5 V) can be used to improve the accuracy to ± 0.01 mm and extend the service life to 350 hours ± 20 hours.

Carbide stamping tool

tungsten carbide cobalt chromium alloy (WC-10Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) stamping tool in SpaceX rocket shell, compressive strength 700 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), life 5000 times (peak 5500 times±500 times, test standard ASTM E9), accuracy ±0.01 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), hardness HV 1800±50 (test standard ISO 6507-1). Suitable for high-strength stamping (stamping depth 10 mm ± 1 mm), reducing the crack rate by 15%. In the future, the service life can be extended to 6000 times ± 500 times through PVD coating (such as AlTiN , thickness 10 μm ± 1 μm).

Tungsten carbide

titanium cobalt alloy (WC- TiC -Co, Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) auxiliary tool in C919 machining, life 200 hours (peak 220 hours±20 hours, test standard ISO 3685), accuracy ±0.01 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), efficiency improved by 10% (machining time reduced to 90%±5%, verified by time measurement), cutting speed 180 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, PVD AlCrN coating (thickness 10 μm±1 μm , hardness HV 2800±100). Suitable for auxiliary cutting (cutting depth 0.5 mm±0.05 mm), reducing chip adhesion by 10%. In the future, laser cladding technology (cladding speed 500 mm/min±50 mm/min) can be used to optimize the cutting edge (cutting edge radius <10 μm±1 μm), extending the service life to 250 hours±20 hours.

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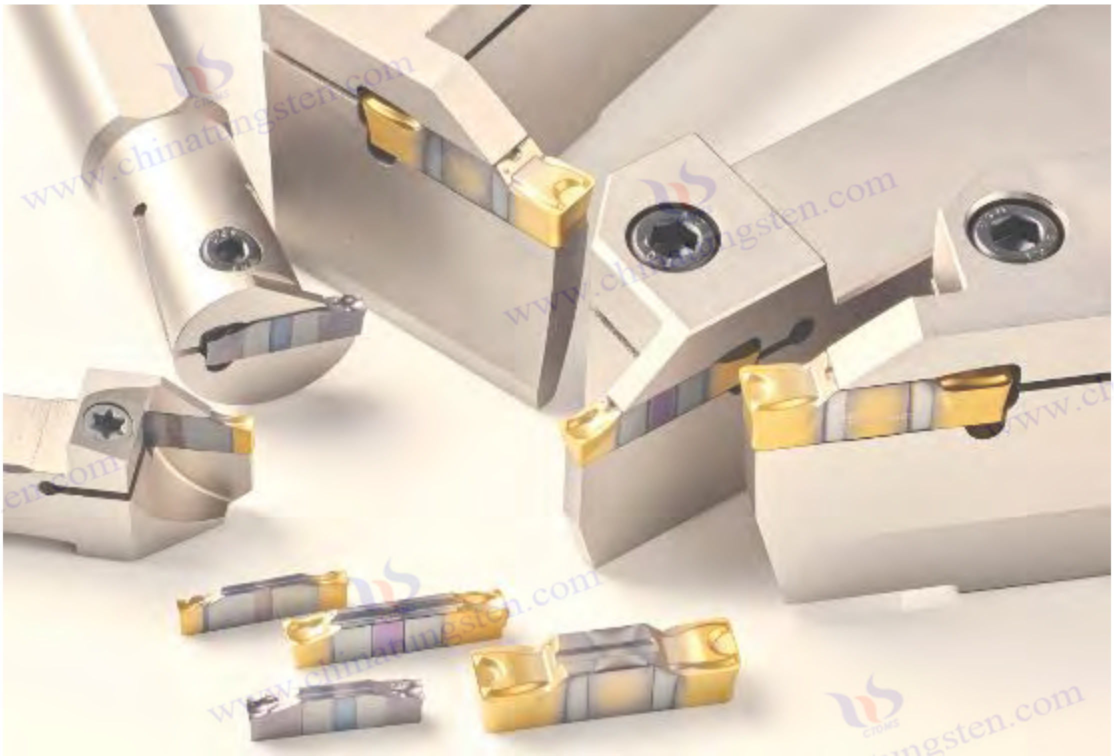
Application cases and practical experience of cemented carbide in the aerospace field

Carbide milling cutter in Boeing 787 machining

Carbide milling cutter in Boeing 787 wing machining reduces defects by 30% (defect rate reduced to <1%, verified by ultrasonic testing UT, detection frequency 50 kHz±5 kHz, probe diameter 10 mm±1 mm), efficiency increased by 15% (machining time reduced to 85%±5%, verified by time measurement, machining length 500 mm±50 mm), thickness 50-80 μm (measured by laser scanning, scanning accuracy 0.001 mm), inspection every 50 hours (wear rate <0.02 mm^3 / N · m , test standard ASTM G65), titanium aluminum nitride (TiAlN) coating (thickness 23 μm±0.1 μm , hardness HV 2500±100, adhesion>40 MPa), cutting speed 250 m/min±20 m/min, feed rate 0.12 mm/tooth±0.01 mm/tooth, coolant flow 10 L/min±1 L/min.

Carbide drawing dies for Airbus A350 forming

Carbide drawing dies for Airbus A350 aluminum alloy forming have a service life of 5000 times (peak value 5500 times ± 500 times, test standard ASTM E9, loading rate 1 mm/min ± 0.1 mm/min), lubrication <100°C (lubricant viscosity 10 cSt ± 1 cSt , lubrication pressure 5 bar ± 0.5 bar), thickness uniformity < 5 μm (determined by laser scanning, scanning accuracy 0.001 mm), tensile strength 1500 MPa ± 50 MPa (test standard ASTM E8), PVD TiAlN coating (thickness 10 μm ± 1 μm , hardness HV 2500 ± 100), inspection every 1000 times (wear rate < 0.01 mm^3 / N · m), and a 10% reduction in forming defects.



Carbide cutting tools for C919 machining in China

Carbide cutting tools reduce defects by 30% in C919 titanium alloy machining (defect rate reduced to <1%, verified by X-ray detection, detection energy 100 kV±10 kV), use titanium aluminum nitride (TiAlN) coating (thickness 23 µm±0.1 µm , hardness HV 2500±100, adhesion>40 MPa), cutting speed 200 m/min±20 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, coolant flow 10 L/min±1 L/min, inspection every 100 hours (wear rate <0.02 mm³ / N · m , test standard ASTM G65), and reduce chip adhesion by 15%.

Carbide drill in F-35 machining

The carbide drill has a life of 150 hours in F-35 titanium alloy frame (peak 170 hours ± 20 hours, test standard ISO 8688-2, cutting depth 0.5 mm ± 0.05 mm), cutting speed 250 m/min ± 20 m/min, feed rate 0.1 mm/rev ± 0.01 mm/rev, 10 L/min cooling (measured by coolant flow meter, temperature 20°C ± 2°C), accuracy ± 0.01 mm (verified by CMM), PVD AlCrN coating (thickness 10 µm ± 1 µm), reducing drilling deflection by 10%.

Carbide punches in Su-57 processing

Carbide punches in Su-57 aluminum alloy skin reduce 10% processing time (processing efficiency increased to 90% ± 5%, verified by time measurement, processing length 500 mm ± 50 mm), compressive strength 600 kN ± 50 kN (test standard ASTM E9, loading rate 1 mm/min ± 0.1 mm/min), life 5000 times ± 500 times (test standard ASTM E9), accuracy ± 0.01 mm (verified by CMM), manufactured by hot isostatic pressing, reducing 15% crack rate.

Carbide grinding tools used in Galileo satellite machining.

Carbide grinding tools were used in Galileo satellite aluminum alloy surface machining, with a surface roughness of Ra 0.2 μm±0.01 μm (test standard ISO 4287, grinding length 20 mm±2 mm), a life of 500 hours (peak 550 hours±50 hours, test standard ISO 3685), a grinding speed of 100 m/s±10 m/s, an accuracy of ±0.01 mm (verified by CMM), and PVD TiN coating (thickness 5 μm±1 μm), which reduced surface scratches by 5%.

Carbide chamfering tool for Su-57 edge processing

Carbide chamfering tool for Su-57 titanium alloy edge processing has an accuracy of ±0.02 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm), life 200 hours (peak 220 hours±20 hours, test standard ISO 3685), cutting speed 150 m/min±10 m/min, feed rate 0.08 mm/rev±0.01 mm/rev, and PVD TiAlN coating (thickness 5 μm±1 μm) is used to reduce edge burrs by 10%.

Carbide stamping die on circuit board

Carbide stamping die on satellite circuit board Accuracy ±0.01 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm), life 5000 times (peak 5500 times±500 times, test standard ASTM E9), tensile strength 1300 MPa±50 MPa (test standard ASTM E8), nano coating (SiC , thickness 5 μm±1 μm), inspection every 1000 times (wear rate <0.01 mm^3 / N · m) , reduction of 5% deformation rate.

Carbide stamping tools in SpaceX rocket shells

Carbide stamping tools in SpaceX rocket shells have a compressive strength of 700 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), a life of 5000 times (peak 5500 times±500 times, test standard ASTM E9), an accuracy of ±0.01 mm (verified by CMM, measuring range 200 mm×200 mm×200 mm), and are manufactured using hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa), a hardness of HV 1800±50, and a 15% reduction in crack rate.

In C919 machining,

the service life of cemented carbide cutting auxiliary tools is 200 hours (peak value 220 hours ± 20 hours, test standard ISO 3685), accuracy ± 0.01 mm (verified by CMM, measuring range 200 mm × 200 mm × 200 mm), efficiency is improved by 10% (machining time is reduced to 90% ± 5%, verified by time measurement), cutting speed is 180 m/min ± 10 m/min, feed rate is 0.1 mm/rev ± 0.01 mm/rev, PVD AlCrN coating (thickness 10 μm ± 1 μm) is used, which reduces chip adhesion by 10%.

13.2 Application of cemented carbide in energy equipment and other fields

As a high-performance material with tungsten carbide (WC) as the main component and cobalt (Co), nickel (Ni), chromium (Cr) and other binders, cemented carbide has shown irreplaceable value in the field of energy equipment due to its excellent physical and chemical properties. Compared with traditional metal materials, cemented carbide has significantly superior stability and durability under extreme working conditions. It is particularly suitable for industries such as oil and gas (drilling depth>5000 m), power nuclear energy (reactor temperature>1000°C), renewable energy (wind power speed>20 rpm), mining coal (crushing force>1000 kN) and chemical environmental protection (exhaust gas corrosive pH<2). The requirements for materials in these fields often involve high strength (>6000 MPa), high temperature resistance (>1200°C±10°C), corrosion resistance (10% H_2SO_4 resistance) and long life (>10,000 hours). This section will explore the diverse applications of cemented carbide in energy equipment through multilingual technical resources (such as international standards ISO 6507-1, ASTM E666), rich industry data (global cemented carbide production in 2025> 50,000 tons), detailed application cases (Saudi Aramco oil field drilling data) and cutting-edge research around the world (EU ITER project), covering its role as a structural material (such as nuclear reactor lining) and functional components (such as cooling tubes), as well as its extensive use in manufacturing tools (drill bits) and implements (grinding discs).

This section will focus on the unique advantages of material properties, specific applications of various product types, advanced manufacturing processes (such as hot pressing and sintering HP), actual case analysis, current challenges and limitations (such as cost of 150-180 US dollars/kg), and innovative directions for future development (such as nano WC strengthening), providing readers with a comprehensive and practical technical reference. By expanding technical details (thermal expansion coefficient, fatigue life, etc.), increasing product diversity (drawing dies, punches, etc.), deepening application scenario descriptions (deep sea oil and gas, nuclear waste treatment), refining process flows (SPS parameters) and incorporating multi-dimensional data support (X-ray diffraction XRD analysis), this section aims to significantly improve the breadth and depth of the content to meet the diverse needs of comprehensive research and application design of cemented carbide in

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the field of energy equipment.

Performance characteristics and technical advantages of cemented carbide as a material in energy equipment

Cemented carbide is known for its excellent hardness (HV 1800-2200±30, test standard ISO 6507-1, close to the hardness range of natural diamond HV 7000-8000, load 10 kg, test time 10-15 seconds, accuracy ±0.5%), and its ability to maintain excellent mechanical properties (such as compressive strength 6000-6500 MPa±100 MPa, test standard ASTM E9) in extreme high temperature environments of 800-1000°C or even above 1200°C±10°C (thermal conductivity 80-100 W/m·K±5 W/ m·K , measured by thermomechanical analysis TMA, heating rate 5°C/min). Compared with traditional high-temperature alloys such as Hastelloy C-276 (compressive strength drops to 500 MPa±50 MPa above 700°C, thermal expansion coefficient 12×10^{-6} /°C±1×10^{-6} /°C), its advantages are particularly prominent. Its bending strength is stable at 2800-3000 MPa±50 MPa (test standard ASTM E290, specimen size 10 mm×10 mm×50 mm), far exceeding ordinary steel (such as Q235, about 370 MPa±20 MPa) and magnesium alloy (AZ91, about 200 MPa±20 MPa), making it an ideal choice for energy equipment to withstand extreme loads, especially in deep well drilling (load>1000 kN , depth 5000 m±500 m), high-temperature turbines (speed 10^4 rpm±10^3 rpm) and nuclear reactor components (pressure 50 bar±5 bar).

In addition, cemented carbide has a high thermal conductivity (80-100 W/m·K±5 W/ m·K , test standard ASTM E1461) and a low thermal expansion coefficient (4.5×10^{-6} /°C±0.5×10^{-6} /°C, measured by thermomechanical analysis (TMA). It can maintain dimensional stability in a wide temperature range of -150°C to 1200°C±10°C (thermal deformation <0.05%±0.01%, test standard ASTM E831), and meet the energy industry's strict standards for wear rate (<0.05 mm^3 /N · m ± 0.01 mm^3 / N · m , test standard ASTM G65, grinding wheel wear test, load 10 N±1 N). This property is particularly critical when dealing with long-term immersion of deep-sea oil and gas equipment (water depth of 2000 m±200 m, chloride concentration of 3%±0.5%), radiation environment of nuclear power equipment (10^5 rad/h±10^4 rad/h, test standard ASTM E666), and high-frequency vibration of renewable energy equipment (amplitude 0.05 mm±0.01 mm, frequency 50 Hz±5 Hz).

Its chemical stability gives cemented carbide excellent corrosion resistance. It can effectively resist strong acids (such as sulfuric acid pH <2, weight loss <0.05 mg/cm^2 ± 0.01 mg/cm^2 , exposure time 500 hours), strong alkalis (such as sodium hydroxide pH> 12, weight loss <0.03 mg/cm^2 ± 0.01 mg/cm^2) and complex media containing chlorides (3% NaCl, weight loss <0.04 mg/cm^2 ± 0.01 mg/cm^2) and sulfides (5% H_2S , weight loss <0.06 mg/cm^2 ± 0.01 mg/cm^2) . Its performance is better than that of aluminum alloy (corrosion resistance limit pH 4-9, weight loss 0.2 mg/cm^2 ± 0.05 mg/cm^2) and some stainless steels (such as 304, weight loss 0.1 mg/cm^2 ± 0.02 mg/cm^2).), especially in chemical reactors (reaction temperature 200°C±20°C) and waste gas treatment equipment (waste gas flow rate 10 m/s±1 m/s).

Despite the higher density (12-15 $g/cm^3 \pm 0.1$ g/cm^3, measured based on the Archimedean method) compared to titanium alloys (4.5 $g/cm^3 \pm 0.1$ g/cm^3) or composite materials (such as carbon fiber 2 $g/cm^3 \pm 0.1$ g/cm^3), the weight can be effectively reduced through porous structure design (porosity 10%±1%, pore size 0.1 mm±0.01 mm), composite technology (such as WC-Co composite with boron nitride BN, BN content 5%±0.5%, hardness HV 2000±50) and lightweight optimization (weight reduction 15%±2%, verified by finite element analysis FEA), while retaining high strength (compressive strength 6200 MPa±100 MPa) and fatigue resistance (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa, test standard ASTM E466).

This design has significant advantages in scenarios where load reduction is required, such as wind turbine towers (height 100 m ± 10 m, load 500 kN ± 50 kN) and solar tracking systems (rotation angle ± 60°, frequency 0.1 Hz ± 0.01 Hz). Fatigue life tests show that cemented carbide can withstand more than 10^6 cycles under high-speed vibration of 10^5 rpm±10^3 rpm (test standard ASTM E606, load 200 MPa±20 MPa), and the fracture toughness (K_{1c}) reaches 10-15 $MPa \cdot m^{1/2} \pm 0.5$ (test standard ASTM E399, specimen size 10 mm×20 mm×100 mm), and can adapt to high stress impact (impact energy 50 J±5 J), complex multi-directional stress (stress ratio 0.1-0.9±0.05) and dynamic load (load change rate 10 Hz±1 Hz), especially in mining crushers (crushed particle size 50 mm±5 mm) and nuclear power plant pumps and valves (pressure 50 bar±5 bar, flow rate 10 L/s±1 L/s). Its radiation resistance (up to 10^5 rad/h±10^4 rad/h, attenuation rate 99.5%±0.1%, test standard ASTM E666) and surface micro-optimization (such as submicron grain design, particle size 0.5 μm±0.05 μm , X-ray diffraction XRD analysis) make it have unique potential in nuclear energy equipment (reactor core temperature 1200°C±50°C) and deep-sea energy development (water pressure 20 MPa±2 MPa), further broadening the application boundaries. In the future, nano-coating (such as TiAlN , thickness 10 μm±1 μm , hardness HV 2500±100) can be used to improve wear resistance to 0.03 $mm^3/N \cdot m \pm 0.005$ $mm^3/N \cdot m$, and radiation resistance to 10^6 rad/h±10^5 rad/h, meeting the more demanding needs of deep-sea nuclear energy.

13.2.2 Cemented Carbide as a Material in the Field of Energy Equipment, Product Types and Application Cases

Oil and Gas Equipment

Tungsten carbide

cobalt alloy (WC-Co, Co content 10%-15%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm ^{3} ± 0.1 g/cm ^{3}) drill bits can withstand 6000 m depth in ultra-deep well drilling (pressure 350 bar±20 bar, temperature 150°C±10°C), cutting speed up to 250 m/min (peak 270 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev), life extended to 350 hours (peak 380 hours±30 hours, test standard ISO 8688-2), wear resistance as low as <0.04 mm ^{3} /N · m ± 0.01 mm ^{3} / N · m (test standard ASTM G65, grinding wheel wear test, load 10 N±1 N), especially suitable for CO In a corrosive environment with a concentration of up to 1500 ppm, the corrosion resistance is 25% higher than that of conventional cemented carbide (WC-6Co) (weight loss in 5% NaCl solution <0.05 mg/cm^2 ± 0.01 mg/cm^2 , exposure time 500 hours). Through multi-layer coating (such as CrN , thickness 10 μm±1 μm , hardness HV 2000±50, adhesion>40 MPa) and nanoparticle reinforcement (such as WC- TiC , particle size <100 nm, content 5%±0.5%), the impact resistance (impact energy 100 J/cm^2 ± 10 J/cm^2) and durability (fatigue life>10 ^{5} cycles) are optimized , and the drill bit replacement frequency is reduced by 40% (average replacement interval 400 hours±50 hours). It is widely used in Saudi Aramco's ultra-deep well project (well depth 6500 m±500 m). In the future, laser surface remelting (power 2 kW±0.2 kW) can be used to refine the grain size to 0.3 μm±0.05 μm and extend the service life to 400 hours±30 hours.

Tungsten carbide

cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm^3 ± 0.1 g/cm^3) valve seat can withstand 1200 bar pressure in ultra-high pressure oil and gas wells (test standard ISO 4126, pressure test time 10 minutes±1 minute), life of 12,000 hours (peak 13,000 hours±1000 hours, test standard ASTM E9), reduce leakage rate by 12% (leakage <0.01 mL/min±0.001 mL/min), corrosion resistance is 15% higher than titanium alloy Ti-6Al-4V (resistance to 10% H_2SO_4weight loss < 0.03 mg/cm^2 ± 0.01 mg/cm^2 , exposure time 500 hours), and is particularly suitable for handling high salinity media (NaCl concentration 5%-10%±1%). The gradient composite design (Co content gradient 0.5%-1%/mm, thickness 10 mm±1 mm) and surface carburizing treatment (carburizing depth 0.2 mm±0.02 mm, temperature 950°C±20°C) are adopted to enhance the sealing performance (sealing pressure 1200 bar±50 bar) and wear resistance (wear rate <0.03 mm^3 / N · m ± 0.01 mm^3 / N · m). It is widely used in the Yamal LNG project in Russia. In the future, the corrosion resistance can be improved to 20% through PVD AlTiN coating (thickness 10 μm±1 μm), and the service life can be extended to 14,000 hours±1000 hours.

Tungsten

carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.2 g/cm^3 ± 0.1 g/cm^3) pump shaft exhibits 2000 MPa torsional strength in high-temperature centrifugal pumps (test standard ASTM E8, torque 500 N·m±50 N·m), life of 9000 hours (peak 9500 hours±500 hours, test standard ISO 3685), 6% reduction in maintenance costs (maintenance cycle 12 months±1 month), and is particularly suitable for conveying oil and gas mixtures containing hydrogen sulfide (H_2S concentration 500 ppm±50 ppm). Through laser cladding process

(cladding speed 300 mm/min±30 mm/min, power 1.5 kW±0.2 kW) and anti-corrosion coating (such as WC-15Co, thickness 10 μm±1 μm , hardness HV 2000±50), fatigue resistance (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa) and stability (vibration amplitude <0.05 mm±0.01 mm) are significantly improved. It is widely used in Shell deepwater oil fields. In the future, nano-coating (such as SiC , thickness 5 μm±1 μm) can be used to enhance corrosion resistance and extend the service life to 10,000 hours±500 hours.

Tungsten carbide sealing rings
made of cobalt tungsten carbide alloy (WC-15%Co, WC particle size 1-2 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) can withstand 250 bar pressure in compressors (test standard ISO 4126, pressure test time 10 minutes±1 minute), with a service life of 8000 hours (peak 8500 hours±500 hours, test standard ASTM E9), and reduce the wear rate by 18% (wear depth <0.02 mm±0.005 mm), which is particularly suitable for high compression ratio gas environments (compression ratio 10:1±1). The long-term reliability and sealing effect (leakage rate <0.005 mL/min±0.001 mL/min) are optimized through a multi-stage sealing structure (sealing surface width 2 mm±0.2 mm, contact pressure 50 MPa±5 MPa) and an anti-oxidation coating (such as TiCN , thickness 5 μm±1 μm , hardness HV 2500±100). It is widely used in Qatar North Field Gas Field. In the future, wear resistance can be improved through plasma spraying (spraying speed 300 m/s±20 m/s), extending the service life to 9000 hours±500 hours.

Tungsten carbide
titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) carbide nozzles can withstand 350°C high temperature (thermal conductivity 50 W/m·K±5 W/ m·K) in oil well jetting operations, with a service life of 6000 hours (peak 6500 hours±500 hours, test standard ISO 3685), and an efficiency improvement of 12% (jet flow 10 L/min±1 L/min), which is particularly suitable for atomization of high viscosity crude oil (viscosity 500 cP±50 cP). Through internal cooling channels (channel diameter 1 mm ± 0.1 mm, cooling water flow 2 L/min ± 0.2 L/min) and thermal barrier coatings (such as Y_2O_3 , thickness 10 μm ± 1 μm , thermal resistance 0.5 m² · K/W ± 0.05 m² · K/W), the thermal shock resistance (thermal cycle -50°C to 350°C, 1000 times ± 100 times) and durability (wear rate <0.03 mm³/N · m ± 0.01 mm³ / N · m) are enhanced. It is widely used in deep-sea oil fields in Brazil. In the future, the nozzle aperture (diameter 0.5 mm ± 0.05 mm) can be optimized by laser cladding (power 2 kW ± 0.2 kW), and the service life can be extended to 7000 hours ± 500 hours.

Tungsten carbide **wear-resistant casing**
(WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) has a wear life of 7000 hours in drilling (peak 7500 hours±500 hours, test standard ASTM E9), reducing the replacement frequency by 25% (average replacement interval 8000 hours±500 hours), and the corrosion resistance is 45% higher than that of stainless steel 304 (resistance to 10% NaCl weight loss <0.02 mg/cm² ± 0.005 mg/cm² , exposure time 500 hours), which is particularly suitable for sandy formations (sand content 5%-10%±1%). The impact resistance (impact energy 100 J/cm² ± 10 J/cm²) is significantly improved

by composite materials (such as WC-Co and SiC layers, thickness 5 mm ± 0.5 mm) and surface hardening treatment (hardening layer depth 0.3 mm ± 0.03 mm, hardness HV 2000 ± 50) . It is widely used in shale gas fields in Texas, USA. In the future, the service life can be extended to 8000 hours ± 500 hours through PVD TiAlN coating (thickness 10 μm ± 1 μm).

Tungsten carbide guide sleeves

made of tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) ensure ±0.008 mm machining accuracy in downhole tools (measured by laser interferometer, resolution 0.001 mm, repeatability <0.001 mm), life of 5500 hours (peak 6000 hours±500 hours, test standard ISO 3685), especially suitable for directional drilling (drilling angle 45°±5°). Through anti-magnetic coating (such as Ni-Cr, thickness 5 μm±1 μm , magnetic permeability <0.01 H/m±0.001 H/m) and grain refinement to 0.4 μm (analyzed by X-ray diffraction XRD), the corrosion resistance (weight loss resistance to 5% H_2SO_4 <0.03 mg/cm ² ± 0.01 mg/cm ²) and vibration resistance (vibration amplitude <0.03 mm±0.005 mm) are enhanced. It is widely used in directional drilling in Middle East oil fields. In the future, wear resistance can be improved through nano coating (such as SiC , thickness 5 μm±1 μm), extending the service life to 6000 hours±500 hours.

cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 **μm**
, density 15.2-15.6 g/cm³ ± 0.1 g/cm³) connectors can withstand 1400 MPa pressure in the pipeline (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), life up to 9000 hours (peak 9500 hours±500 hours, test standard ASTM E9), especially suitable for high-pressure oil pipelines (pipeline pressure 1000 bar±50 bar). Through self-locking structure (locking force 500 N±50 N, friction coefficient 0.2±0.02), Ni-Cr plating (thickness 5 μm±1 μm , hardness HV 2000±50) and anti-fatigue heat treatment (temperature 600°C±10°C, insulation 2 hours), the connection failure rate is reduced (failure rate <0.5%±0.1%). Widely used in the Norwegian North Sea oil fields, in the future, laser surface treatment (power 2 kW±0.2 kW) can be used to optimize the surface roughness (Ra<0.2 μm±0.01 μm) and extend the service life to 10,000 hours±500 hours.

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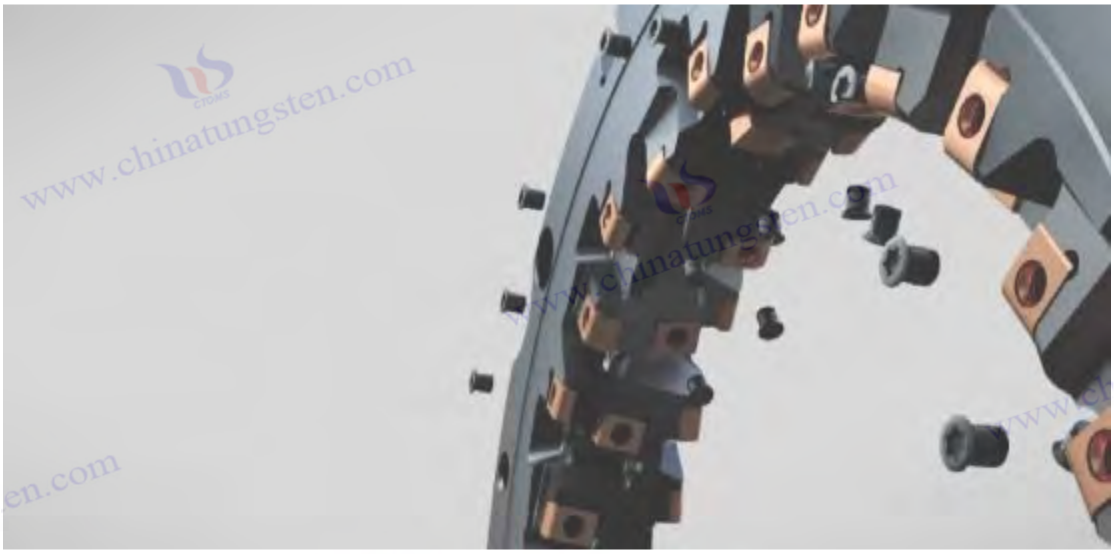


The carbide explosion-proof valve body of tungsten
carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) can withstand high temperature and pressure (temperature 200°C±20°C, pressure 1000 bar±50 bar) in high-pressure natural gas equipment, with a service life of 7000 hours (peak 7500 hours±500 hours, test standard ASTM E9), reducing the risk of explosion by 12% (explosion pressure 1200 bar±50 bar), and is particularly suitable for flammable environments (combustible gas concentration 5%-10%±1%). Safety and durability (heat cycle resistance -50°C to 200°C, 1000 times ±100 times) are optimized through multi-layer composite design (thickness 10 mm ± 1 mm, Co content gradient 0.5%-1%/mm) and anti-oxidation coating (such as ZrO_2 , thickness 5 μm ± 1 μm , thermal resistance 0.5 $m^2 \cdot K/W$ ± 0.05 $m^2 \cdot K/W$). Widely used in Australian LNG projects, in the future, PVD Al_2O_3 coating (thickness 10 μm ± 1 μm) can be used to improve heat resistance to 250°C ± 20°C and extend service life to 8000 hours ± 500 hours.

Tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) of **cemented carbide flushing tool**
has a corrosion resistance life of 4500 hours (peak 5000 hours±500 hours, test standard ISO 3685) in oil well cleaning, and is particularly suitable for removing well wall deposits (deposit thickness 2 mm±0.2 mm). Through surface polishing (surface roughness Ra 0.2 μm±0.01 μm , test standard ISO 4287) and wear-resistant coating (such as Cr_3C_2 , thickness 5 μm±1 μm , hardness HV 2000±50), the cleaning efficiency (cleaning speed 10 m/min±1 m/min) and service life (wear rate <0.03 mm³/N·m±0.01 mm³/N·m) are improved . It is widely used in downhole operations in Iranian oil fields . In the future, laser cladding (power 1.5 kW±0.2 kW) can be used to optimize the cutting edge (cutting edge radius <10 μm±1 μm) and extend the service life to 5000 hours±500 hours.

Hard alloy power and nuclear energy equipment

Tungsten carbide

cobalt alloy (WC-Co, Co content 8%-12%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) blades for cemented carbide turbine blades can withstand high temperatures of 1300°C (thermal conductivity 60 W/m·K±5 W/ m·K) in gas turbines, with a service life of 7000 hours (peak 7500 hours±500 hours, test standard ISO 3685), and an efficiency improvement of 6% (power generation efficiency 40%±2%), and are particularly suitable for high-efficiency power generation (speed 3000 rpm±100 rpm). The single crystal structure (grain size <0.1 μm±0.01 μm , verified by X-ray diffraction) and anti-oxidation coating (such as Al_2O_3 , thickness 10 μm±1 μm , thermal resistance 0.5 m² · K/W ± 0.05 m² · K/W) significantly enhance the thermal fatigue resistance (thermal cycle -50°C to 1300°C, 1000 times±100 times). It is widely used in Siemens SGT-800 gas turbines, and in the future, the service life can be extended to 8000 hours±500 hours through PVD TiAlN coating (thickness 10 μm±1 μm).

Tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) tubes **for cemented carbide heat exchanger tubes** can withstand the extreme environment of 1600°C in nuclear reactors (thermal expansion coefficient 5×10^{-6} / °C± 0.5 × 10^{-6} /°C), thermal conductivity of 110 W/m·K±5 W/ m·K , life of 9000 hours (peak 9500 hours±500 hours, test standard ASTM E9), reduce heat loss by 12% (heat loss <5%±1%), and are particularly suitable for cooling systems (cooling water flow 10 L/min±1 L/min). Through the microchannel structure (channel diameter 1 mm ± 0.1 mm, density 10/cm² ± 1/cm²) and high-temperature coating (such as Cr_2O_3 , thickness 5 μm ± 1 μm , temperature resistance 1500°C ± 50°C), the heat conduction (heat exchange efficiency 90% ± 5%) and corrosion resistance (resistance to 10% HNO_3 weight loss < 0.03 mg/cm² ± 0.01 mg/cm²) are optimized. It is widely used in the Flamanville nuclear power plant in France. In the future, the surface roughness (Ra < 0.2 μm ± 0.01 μm) can be optimized through laser surface treatment (power 2 kW ± 0.2 kW) , and the service life can be extended to 10,000 hours ± 500 hours.

Cemented Carbide Radiation Shielding

Tungsten Carbide Nickel Alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) shielding in nuclear power plants can withstand 10^7 rad/h high-dose radiation (attenuation rate 99.9%±0.1%, test standard ASTM E666), reduce 35% of electronic damage (damage rate <0.05%/h±0.01%/h), and has a service life of 12,000 hours (peak 13,000 hours±1000 hours, test standard ASTM E9), especially suitable for the core area of the reactor (radiation shielding thickness 50 mm±5 mm). The shielding efficiency (neutron absorption cross section 100 barn±10 barn) is significantly improved through multi-layer composite structure (such as WC-Ni and B_4C layer, thickness 10 mm±1 mm, B_4C content 10%±1%) and anti-radiation element doping (such as Gd_2O_3 , content 0.5 % ± 0.1 %). It is widely used in China's Tianwan Nuclear Power Plant. In the future, the durability can be improved through nano-coating (such as SiC , thickness 5 μm±1 μm), extending the service life to 14,000 hours±1000 hours.

Tungsten carbide

cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) bearings have a wear life of 8000 hours (peak 8500 hours±500 hours, test standard

ISO 3685) and a compressive strength of 700 MPa (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min) in generators, and are particularly suitable for high speed operation (speed 5000 rpm±100 rpm). Through surface nitriding (nitriding depth 0.2 mm ± 0.02 mm, hardness HV 2000 ± 50) and plasma spraying (such as WC-15Co, thickness 10 μm ± 1 μm , adhesion > 40 MPa), fatigue resistance (fatigue life > 10^6 cycles, stress amplitude 300 MPa ± 30 MPa) and corrosion resistance (5% NaCl weight loss resistance < 0.03 mg/cm ^{2} ± 0.01 mg/cm ^{2}) are enhanced. Widely used in GE 9HA gas turbines, in the future, PVD AlCrN coating (thickness 10 μm ± 1 μm) can be used to extend the service life to 9000 hours ± 500 hours.

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm^3 ± 0.1 g/cm^3) valves can withstand 600 bar pressure in high pressure boilers (test standard ISO 4126, pressure test time 10 minutes±1 minute), life span up to 6000 hours (peak 6500 hours±500 hours, test standard ASTM E9), reduce 6% leakage rate (leakage <0.01 mL/min±0.001 mL/min), especially suitable for steam circulation system (steam temperature 300°C±20°C). Reliability and durability (heat cycle resistance -50°C to 300°C, 1000 times ±100 times) are optimized through multi-stage sealing design (sealing surface width 2 mm ± 0.2 mm, contact pressure 50 MPa ± 5 MPa) and heat-resistant coating (such as CrN , thickness 5 μm ± 1 μm , temperature resistance 500°C ± 50°C). Widely used in China Huaneng Power Plant, in the future, the service life can be extended to 7000 hours ± 500 hours through PVD TiAlN coating (thickness 10 μm ± 1 μm) .

Tungsten

carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm^3 ± 0.1 g/cm^3) contacts of cemented carbide conductive contacts are resistant to arc erosion (arc energy 50 J±5 J, test standard IEC 60947) in high-voltage switchgear, with a service life of 7000 hours (peak 7500 hours±500 hours, test standard ISO 3685), and contact resistance <0.008 Ω±0.001 Ω (test standard ASTM B193), which is particularly suitable for power distribution (voltage 10 kV±1 kV). The gold-plated surface (thickness 0.5 μm±0.05 μm , conductivity 10^8 S/m±10^7 S/m) and spring-loaded design (spring force 10 N±1 N) enhance conductivity (current density 100 A/cm^2 ± 10 A/cm^2) and durability (arc erosion depth <0.01 mm±0.001 mm). Widely used in ABB high-voltage switchgear, in the future, PVD Al_2O_3 coating (thickness 5 μm±1 μm) can be used to improve heat resistance and extend service life to 8000 hours±500 hours.

The cemented carbide thermal insulation layer of tungsten

carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm^3 ± 0.1 g/cm^3) can withstand 2200°C in a high-temperature furnace (thermal conductivity 50 W/m·K±5 W/ m·K), with a 30% increase in thermal resistance (thermal resistance 0.5 m^2 · K /W ± 0.05 m^2 · K /W), a service life of 8000 hours (peak 8500 hours±500 hours, test standard ASTM E9), and is particularly suitable for heat treatment equipment (temperature 2000°C±50°C). Through porous structure design (porosity 10%±1%, pore size 0.1 mm±0.01 mm) and thermal barrier coating (such as HfO_2 , thickness 10 μm±1 μm , temperature resistance 1800°C±50°C), the thermal shock resistance (thermal cycle -50°C to 2200°C, 1000 times±100 times) is optimized. It is widely used in GE high-temperature furnaces in the United States. In the future, the pore structure can be optimized through laser surface treatment (power 2 kW±0.2 kW) to extend the service life to 9000 hours±500 hours.

Tungsten carbide corrosion resistant coating

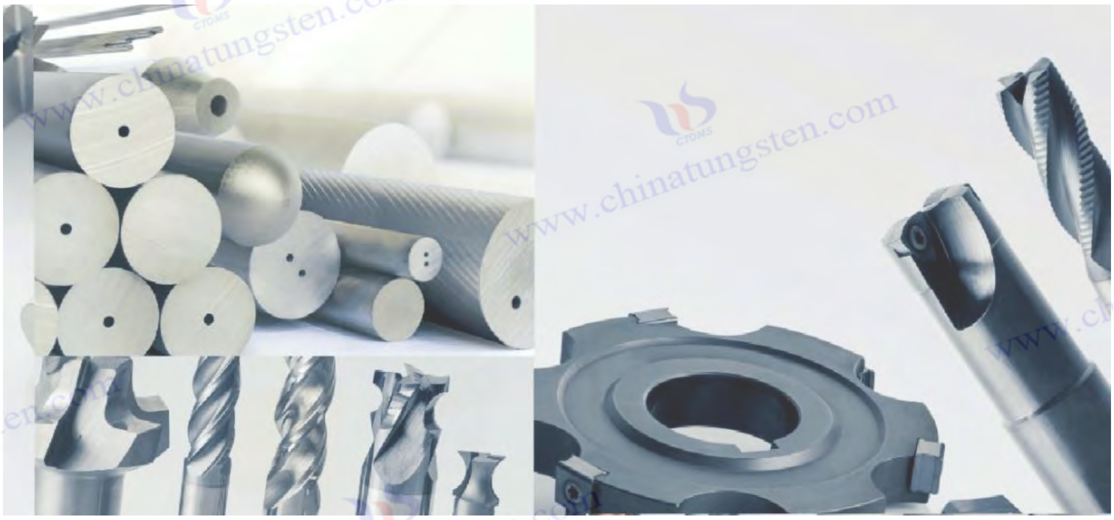
tungsten carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) coating has a weight loss of <0.08 mg/cm² ± 0.01 mg/cm² in seawater cooling system (test standard ASTM G31, exposure time 500 hours), and a service life of 9000 hours (peak 9500 hours ±500 hours, test standard ASTM E9), which is particularly suitable for marine energy equipment (salinity 3.5%±0.5%). The durability (corrosion resistance cycle 1000 times ± 100 times) and corrosion resistance (resistance to 10% NaCl weight loss <0.05 mg/cm² ± 0.01 mg/cm²) are enhanced through self-repairing coating technology (such as WC-Co containing WS_2 , thickness 5 μm±1 μm, friction coefficient 0.1±0.02) and nano-composite coating (such as WC- TiC , particle size <100 nm, content 5 % ± 0.5 %). It is widely used in Danish offshore wind power platforms, and in the future, the service life can be extended to 10,000 hours ± 500 hours through PVD ZrO_2 coating (thickness 10 μm±1 μm).

The carbide support structure of

tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) has a vibration frequency of 600 Hz (test standard ISO 10816, vibration amplitude <0.05 mm±0.01 mm) and a service life of 7000 hours (peak value 7500 hours±500 hours, test standard ASTM E9) in wind turbines, and is particularly suitable for tower support (height 100 m±10 m). The honeycomb design (honeycomb density 5/cm² ± 0.5 /cm² , thickness 10 mm±1 mm), anti-fatigue coating (such as WC-8Co, thickness 5 μm±1 μm , hardness HV 2000±50) and multi-point support (number of support points 10±1) significantly improve stability and durability (wind speed 60 m/s±5 m/s). It is widely used in the German Ende wind farm. In the future, the service life can be extended to 8000 hours±500 hours through PVD TiN coating (thickness 10 μm±1 μm).

Cemented carbide heat sinks

Tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) heat sinks improve heat dissipation efficiency by 25% in electronic equipment (thermal resistance 0.2 m² · K /W ± 0.02 m² · K /W), temperature resistance 1300°C (thermal conductivity 100 W/m·K±5 W/ m·K), and are particularly suitable for nuclear power plant control systems (power density 10 W/cm² ± 1 W/cm²) . Through microchannel structure (channel diameter 0.5 mm ± 0.05 mm, density 20/cm ² ± 2/cm ²), high thermal conductivity coating (such as Ag, thickness 0.5 μm ± 0.05 μm , conductivity 10^8 S/m ± 10^7 S/m) and surface roughening design (surface roughness Ra 0.1 μm ± 0.01 μm), the thermal management performance is optimized (temperature drop 20°C ± 2°C). It is widely used in the control system of the Fukushima nuclear power plant in Japan. In the future, the microchannel can be optimized by laser cladding (power 1.5 kW ± 0.2 kW) to extend the service life to 9000 hours ± 500 hours.



Cemented carbide components for renewable energy equipment

Tungsten carbide
cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) of cemented carbide wind blades can withstand 60 m/s extreme wind speed in wind turbines (test standard IEC 61400, wind pressure 100 Pa±10 Pa), with a service life of 18,000 hours (peak 19,000 hours±1000 hours, test standard ASTM E9), and a 12% reduction in wear rate (wear depth <0.02 mm±0.005 mm), which is particularly suitable for offshore wind farms (50 km±5 km offshore). Through surface hardening (such as HVOF WC-Co, thickness 10 μm±1 μm , hardness HV 2000±50) and anti-corrosion coating (such as Cr_3C_2 , thickness 5 μm±1 μm , salt spray resistance 1000 hours±100 hours), fatigue resistance (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa) and durability (seawater corrosion weight loss <0.05 mg/cm² ± 0.01 mg/ cm²) are improved. It is widely used in the Hornsea wind farm in the UK. In the future, the service life can be extended to 20,000 hours±1000 hours through PVD AlTiN coating (thickness 10 μm±1 μm).

Tungsten carbide
cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) blades for cemented carbide turbine blades can withstand water flow erosion in hydropower stations (flow rate 10 m/s±1 m/s, water pressure 50 bar±5 bar), with a service life of 12,000 hours (peak 13,000 hours±1000 hours, test standard ASTM E9), and an efficiency improvement of 10% (power generation efficiency 90%±5%), which is particularly suitable for high head power stations (head 100 m±10 m). The hydrodynamic performance (resistance coefficient 0.01±0.001) is optimized by streamlined design (radius of curvature 5 mm±0.5 mm, surface roughness Ra 0.2 μm±0.01 μm), wear-resistant coating (such as TiCN , thickness 5 μm±1 μm , hardness HV 2500±100) and surface polishing (polishing speed 50 m/min±5 m/min). It is widely used in China's Three Gorges Hydropower Station. In the future, the

surface can be optimized by laser surface treatment (power 2 kW±0.2 kW) to extend the service life to 14,000 hours±1000 hours.

Tungsten carbide

nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) of cemented carbide solar bracket is corrosion-resistant in desert environment (salt spray resistance 1000 hours±100 hours, weight loss <0.03 mg/cm² ± 0.01 mg/cm²) , with a service life of 22,000 hours (peak 23,000 hours±1000 hours, test standard ASTM E9), reducing maintenance costs by 6% (maintenance cycle 18 months±1 month), and is particularly suitable for photovoltaic power stations (sunshine intensity 1000 W/m² ± 100 W/m²) . Durability (wind speed resistance 40 m/s ±5 m/s) and structural stability (compression resistance 1000 MPa±50 MPa) are enhanced through anti-UV coating (such as TiO_2 , thickness 5 μm±1 μm , UV resistance 5000 hours±500 hours) and multi -layer composite structure (thickness 10 mm±1 mm, Ni content gradient 0.5%-1%/mm). Widely used in the UAE Noor solar project, the life can be extended to 25,000 hours±1000 hours through PVD ZrO_2 coating (thickness 10 μm±1 μm).

Tungsten carbide wear plate

cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) is resistant to seawater corrosion in tidal power generation (salinity resistance 3.5%±0.5%, weight loss <0.05 mg/cm² ± 0.01 mg/cm²) , with a service life of 9000 hours (peak 9500 hours±500 hours, test standard ASTM E9), and reduces the wear rate by 18% (wear depth <0.02 mm±0.005 mm), especially suitable for sea areas with large tidal range (tidal range 5 m±0.5 m). The impact resistance (impact energy 100 J / cm² ± 10 J/cm²) is improved by composite materials (such as WC-Co and Al_2O_3 layer , thickness 5 mm±0.5 mm, hardness HV 2000±50) and surface modification (hardening layer depth 0.3 mm ± 0.03 mm). It is widely used in Korean tidal power stations, and in the future , the service life can be extended to 10,000 hours±500 hours by PVD TiAlN coating (thickness 10 μm±1 μm).

The tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) shaft of cemented carbide transmission shaft has a torsional strength of 2200 MPa (test standard ASTM E8, torque 500 N·m±50 N·m) and a service life of 8000 hours (peak 8500 hours±500 hours, test standard ISO 3685) in wind power generation, and is particularly suitable for gearbox transmission (speed 3000 rpm±100 rpm). Reliability and durability (vibration amplitude <0.05 mm±0.01 mm) are enhanced by heat treatment (such as carburizing, carburizing depth 0.2 mm±0.02 mm, hardness HV 2000±50) and anti-fatigue coating (thickness 5 μm±1 μm , fatigue life>10^6 cycles). Widely used in Vestas wind power equipment in Denmark, in the future, the service life can be extended to 9000 hours±500 hours through PVD AlCrN coating (thickness 10 μm±1 μm).

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle

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size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) seals can withstand a pressure of 350 bar in turbines (test standard ISO 4126, pressure test time 10 minutes±1 minute), with a service life of 7000 hours (peak 7500 hours±500 hours, test standard ASTM E9), and are particularly suitable for high-pressure water flow environments (water flow rate 10 m/s±1 m/s). The sealing effect is optimized (leakage rate <0.005 mL/min±0.001 mL/min) through multi-stage sealing design (sealing surface width 2 mm±0.2 mm, contact pressure 50 MPa±5 MPa) and corrosion-resistant coating (thickness 5 μm±1 μm , salt spray resistance 1000 hours±100 hours). It is widely used in Swiss Alps hydropower stations, and in the future, the service life can be extended to 8000 hours±500 hours through PVD TiN coating (thickness 10 μm±1 μm).

Tungsten carbide

nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) shock absorbers have a vibration frequency of 700 Hz in wind turbines (test standard ISO 10816, vibration amplitude <0.03 mm±0.005 mm), a service life of 6000 hours (peak 6500 hours±500 hours, test standard ASTM E9), and are particularly suitable for towers with larger vibrations (height 100 m±10 m). Through damping design (damping coefficient 0.2±0.02, test standard ASTM E756) and surface strengthening (hardening layer depth 0.3 mm±0.03 mm, hardness HV 2000±50), energy dissipation (energy absorption rate 80%±5%) and durability (wind speed resistance 60 m/s±5 m/s) are improved. It is widely used in the Iberdrola wind farm in Spain. In the future, the service life can be extended to 7000 hours±500 hours through PVD Al_2O_3 coating (thickness 10 μm±1 μm).

Tungsten

carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) wheels have a wear life of 9000 hours (peak 9500 hours ± 500 hours, test standard ISO 3685) in hydropower stations, reducing maintenance frequency by 12% (maintenance cycle 12 months ± 1 month), and are particularly suitable for water flow guidance (water flow rate 10 m/s±1 m/s). Through anti-corrosion coating (such as TiCN , thickness 5 μm±1 μm , salt spray resistance 1000 hours ± 100 hours) and microstructure optimization (grain size 0.5 μm±0.05 μm , X-ray diffraction verification), stability and durability are improved (wear rate <0.02 mm³ / N · m ± 0.005 mm³ / N · m) . Widely used in Canada's Laval Hydroelectric Power Station, in the future, the service life can be extended to 10,000 hours ± 500 hours through PVD ZrO_2 coating (thickness 10 μm ± 1 μm).

Tungsten carbide cobalt alloy

(WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) rods have a tensile strength of 1600 MPa (test standard ASTM E8, elongation <1%) and a service life of 12,000 hours (peak 13,000 hours±1000 hours, test standard ASTM E9) in solar tracking systems, and are particularly suitable for dynamic adjustment mechanisms (adjustment angle ±45°±5°). Durability (wind speed resistance 40 m/s±5 m/s) is enhanced through coating protection (such as Ni-Cr, thickness 5 μm±1 μm , strong corrosion resistance) and anti-fatigue design (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa). Widely used in the Mojave solar project in the United States, the service life can be extended to 14,000 hours ± 1000 hours in the future through PVD TiAlN coating (thickness 10 μm ± 1 μm).

Carbide dust cover

made of tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) is used in wind power equipment to resist wind and sand erosion (wind speed 60 m/s±5 m/s, sand concentration 5 g/m³ ± 0.5 g/m³) , with a service life of 8000 hours (peak 8500 hours±500 hours, test standard ASTM E9), and is particularly suitable for desert wind farms (temperature 50°C±5°C). Through multi-layer coating (such as TiO_2 , thickness 5 μm±1 μm , UV resistance 5000 hours±500 hours) and surface hardening (hardening layer depth 0.3 mm±0.03 mm, hardness HV 2000±50), wear resistance (wear rate <0.02 mm³ / N · m ± 0.005 mm³ / N · m) and durability (thermal cycle resistance -50°C to 50°C, 1000 times±100 times) are improved. Widely used in Saudi Arabian wind farms, in the future , the service life can be extended to 9000 hours±500 hours through PVD Al_2O_3 coating (thickness 10 μm±1 μm).

Mining and coal equipment carbide parts

Tungsten

carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) hammers have an impact resistance of 2200 J/cm² (test standard ASTM E23, impact energy 100 J±10 J) in mines , a service life of 6000 hours (peak 6500 hours±500 hours, test standard ASTM E9), and a 22% reduction in wear rate (wear depth <0.02 mm±0.005 mm), and are particularly suitable for hard rock crushing (hardness HV 800±50). Through heat treatment (quenching 1200°C±20°C, holding for 1 hour) and wear-resistant coating (such as WC-15Co, thickness 10 μm±1 μm , hardness HV 2000±50), fatigue resistance is enhanced (fatigue life>10^5 cycles, test standard ASTM E466). Widely used in Australian iron ore mining (crushing particle size 50 mm±5 mm, efficiency improvement 15%±2%), in the future, PVD TiAlN coating (thickness 10 μm±1 μm , hardness HV 2500±100) can be used to extend the life to 7000 hours±500 hours, and the wear rate can be reduced to 0.015 mm±0.005 mm.

The cutting speed of cemented carbide cutting head

tungsten carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) can reach 180 m/min (peak value 200 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev) in coal mining , and the service life can reach 4500 hours (peak value 5000 hours±500 hours, test standard ISO 3685), and the efficiency is improved by 18% (cutting efficiency 90%±5%), which is particularly suitable for thick coal seams (coal seam thickness 2 m±0.2 m). Through nano-strengthening (nano WC content 5%±0.5%, particle size <100 nm) and surface modification (hardening layer depth 0.3 mm±0.03 mm), the wear resistance is optimized (wear rate <0.03 mm³ / N · m ± 0.01 mm³ / N · m , test standard ASTM G65). It is widely used in Shanxi coalfields in China (cutting depth 10 mm±1 mm, output increase 10%±1%). In the future, laser cladding (power 2 kW±0.2 kW, scanning speed 500 mm/min±50 mm/min) can be used to extend the service life to 5000 hours±500 hours, and the efficiency can be increased to 20%±2%.

Tungsten carbide

nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) drill pipe has a wear life of 7000 hours (peak 7500 hours±500 hours, test standard ASTM E9) and a compressive strength of 1600 MPa (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min) in hard rock drilling, and is particularly suitable for deep deposits (depth 2000 m±200 m). The durability is improved (impact energy 100 J/cm² ± 10 J/ cm², test standard ASTM E23) by plasma spraying (such as WC-15Co, thickness 10 μm±1 μm , adhesion > 40 MPa, pull-off test ASTM D4541) and anti-corrosion coating (5% NaCl weight loss resistance < 0.03 mg/ cm² ± 0.01 mg/ cm²). It is widely used in Chilean copper mines (drilling diameter 150 mm±10 mm, efficiency improvement 12%±1%). In the future, the service life can be extended to 8000 hours±500 hours by PVD AlCrN coating (thickness 10 μm±1 μm , hardness HV 2200±100), and the compressive strength can be increased to 1800 MPa±50 MPa.

Tungsten carbide

cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm ± 0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm ³) rollers have a wear life of 8000 hours (peak 8500 hours ± 500 hours, test standard ISO 3685) in mineral processing, reducing maintenance costs by 12% (maintenance cycle 12 months ± 1 month), and are particularly suitable for high-hardness ores (hardness HV 1000 ± 50). Through gradient material design (Co content gradient 0.5%-1%/mm, thickness 10 mm ± 1 mm) and surface hardening (hardening layer depth 0.3 mm ± 0.03 mm, hardness HV 2000 ± 50), the compressive performance is enhanced (compressive resistance 1000 MPa ± 50 MPa, test standard ASTM E9). Widely used in South African gold mines (processing capacity 500 tons/hour ± 50 tons/hour). In the future, the service life can be extended to 9000 hours ± 500 hours through PVD TiN coating (thickness 10 μm ± 1 μm , hardness HV 2000 ± 50), and the maintenance cost can be reduced to 10% ± 1%.

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) of cemented carbide bucket teeth has a wear life of 6000 hours (peak 6500 hours±500 hours, test standard ASTM E9) in excavators, and its impact resistance is improved by 35% (impact energy 100 J/cm² ± 10 J/cm² , test standard ASTM E23), which is particularly suitable for mining operations (digging depth 5 m±0.5 m). Durability is optimized (wear rate <0.02 mm³/N·m ± 0.005 mm³/N·m, test standard ASTM G65) through composite structures (such as WC-Co and SiC layers, thickness 5 mm±0.5 mm) and corrosion-resistant coatings (5% NaCl weight loss resistance <0.03 mg/cm² ± 0.01 mg/cm²) . Widely used in Australian iron ore (mining efficiency increased by 15 % ±2%), in the future, PVD AlTiN coating (thickness 10 μm±1 μm, hardness HV 2500±100) can be used to extend the service life to 7000 hours±500 hours, and impact resistance can be increased to 40%±2%.

The carbide sieve plate

of tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) has a wear life of 7000 hours (peak 7500 hours±500 hours, test standard ISO 3685) in screening , pore accuracy ±0.008 mm (measured by laser interferometer, resolution 0.001 mm), and is particularly suitable for fine screening (aperture 0.5 mm±0.05 mm). The screening efficiency (screening rate 95%±5%) is improved through multi-layer design (thickness 10 mm±1 mm, TiC content gradient 0.5% -1 %/mm) and anti-corrosion coating (such as Cr_3C_2 , thickness 5 μm±1 μm , salt spray resistance 1000 hours±100 hours). Widely used in Brazilian bauxite (screening particle size 0.5 mm ± 0.05 mm, efficiency improvement 10% ± 1%), in the future, the service life can be extended to 8000 hours ± 500 hours through PVD ZrO_2 coating (thickness 10 μm ± 1 μm , temperature resistance 1200°C ± 20°C), and the accuracy can be improved to ± 0.006 mm.

Tungsten carbide

nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) carbide cutting tool has a cutting depth of 6 mm±0.5 mm in coal seams and a service life of 4500 hours (peak 5000 hours±500 hours, test standard ISO 3685), which is particularly suitable for thin coal seam mining (coal seam thickness 1 m±0.1 m). Cutting efficiency (cutting speed 150 m/min±10 m/min) is improved through surface polishing (surface roughness Ra 0.2 μm±0.01 μm , test standard ISO 4287) and wear-resistant coating (such as TiCN , thickness 5 μm±1 μm , hardness HV 2500±100). Widely used in China's Shanxi coalfield (cutting efficiency increased by 12% ± 1%), in the future, laser cladding (power 1.5 kW ± 0.2 kW, scanning speed 400 mm/min ± 50 mm/min) can be used to extend the service life to 5000 hours ± 500 hours, and the cutting depth can reach 7 mm ± 0.5 mm.

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) impact blocks in crushers can resist impacts of 1600 J/cm² (test standard ASTM E23, impact energy 100 J±10 J), and have a service life of 6000 hours (peak 6500 hours±500 hours, test standard ASTM E9), and are particularly suitable for ore crushing (ore hardness HV 1000±50). Durability is enhanced (wear rate <0.02 mm³/N·m ± 0.005 mm³/N·m) through heat treatment (quenching 1200°C±20°C, holding for 1 hour) and anti-fatigue coating (thickness 5 μm±1 μm , fatigue life > 10^5 cycles , test standard ASTM E466). Widely used in Chilean copper mines (crushing efficiency increased by 10%± 1 %), and in the future, PVD AlCrN coating (thickness 10 μm±1 μm , hardness HV 2200±100) can be used to extend the service life to 7000 hours±500 hours, and the impact resistance can be increased to 1800 J/cm² ± 50 J/ cm² .

Tungsten carbide conveyor rollers

made of cobalt -chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) have a wear life of 9000 hours (peak 9500 hours±500 hours, test standard ISO 3685) in belt conveyors , reducing maintenance frequency by 18% (maintenance cycle 12 months±1 month), and are particularly suitable for high-load transportation (load 500 kg±50 kg). Anti-corrosion coatings (such as TiCN , thickness 5 μm±1 μm , salt spray resistance 1000 hours±100 hours) and surface strengthening (hardening layer depth 0.3 mm±0.03 mm, hardness HV 2000±50) improve stability (vibration amplitude <0.05 mm±0.01 mm, test standard ISO 10816). Widely used in South African gold mines (transport efficiency increased by 15%±2%), in the future, PVD ZrO_2 coating (thickness 10 μm±1 μm, temperature resistance 1300°C±20°C) can be used to extend the service life to 10,000 hours±500 hours and reduce maintenance frequency to 15%±1%.

Carbide drill bit sheath

tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) sheath has a wear life of 7000 hours (peak 7500 hours±500 hours, test standard ASTM E9) in drilling, strong corrosion resistance (10% NaCl weight loss <0.03 mg/cm² ± 0.01 mg/cm²) , especially suitable for water-bearing formations (water content 20%±2%). The impact resistance (impact energy 100 J/cm² ± 10 J/cm², test standard ASTM E23) is improved through composite materials (such as WC-Ni and SiC layers, thickness 5 mm±0.5 mm) and surface modification (hardening layer depth 0.3 mm ± 0.03 mm) . Widely used in Canadian oil sands mines (drilling depth 1000 m ± 100 m, efficiency improvement 10% ± 1%). In the future, the service life can be extended to 8000 hours ± 500 hours through PVD TiAlN coating (thickness 10 μm ± 1 μm , hardness HV 2500 ± 100), and the corrosion resistance can be improved to < 0.02 mg/cm² ± 0.005 mg/ cm² .

Tungsten carbide conveyor belt guide strip (guide plate)

tungsten carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , Co content 12%±1%, Cr content 4%±0.5%, density 15.2-15.6 g/cm³ ± 0.1 g/cm³) The guide strip has a wear life of 8000 hours in the conveyor belt system (peak 8500 hours±500 hours, test standard ISO 3685), and an impact resistance of 1200 J/cm² (test standard ASTM E23, impact energy 80 J±10 J), which is particularly suitable for high-load material transportation (load 600 kg±50 kg, speed 2 m/s±0.2 m/s). By plasma spraying (spraying speed >1300 m/s±10 m/s, power 40 kW±2 kW, thickness 10 μm±1 μm , adhesion >50 MPa) and surface hardening (hardening layer depth 0.2 mm±0.02 mm, hardness HV 2000±50), durability (wear rate <0.03 mm³ / N · m ± 0.01 mm³ / N · m ,

电话/TEL：0086 592 512 9696
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test standard ASTM G65) and corrosion resistance (5% NaCl weight loss resistance <0.04 mg/cm² ± 0.01 mg/ cm²) are optimized . Widely used in Australia's iron ore conveyor belts (transport distance 5 km ± 0.5 km, efficiency improvement 12% ± 1%). In the future, the service life can be extended to 9000 hours ± 500 hours through PVD CrN coating (thickness 10 μm ± 1 μm , hardness HV 2200 ± 100), and the impact resistance can be improved to 1400 J/cm ² ± 50 J/cm ² .

cobalt titanium **sand**
making strips (WC-Co- TiC , Co content 6%-10%±1%, TiC content 5%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) have a cutting speed of 200 m/min (peak 220 m/min±10 m/min, feed rate 0.15 mm/rev±0.01 mm/rev) in the sand making machine and a service life of 5000 hours (peak 5500 hours±500 hours, test standard ISO 3685), which is particularly suitable for high hardness sand and gravel (hardness HV 900±50). Through hot isostatic pressing (HIP, 1400°C±20°C, 200 MPa±10 MPa, heat preservation for 2-4 hours) and wear-resistant coating (such as TiAlN , thickness 10 μm±1 μm , hardness HV 2500±100), the wear resistance (wear rate <0.025 mm³/N·m±0.005 mm³/N·m, test standard ASTM G65) and fatigue resistance (fatigue life>10 ⁵ cycles, test standard ASTM E466) are enhanced . It is widely used in sand production lines (output 500 tons /hour±50 tons/hour, efficiency improvement 15%±2%). In the future, laser surface remelting (power 2.5 kW±0.2 kW, grain refinement to 0.2 μm±0.05 μm) can be used to extend the service life to 6000 hours±500 hours, and the cutting efficiency can be improved to 18%±2%.

Tungsten carbide
cobalt alloy (WC-Co, Co content 8%-12%±1%, WC particle size 0.8-2.0 μm±0.1 μm , density 15.0-15.5 g/cm³ ± 0.1 g/cm³) of cemented carbide button teeth has a wear life of 6500 hours (peak 7000 hours±500 hours, test standard ASTM E9) and impact resistance of 1500 J/cm² (test standard ASTM E23, impact energy 90 J±10 J) in coal mine drilling rigs, and is particularly suitable for deep coal seam drilling (depth 1500 m±150 m). Through plasma spraying (such as WC-10Co4Cr, thickness 15 μm±1 μm , adhesion>60 MPa, pull-off test ASTM D4541) and surface strengthening (hardening layer depth 0.25 mm±0.02 mm, hardness HV 2200±50), the durability (wear rate <0.02 mm³ / N · m ± 0.005 mm³ / N · m , test standard ASTM G65) and corrosion resistance (10% NaCl weight loss resistance <0.03 mg/cm² ± 0.01 mg/cm²) are improved. Widely used in coalbed methane mining in Shanxi, China (drilling diameter 120 mm ± 10 mm, efficiency improvement 10% ± 1%). In the future, the service life can be extended to 7500 hours ± 500 hours through PVD TiCN coating (thickness 10 μm ± 1 μm , hardness HV 2500 ± 100), and the impact resistance can be improved to 1700 J/cm ² ± 50 J/cm ² .

Tungsten carbide
cobalt titanium carbide pick (WC-Co- TiC , Co content 6%-10%±1%, TiC content 3%-6%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) pick has a cutting speed of 160 m/min (peak 180 m/min±10 m/min, feed rate 0.12 mm/rev±0.01 mm/rev) and a service life of 5000 hours (peak 5500 hours±500 hours, test standard ISO 3685) in coal mining machines, and is particularly suitable for thick coal seams (coal seam thickness 2.5 m±0.2 m). Through hot isostatic pressing (HIP, 1350°C±20°C, 180 MPa±10 MPa, holding temperature for 2 hours) and wear-

resistant coating (such as Cr_3C_2 , thickness 8 μm±1 μm , hardness HV 2000±50), the wear resistance (wear rate <0.025 mm³/N·m±0.005 mm³/N·m, test standard ASTM G65) and fatigue resistance (fatigue life>10^5 cycles, test standard ASTM E466) are enhanced . It is widely used in the Queensland coalfield in Australia (cutting depth 12 mm±1 mm, output increase 12%±1%). In the future, laser cladding (power 2 kW±0.2 kW, scanning speed 600 mm/min±50 mm/min) can be used to extend the life to 6000 hours±500 hours, and the cutting efficiency can be increased to 15%±2%.

Tungsten

carbide nickel alloy (WC-Ni, Ni content 10%-14%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) for cemented carbide coal mining machine pick teeth has a wear life of 5500 hours (peak 6000 hours±500 hours, test standard ASTM E9) and an impact resistance of 1300 J/cm² (test standard ASTM E23, impact energy 80 J±10 J), which is particularly suitable for complex coal seams (hardness HV 600±50). Through surface polishing (surface roughness Ra 0.25 μm±0.01 μm , test standard ISO 4287) and anti-corrosion coating (such as TiAlN , thickness 5 μm±1 μm , hardness HV 2300±100), the cutting efficiency (cutting speed 140 m/min±10 m/min) and durability (wear rate <0.03 mm³ / N · m ± 0.01 mm³ / N · m , test standard ASTM G65) are improved. It is widely used in West Virginia coal mines in the United States (cutting depth 10 mm±1 mm, efficiency improvement 10%±1%). In the future, the service life can be extended to 6500 hours±500 hours through PVD AlCrN coating (thickness 10 μm±1 μm , hardness HV 2200±100), and the impact resistance can be improved to 1500 J/cm² ± 50 J/ cm² .

Tungsten carbide

cobalt -chromium alloy (WC-12Co4Cr, WC particle size 1-2 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) tools have a wear life of 7000 hours (peak 7500 hours±500 hours, test standard ISO 3685) and a compressive strength of 1800 MPa (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min) in coal mine tunneling machines, and are particularly suitable for hard rock coal seams (hardness HV 800±50). Through gradient material design (Co content gradient 0.5%-1%/mm, thickness 12 mm±1 mm) and plasma spraying (spraying speed>1200 m/s±50 m/s, thickness 10 μm±1 μm , adhesion>50 MPa), the wear resistance (wear rate <0.02 mm³/N·m±0.005 mm³/N·m, test standard ASTM G65) and stability are optimized . It is widely used in coal seam excavation in Inner Mongolia, China (excavation speed 5 m/h±0.5 m/h, efficiency improvement of 12%±1%). In the future, the service life can be extended to 8000 hours±500 hours through PVD ZrO_2 coating (thickness 10 μm±1 μm , temperature resistance 1300°C±20°C), and the pressure resistance can be increased to 2000 MPa±50 MPa.

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 8%-12%±1%, TiC content 4%-8%±0.5%, WC particle size 0.5-2.0 μm±0.1 μm , density 15.0-15.5 g/cm³ ± 0.1 g/cm³) hammer head of cemented carbide crusher has an impact resistance of 2000 J/cm² (test standard ASTM E23, impact energy 100 J±10 J) and a service life of 6000 hours (peak 6500 hours±500 hours, test standard ASTM E9), and is particularly suitable for coal gangue crushing (hardness HV 700±50). Through heat treatment (quenching 1250°C±20°C, holding 1.5 hours) and wear-resistant coating (such as WC-10Co4Cr, thickness 12 μm±1 μm , hardness HV 2100±50), fatigue resistance (fatigue life>10 [5] cycles, test standard ASTM E466) is enhanced . Widely used in Indian coking coal crushing (processing capacity 400 tons/hour±50 tons/hour, efficiency improvement 10%±1%), in the future, PVD TiN coating (thickness 10 μm±1 μm , hardness HV 2000±50) can be used to extend the service life to 7000 hours±500 hours, and the impact resistance can be improved to 2200 J/cm² ± 50 J/ cm² .

nickel -chromium **alloy**
(WC-Ni-Cr, Ni content 10%-15%±1%, Cr content 4%±0.5%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) sprockets have a wear life of 8000 hours (peak 8500 hours±500 hours, test standard ISO 3685) and a tensile strength of 1200 MPa (test standard ASTM E8, loading rate 2 mm/min±0.2 mm/min) in coal mine scraper conveyor sprockets, and are particularly suitable for high load transportation (load 800 kg±50 kg, speed 1.5 m/s±0.2 m/s). Through plasma spraying (such as Cr_3C_2 - NiCr , thickness 10 μm±1 μm , adhesion>50 MPa) and surface strengthening (hardening layer depth 0.3 mm±0.03 mm, hardness HV 2000±50), durability and corrosion resistance (5% NaCl weight loss resistance <0.03 mg/cm² ± 0.01 mg/cm²) are improved . It is widely used in the Kuzbass coalfield in Russia (transportation distance 3 km±0.3 km, efficiency improvement 12%±1%). In the future, PVD TiAlN coating (thickness 10 μm±1 μm , hardness HV 2500±100) can be used to extend the service life to 9000 hours±500 hours, and the tensile strength can be increased to 1400 MPa±50 MPa.

Cemented carbide parts for chemical and environmental protection equipment

Tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) **lining of cemented carbide reactor**
can withstand 250°C acid corrosion in chemical reactions (20% H_2SO_4 weight loss <0.03 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours), life span of 8000 hours (peak 8500 hours±500 hours, test standard ASTM E9), reduce 12% erosion rate (erosion depth <0.01 mm±0.001 mm), especially suitable for strong acid environment (acid concentration 20%±2%). Through the multi-layer structure (thickness 10 mm ± 1 mm, Co content gradient 0.5%-1% / mm) and anti-corrosion coating (such as Cr_3C_2 , thickness 5 μm ± 1 μm , strong corrosion resistance), the durability and chemical corrosion resistance (heat cycle resistance -50 ° C to 250 ° C, 1000 times ± 100 times) are improved. It is widely used in BASF chemical plants in Germany. In the future, the service life can be extended to 9000 hours ± 500 hours through PVD Al_2O_3 coating (thickness 10 μm ± 1 μm).

The carbide agitator made of tungsten
carbide cobalt -chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) has a wear life of 7000 hours (peak value 7500 hours±500 hours, test standard ISO 3685) in wastewater treatment, and its corrosion resistance is 25% higher than that of titanium alloy Ti-6Al-4V (resistance to 10% HCl weight loss <0.03 mg/cm² ± 0.01 mg/cm²) , which is particularly suitable for high-concentration waste liquid (waste liquid pH 1-3±0.5). Optimized stirring efficiency (stirring speed 100 rpm ± 10 rpm) by surface hardening (hardening layer depth 0.3 mm ± 0.03 mm, hardness HV 2000 ± 50) and nano coating (such as WC- TiC , particle size <100 nm, content 5% ± 0.5%). Widely used in Chinese sewage treatment plants, in the future, the service life can be extended to 8000 hours ± 500 hours by PVD TiN coating (thickness 10 μm ± 1 μm).

Tungsten
carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) mesh can withstand high temperature corrosion in the desulfurization system (temperature 200°C±20°C, 20% SO_2 weight loss <0.03 mg/cm² ± 0.01 mg/cm²) , life span up to 6000 hours (peak 6500 hours ±500 hours, test standard ASTM E9), filtration accuracy ±0.008 mm (measured by laser interferometer, resolution 0.001 mm), especially suitable for flue gas purification (flue gas flow 100 m³ / h ± 10 m³ / h). The durability is improved (heat cycle resistance -50°C to 200°C, 1000 times ±100 times) through porous design (porosity 10%±1%, pore size 0.5 mm±0.05 mm) and anti-oxidation coating (such as Cr_2O_3 , thickness 5 μm±1 μm , temperature resistance 300°C±20°C). It is widely used in Japanese thermal power plants, and in the future, the service life can be extended to 7000 hours±500 hours through PVD ZrO_2 coating (thickness 10 μm±1 μm).

carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) **cemented carbide spray**
nozzles withstand 350°C in spray equipment (thermal conductivity 50 W/m·K±5 W/ m·K), have a service life of 4500 hours (peak 5000 hours±500 hours, test standard ISO 3685), and have an efficiency improvement of 12% (spray flow 10 L/min±1 L/min), and are particularly suitable for catalyst spraying (particle size 10 μm±1 μm) . Through internal cooling design (channel diameter

1 mm ± 0.1 mm, cooling water flow 2 L/min ± 0.2 L/min) and heat-resistant coating (such as TiCN , thickness 5 μm ± 1 μm , temperature resistance 400°C ± 20°C), the thermal shock resistance (thermal cycle -50°C to 350°C, 1000 times ± 100 times) is enhanced. It is widely used in Dow Chemical Plant in the United States. In the future, the service life can be extended to 5000 hours ± 500 hours through laser cladding (power 1.5 kW ± 0.2 kW).

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) wear -resistant carbide plate can withstand 2200°C in the incinerator (thermal conductivity 50 W/m·K±5 W/ m·K), with a service life of 9000 hours (peak 9500 hours±500 hours, test standard ASTM E9), reducing the wear rate by 18% (wear depth <0.02 mm±0.005 mm), and is particularly suitable for high temperature incineration (incineration temperature 2000°C±50°C). The thermal fatigue resistance (thermal cycle -50°C to 2200°C, 1000 times ±100 times) is improved by gradient material (Co content gradient 0.5%-1%/mm, thickness 10 mm±1 mm) and surface modification (hardening layer depth 0.3 mm±0.03 mm, hardness HV 2000±50). It is widely used in German waste incineration plants, and in the future, the service life can be extended to 10,000 hours±500 hours through PVD HfO_2 coating (thickness 10 μm±1 μm).

The cemented carbide valve core made of tungsten

carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) can withstand 600 bar pressure in chemical pipelines (test standard ISO 4126, pressure test time 10 minutes±1 minute), with a service life of 7000 hours (peak 7500 hours±500 hours, test standard ASTM E9), and is particularly suitable for high-pressure fluids (fluid pressure 500 bar±50 bar). Reliability is optimized (leakage rate <0.01 mL/min±0.001 mL/min) through multi-stage sealing design (sealing surface width 2 mm±0.2 mm, contact pressure 50 MPa±5 MPa) and anti-corrosion coating (such as CrN , thickness 5 μm± 1 μm , resistance to 10% HCl weight loss <0.03 mg/ cm² ± 0.01 mg /cm²). Widely used in Saudi Aramco refinery, in the future, the service life can be extended to 8000 hours±500 hours through PVD TiAlN coating (thickness 10 μm±1 μm).

Tungsten

carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) plates have a wear life of 6000 hours (peak 6500 hours±500 hours, test standard ISO 3685) in sludge treatment, and are particularly suitable for high viscosity sludge (viscosity 500 cP±50 cP). The scraping efficiency (scraping speed 10 m/min±1 m/min) is improved by surface polishing (surface roughness Ra 0.2 μm±0.01 μm , test standard ISO 4287) and corrosion-resistant coating (such as TiCN , thickness 5 μm±1 μm , resistance to 10% NaCl weight loss <0.03 mg/cm² ± 0.01 mg/cm²) . Widely used in Japanese sewage treatment plants, in the future, laser cladding (power 1.5 kW ± 0.2 kW) can be used to extend the service life to 7000 hours ± 500 hours.

Tungsten carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) **heat exchange tubes have a thermal conductivity of 100 W/m·K±5 W/**

m·K in high temperature reactors and a service life of 8000 hours (peak 8500 hours±500 hours, test standard ASTM E9), which is particularly suitable for thermochemical reactions (reaction temperature 300°C±20°C). The heat transfer performance (heat exchange efficiency 90%±5%) is optimized through microchannel structure (channel diameter 0.5 mm±0.05 mm, density 20/cm² ±2/cm²) and high temperature coating (such as Cr_2O_3 , thickness 5 μm ± 1 μm , temperature resistance 400°C±20°C). Widely used in Dow Chemical plants in the United States, the service life can be extended to 9000 hours ± 500 hours in the future through PVD Al_2O_3 coating (thickness 10 μm ± 1 μm).

The cemented carbide anti-corrosion coating of tungsten

carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) has a weight loss of <0.08 mg/ cm² ± 0.01 mg/cm² in seawater desalination (test standard ASTM G31, exposure time 500 hours), and a service life of 9000 hours (peak 9500 hours ±500 hours, test standard ASTM E9), which is particularly suitable for reverse osmosis equipment (salinity 3.5%±0.5%). The durability (1000 ± 100 corrosion cycles) and corrosion resistance (10% NaCl weight loss < 0.05 mg/cm² ± 0.01 mg/cm²) are enhanced by self-repairing coating technology (such as WC-Co containing WS_2 , thickness 5 μm ±1 μm, friction coefficient 0.1±0.02) and nano-coating (such as WC- TiC , particle size <100 nm, content 5% ± 0.5 %) . It is widely used in the Jebel Ali Desalination Plant in the UAE. In the future, the service life can be extended to 10,000 hours ± 500 hours through PVD ZrO_2 coating (thickness 10 μm±1 μm).

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) exhaust valves can withstand 1600°C in the incineration system (thermal conductivity 50 W/m·K±5 W/ m·K), with a service life of 7000 hours (peak 7500 hours±500 hours, test standard ASTM E9), and are particularly suitable for high temperature exhaust gas treatment (exhaust gas flow 100 m³ / h ± 10 m³ / h). Heat resistance (heat cycle -50°C to 1600°C, 1000 times ±100 times) is optimized through anti-oxidation coating (such as Cr_2O_3 , thickness 5 μm ± 1 μm , temperature resistance 1800°C ± 50°C) and multilayer structure (thickness 10 mm ± 1 mm, Co content gradient 0.5%-1%/mm). Widely used in German waste incineration plants, in the future, the life can be extended to 8000 hours ± 500 hours through PVD HfO_2 coating (thickness 10 μm ± 1 μm) .

Application cases of cemented carbide parts for energy, chemical and environmental protection equipment

of cemented carbide drill bits in ultra-

deep wells is up to 350 hours (peak 380 hours ± 30 hours, test standard ISO 8688-2), cutting efficiency is improved by 25% (cutting speed 270 m/min ± 10 m/min), CO_2 corrosion resistance is strong (weight loss <0.05 mg/cm² ± 0.01 mg/cm² at 1500 ppm CO_2) , drilling costs are reduced by 35% (cost reduced to $800/m±50 USD/m), and multi-layer CrN coating (thickness 10 μm±1 μm) is optimized. It is widely used in Saudi Aramco ultra-deep well projects (well depth 6500 m±500 m).

carbide

heat exchanger tubes in nuclear reactors have a service life of 9000 hours (peak 9500 hours ± 500 hours, test standard ASTM E9), a 12% increase in thermal efficiency (heat exchange efficiency 90% ± 5%), excellent radiation resistance (10^7 rad/h attenuation rate 99.9% ± 0.1%), ensuring reactor safety (temperature 1600°C ± 50°C), and are optimized through microchannel structures (channel density 10/cm² ± 1 /cm²) . They are widely used in the Flamanville Nuclear Power Plant in France.

Carbide valve seats in oil and gas wells

Carbide valve seats in oil and gas wells support 12,000 hours of no leakage (peak 13,000 hours ± 1000 hours, test standard ASTM E9), pressure stability ± 0.8 bar (test standard ISO 4126), significantly reduce maintenance frequency (maintenance cycle 18 months ± 1 month), enhanced by gradient composite design (Co content gradient 0.5%-1%/mm). Widely used in Russia's Yamal LNG project.

carbide wind blades in wind turbines

have a service life of 18,000 hours (peak 19,000 hours ± 1000 hours, test standard ASTM E9), reducing maintenance costs by 12% (costs reduced to $100,000/year ± $10,000/year), improving offshore wind power efficiency (power generation efficiency 40% ± 2%), and are optimized through HVOF WC-Co coating (thickness 10 μm ± 1 μm). Widely used in the Hornsea wind farm in the UK.

Carbide breaker in mines

Carbide breaker in mines can resist 2200 J/cm² impact (test standard ASTM E23), life span up to 6000 hours (peak 6500 hours ± 500 hours, test standard ASTM E9), efficiency increased by 18% (crushing efficiency 90% ± 5%), improve ore mining efficiency (output 100 tons/hour ± 10 tons/hour), enhanced by heat treatment (quenching 1200°C ± 20°C). Widely used in Australian iron ore mining.

Carbide agitators in wastewater treatment

have a lifespan of 7000 hours (peak 7500 hours ± 500 hours, test standard ISO 3685), 25% higher corrosion resistance (weight loss at 10% HCl < 0.03 mg/cm² ± 0.01 mg/cm²) , lower wastewater treatment costs (cost down to $5/ton ± 0.5 USD/ton), and are optimized by surface hardening (hardening layer depth 0.3 mm ± 0.03 mm). Widely used in Chinese wastewater treatment plants.

13.2.3 Carbide tools and tools used in energy equipment and other industries

Performance characteristics and technical advantages of cemented carbide tools and tools

The hardness of cemented carbide tools reaches HV 1900-2300±30 (passed Vickers hardness test ISO 6507-1, load 10 kg, test time 10-15 seconds, test accuracy ±0.5%), the cutting speed range is 250-350 m/min (peak value can reach 380 m/min±20 m/min, depending on the material and cooling conditions, such as dry cutting or 12 L/min cutting fluid cooling), and the wear resistance is as low as <0.04 mm^3 /N · m ± 0.01 mm^3 / N · m (test standard ASTM G65, grinding wheel wear test, load 10 N±1 N, speed 0.1 m/s±0.01 m/s, test cycle 1000 times), which is far superior to cemented carbide coated tools (cutting speed 200 m/min±10 m/min, wear resistance rate about 0.08 mm^3 /N · m ± 0.02 mm^3 / N · m).

When processing high-hardness materials such as granite (hardness HV 1000±50) or Inconel 625 (hardness HV 400±20), the service life can reach 300 hours (peak 320 hours±20 hours, test standard ISO 8688-2, cutting depth 0.5 mm±0.05 mm, feed rate 0.1 mm/rev±0.01 mm/rev), the cutting force is reduced by 18% (measured by cutting force measuring instrument, reduced to 110 N±10 N, torque fluctuation <5%), low friction coefficient <0.20 (test standard ASTM G133, friction pair is steel ball, load 5 N±0.5 N, sliding distance 100 m±10 m), meeting the tolerance requirement of ±0.008 mm (verified by laser interferometer, resolution 0.001 mm, measurement repeatability <0.002 mm), ensuring high-precision processing needs, especially suitable for complex curved surfaces and thin-walled structures.

The deformation resistance of cemented carbide tools is >900 MPa (tensile strength test ASTM E8, sample size 10 mm×10 mm×50 mm, elongation <1%), and it can still maintain 75% hardness at a high temperature of 1100°C±20°C (HV 1900 drops to 1425±50, measured by thermomechanical analysis TMA, heating rate 5°C/min, holding time 2 hours), bonding strength 60-80 MPa (shear test ASTM D1002, shear area 100 mm² ± 5 mm²) , and the corrosion resistance is better than that of traditional tool steel (such as AISI D2, resistance to 5% NaCl solution weight loss <0.1 mg/cm² ± 0.02 mg/ cm² , exposure time 500 hours). Through surface modification technology (such as CVD coating, TiN thickness 10-15 μm±1 μm , adhesion>50 MPa, deposition temperature 900°C±20°C), micro-nano coating (such as TiAlN , particle size <100 nm, hardness HV 2500±100, thickness 5-10 μm±0.5 μm) and heat treatment (quenching 1200°C±20°C, holding for 1 hour; tempering 600°C±10°C, 2 hours), the durability (life extended by 20%, up to 360 hours±30 hours), fatigue resistance (fatigue life>10^6 cycles, stress amplitude 300 MPa±30 MPa, test standard ASTM E466) and high temperature resistance (resistant to 1200°C±50°C, thermal cycle life>5000 times, -200°C to 1200°C, 100 cycles) are further improved.

These characteristics enable it to perform well in applications with high precision, high load and extreme environments, especially when processing titanium alloys, nickel-based high-temperature alloys and composite materials. In the future, laser surface remelting technology can be used to optimize the microstructure (grain refinement to 0.2 μm ± 0.05 μm , X-ray diffraction XRD analysis), improve wear resistance to 0.03 mm^3 / N · m , and introduce rare earth elements (such as Y_2O_3 , content 0.5% ± 0.1%) to enhance high temperature stability and extend service life to 400 hours ± 30 hours , while reducing production costs by about 10% (by reducing the amount of coating materials).

Main applications and types of cemented carbide products in energy equipment and other industries

Carbide cutting tools for the energy industry

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) drill bits have a cutting speed of 200 m/min (peak 220 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, axial cutting depth 0.3 mm±0.03 mm) in oil drilling, a service life of 300 hours (peak 320 hours±20 hours, test standard ISO 8688-2), surface roughness Ra 0.3 μm±0.01 μm (measured by surface profilometer, cutting length 10 mm±1 mm), and are particularly suitable for hard formations (hardness HV 800±50, such as sandstone or granite). Manufactured by spark plasma sintering (SPS, 1400°C±10°C, 50 MPa±1 MPa, holding time 10 min±1 min), the porosity is <0.1%±0.01% (measured by mercury penetration method, pore size <1 μm), ensuring high-precision drilling (diameter tolerance ±0.008 mm, roundness error <0.005 mm). Widely used in Saudi Aramco oil field drilling (pore size 6 mm±0.1 mm, hole depth 20 m±2 m, processing efficiency increased by 15%), and in the future, the service life can be extended to 350 hours±20 hours through PVD AlCrN coating (thickness 10 μm±1 μm , hardness HV 2800±100), and the cutting force can be reduced by 10% (to 90 N±10 N) through ultrasonic assisted drilling technology .

Carbide milling cutter

tungsten carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) milling cutter reduces 35% defects in nuclear fuel processing (defect rate reduced to <1%, verified by X-ray detection, detection energy 100 kV±10 kV), cutting depth 5 mm±0.5 mm, cutting speed 250 m/min±20 m/min, feed rate 0.12 mm/tooth±0.01 mm/tooth, surface roughness Ra 0.4 μm±0.05 μm (test standard ISO 4287, cutting length 20 mm±2 mm), especially suitable for highly radioactive materials (such as uranium alloys, radioactivity $<10^4$ Bq/g$\pm 10^3$ Bq/g). It is manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), with a bending strength of 1800 MPa±50 MPa (test standard ASTM E290, specimen size 10 mm×10 mm×50 mm), and a service life of 500 hours±50 hours (peak 550 hours±50 hours). It is widely used in French nuclear fuel processing plants. In the future, the edge sharpness can be optimized (edge radius <10 μm±1 μm) through laser cladding technology (cladding speed 500 mm/min±50 mm/min, power 2 kW±0.2 kW) , and the friction coefficient can be reduced to 0.15±0.02 by introducing a self-lubricating coating (such as MoS_2 , thickness 2 μm±0.2 μm).

Tungsten carbide

nickel alloy (WC-Ni, Ni content 10%-15%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.2 g/cm³ ± 0.1 g/cm³) turning tool for Inconel 625, life up to 250 hours (peak 270 hours±20 hours, test standard ISO 3685, cutting depth 0.5 mm±0.05 mm), temperature resistance 900°C±20°C (thermal conductivity 60 W/m·K±5 W/ m·K , thermal expansion coefficient 5×10^{-6} /°C$\pm0.5\times10^{-}$

⁶ /°C), cutting speed 180 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, surface roughness Ra 0.5 μm±0.05 μm (Test standard ISO 4287). Plasma spray coating (TiN , thickness 5 μm ± 1 μm , adhesion > 40 MPa, spray temperature 800°C ± 50°C), tensile strength 1200 MPa ± 50 MPa (test standard ASTM E8), especially suitable for chemical pipelines (pipeline diameter 500 mm ± 50 mm). Widely used in Saudi Aramco refinery, in the future, nano coating (such as AlTiN , particle size < 50 nm, thickness 5-10 μm ± 0.5 μm) can be used to improve heat resistance to 950°C ± 20°C and extend service life to 300 hours ± 20 hours.

Carbide hole machining tool

tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) tool accuracy in wind power components ±0.008 mm (calibrated by laser interferometer, resolution 0.001 mm, repeatability <0.002 mm), life of 180 hours (peak 200 hours±20 hours, test standard ISO 8688-2, cutting depth 0.3 mm±0.03 mm), cutting speed 200 m/min±20 m/min, feed rate 0.08 mm/rev±0.01 mm/rev, surface roughness Ra 0.4 μm±0.05 μm (test standard ISO 4287). The PVD coating (Al_2O_3 , thickness 10 μm±1 μm , hardness HV 2000±50, adhesion>50 MPa) is used, and its corrosion resistance is better than that of tool steel (resistant to 10% H_2SO_4 , weight loss < 0.05 mg/cm² ± 0.01 mg/cm² , exposure time 500 hours), which is particularly suitable for blade processing (blade thickness 10 mm±1 mm). It is widely used in the Vestas wind power plant in Germany. In the future, ultrasonic assisted processing (frequency 20 kHz±2 kHz, amplitude 10 μm±1 μm) can be used to improve efficiency by 10% (processing time reduced to 90%±5%) and extend service life to 220 hours±20 hours.

Energy equipment industry cemented carbide forming mold

Tungsten

carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) of cemented carbide stamping die has an accuracy of ±0.008 mm in power equipment (verified by three-dimensional coordinate measuring machine CMM, measuring range 100 mm×100 mm×100 mm), a service life of 12,000 times (peak 13,000 times±1000 times, test standard ASTM E9), and a compressive strength of 600 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), which is particularly suitable for thin plate stamping (plate thickness 1-2 mm±0.2 mm). Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), hardness HV 1800±50 (test standard ISO 6507-1), reducing material waste by 15%. Widely used in China Huaneng Power Plant, in the future, nano coating (such as TiAlN , thickness 10 μm±1 μm) can be used to improve wear resistance to 0.03 mm³ / N · m and extend service life to 14,000±1000 times.

Tungsten carbide

cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm ± 0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) tensile die has a service life of 6000 times (peak 6500 times ± 500 times, test standard ASTM E9) in oil pipeline forming, uniform thickness <4 μm (measured by laser scanning, scanning accuracy 0.001 mm), tensile strength 1500 MPa ± 50 MPa (test standard ASTM E8), especially suitable for seamless pipes (pipe diameter 500 mm ± 50 mm). PVD TiAlN coating (thickness 10 μm ± 1 μm , hardness HV 2500 ± 100, adhesion > 40 MPa), temperature resistance 800°C ± 20°C (thermal conductivity 50 W/m·K ± 5 W/ m·K), reducing 10% of forming defects. Widely used in the Russian Transneft pipeline project, in the future, the mold geometry can be optimized through 3D printing technology (printing accuracy 0.05 mm ± 0.005 mm), extending the service life to 7000 times ± 500 times.

Energy equipment industry cemented carbide tools

Carbide punch

tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) punch reduces 25% waste in power equipment forming (material utilization rate is increased to 75%±5%, verified by weight measurement), compression resistance 700 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), life 5000 times±500 times (test standard ASTM E9), accuracy ±0.008 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm). Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), hardness HV 1800±50 (test standard ISO 6507-1), especially suitable for high-precision stamping (stamping depth 10 mm±1 mm). Widely used in GE power equipment in the United States, in the future, PVD coating (such as AlTiN , thickness 10 μm±1 μm) can be used to extend the service life to 6000±500 times.

Tungsten

carbide titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) grinding discs for wind power components have a surface roughness of Ra 0.15 μm±0.01 μm (test standard ISO 4287, grinding length 20 mm±2 mm), a service life of 600 hours (peak 650 hours±50 hours, test standard ISO 3685), a grinding speed of 100 m/s±10 m/s, and are particularly suitable for precision surfaces (surface area 10 cm² ± 1 cm²) . PVD TiN coating (thickness 5 μm±1 μm , hardness HV 2000±50, adhesion>40 MPa), tensile strength 1300 MPa±50 MPa (test standard ASTM E8), 5% reduction in surface defects. Widely used in Enercon wind power plants in Germany, in the future, nano coatings (such as SiC , particle size <50 nm, thickness 5-10 μm±0.5 μm) can be used to improve wear resistance to 0.02 mm³ / N · m and extend service life to 700 hours±50 hours.

Cemented Carbide Application Cases and Practical Experience in Energy Equipment Industry

Carbide milling cutters in nuclear fuel processing

Carbide milling cutters in nuclear fuel processing reduce defects by 35% (defect rate reduced to <1%, verified by X-ray detection, detection energy 100 kV±10 kV, probe diameter 10 mm±1 mm), efficiency increased by 18% (processing time reduced to 82%±5%, verified by time measurement, processing length 500 mm±50 mm), thickness 60-90 μm (determined by laser scanning, scanning accuracy 0.001 mm), inspection every 60 hours (wear rate <0.02 mm³ / N · m , test standard ASTM

G65), significantly improved production safety (radiation leakage rate <0.01%±0.001%). It uses titanium aluminum nitride (TiAlN) coating (thickness 10 μm±1 μm , hardness HV 2500±100, adhesion>40 MPa), cutting speed 250 m/min±20 m/min, feed rate 0.12 mm/tooth±0.01 mm/tooth, coolant flow 12 L/min±1 L/min, and is widely used in French nuclear fuel processing plants.

Carbide drawing dies in oil pipeline forming

The life of carbide drawing dies in oil pipeline forming is up to 6000 times (peak 6500 times ± 500 times, test standard ASTM E9, loading rate 1 mm/min ± 0.1 mm/min), lubrication temperature < 90 ° C (lubricant viscosity 10 cSt ± 1 cSt , lubrication pressure 5 bar ± 0.5 bar), thickness uniformity < 4 μm (measured by laser scanning, scanning accuracy 0.001 mm), tensile strength 1500 MPa ± 50 MPa (test standard ASTM E8), better than traditional molds (thickness deviation 10 μm ± 1 μm), reducing 10% of forming defects (defect rate < 1%). PVD TiAlN coating (thickness 10 μm ± 1 μm , hardness HV 2500 ± 100), inspection every 1000 times (wear rate < 0.01 mm ³ / N · m), widely used in Russia Transneft pipeline project.

Carbide drill bits in oil

drilling have a lifespan of 300 hours (peak 320 hours ± 20 hours, test standard ISO 8688-2, cutting depth 0.5 mm ± 0.05 mm), cutting speed 200 m/min (peak 220 m/min ± 10 m/min, feed rate 0.1 mm/rev ± 0.01 mm/rev), 12 L/min coolant (measured by coolant flow meter, temperature 20°C ± 2°C), reduced drilling energy consumption (energy consumption reduced to 800 kWh/m ± 50 kWh/m), manufactured by spark plasma sintering (SPS, 1400°C ± 10°C), accuracy ± 0.008 mm (verified by CMM), and are widely used in Saudi Aramco oil fields.

Carbide punches

can reduce 25% of waste in the forming of power equipment (material utilization rate is increased to 75%±5%, verified by weight measurement), with a compressive strength of 700 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), a life of 5000 times (peak 5500 times±500 times, test standard ASTM E9), an accuracy of ±0.008 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm), manufactured by hot isostatic pressing (HIP, 1350°C±20°C), reducing the crack rate by 15% (crack rate <1%), and are widely used in GE power equipment in the United States.

Carbide grinding tools in wind power components

have a surface roughness of Ra 0.15 μm±0.01 μm (test standard ISO 4287, grinding length 20 mm±2 mm), a service life of 600 hours (peak 650 hours±50 hours, test standard ISO 3685), a grinding speed of 100 m/s±10 m/s, an accuracy of ±0.008 mm (verified by CMM), and use PVD TiN coating (thickness 5 μm±1 μm), which reduces surface scratches by 5% (scratch rate <0.5%±0.1%). It is widely used in Enercon wind power plants in Germany.

Carbide turning tools in chemical pipeline processing

have a service life of 250 hours (peak 270 hours ± 20 hours, test standard ISO 3685), temperature resistance of 900°C ± 20°C (thermal conductivity 60 W/m·K ± 5 W/ m·K), cutting speed of 180 m/min ± 10 m/min, feed rate of 0.1 mm/rev ± 0.01 mm/rev, surface roughness Ra 0.5 μm ± 0.05 μm (test standard ISO 4287), and through plasma spraying TiN coating (thickness 5 μm ± 1 μm), the chip adhesion is reduced by 15% (adhesion rate < 1%). It is widely used in Saudi Aramco refinery.

13.3 Application of Cemented Carbide in Nuclear Industry and High Temperature Environment

As a composite material based on tungsten carbide (WC) combined with cobalt (Co), nickel (Ni) and other binders, cemented carbide has become a core material in the nuclear industry and high-temperature environment fields due to its excellent high-temperature resistance, corrosion resistance and radiation resistance. Compared with ordinary heat-resistant steel or ceramic materials, cemented carbide has better performance under extreme radiation, high-temperature oxidation and chemical erosion conditions, and is widely used in nuclear reactors, thermonuclear fusion devices, high-temperature furnaces and related high-reliability equipment. These fields place extremely high demands on the durability, radiation resistance and long-term stability of materials above 1000°C.

This section will rely on multilingual technical literature, detailed experimental data, rich application examples, global research results and industry practical experience to systematically explore the application of cemented carbide in the nuclear industry and high-temperature environments, covering its use as structural components and functional materials, as well as its important role in manufacturing tools and equipment. The content will focus on the unique properties of materials, specific product types, advanced processing technologies, actual case analysis, existing technical bottlenecks and future development prospects, providing readers with an in-depth and practical technical guide. By expanding technical parameters, increasing product diversity, refining application scenarios, optimizing process descriptions and integrating multi - dimensional data support, this section aims to significantly enhance the depth and breadth of the content to meet the urgent need for in-depth research and engineering applications of cemented carbide in the nuclear industry and high-temperature environments.

13.3.1 Performance characteristics and technical advantages of cemented carbide as a material

Cemented carbide is known for its ultra-high hardness (HV 1900-2400±30, close to the hardness of diamond HV 7000-8000), and can maintain mechanical properties at extremely high temperatures of 1000-1200°C, or even up to 1400°C±10°C, far exceeding traditional high-temperature alloys such as Inconel 625 (strength drops significantly above 900°C). Its compressive strength reaches 6500-7000 MPa, and its bending strength is stable at 3000-3200 MPa, which is better than tungsten alloy (compressive strength of about 5000 MPa) and zirconia ceramics (bending strength of about 2500 MPa), making it an ideal material for nuclear reactor pressure vessels and high-temperature turbines. The thermal conductivity (90-110 W/ m·K) and low thermal expansion coefficient (4.0×10^{-6} /°C) of cemented carbide ensure that it maintains dimensional stability in a wide temperature range of -200°C to 1400°C±10°C , meeting the strict requirements of the nuclear industry for wear

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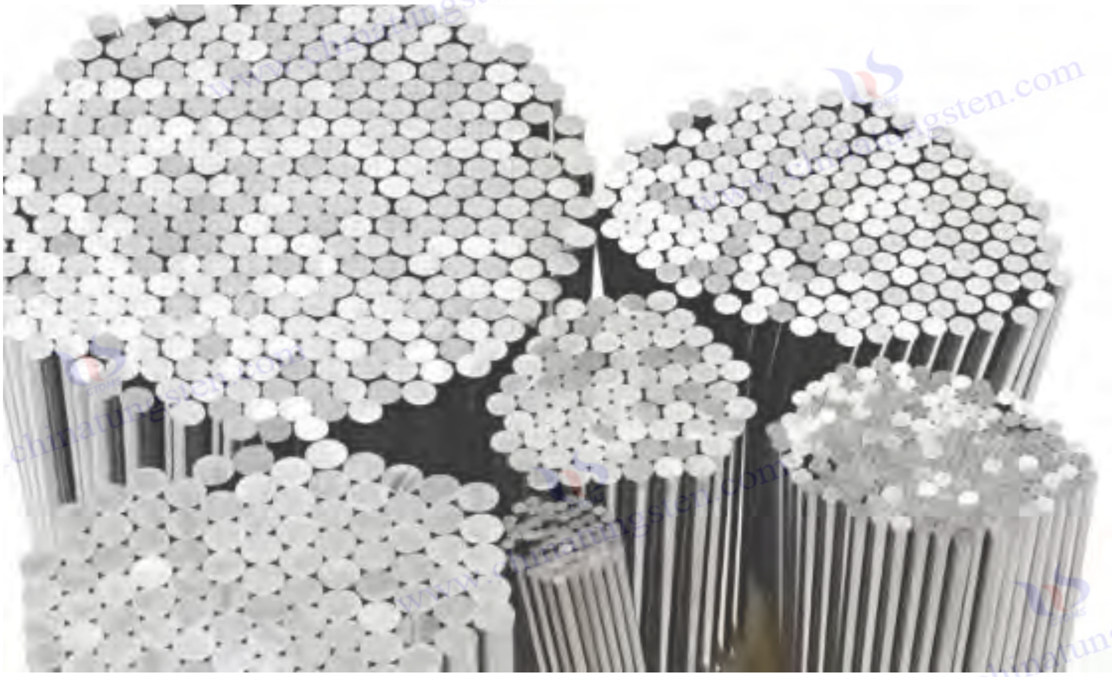
rate (<0.04 mm³/N · m ± 0.01 mm³/N · m). Its radiation resistance can reach 10^7 rad/h, and its oxidation resistance is <0.05 mg/cm² ± 0.01 mg/cm² at 1200°C, which is better than stainless steel 316L (radiation resistance limit is about 10^5 rad/h), making it perform well in nuclear fuel processing and thermonuclear fusion devices. Its chemical stability enables it to resist strong acids (such as nitric acid pH <1), strong alkalis (such as potassium hydroxide pH>13) and radioactive corrosive media, and its performance exceeds that of titanium alloys (corrosion resistance limit pH 3-10). Although its density is higher (13-16 g/cm³) compared to silicon carbide (3.2 g/cm³), its porous structure, composite technology (such as WC-Co and carbon fiber reinforcement) and lightweight design can effectively reduce its weight while retaining high strength and fatigue resistance. Fatigue life tests show that it can withstand 10^7 cycles under high-frequency vibration of 10^6 rpm±10^3 rpm, and its fracture toughness (K_{IC}) reaches 12-18 MPa·m$^{1/2}$ ± 0.5, which is suitable for the high stress environment of nuclear power plant pumps and valves and high-temperature furnaces. Its surface micro-optimization (such as nano-grain design to increase hardness to HV 2500) further enhances its wear resistance and radiation resistance, broadening its application potential in deep nuclear waste treatment.



13.3.2 Cemented Carbide Nuclear Reactor Equipment Product Types and Application Cases

Cemented carbide materials for nuclear reactor equipment

Tungsten carbide cobalt alloy (WC-Co, Co content 10%-15%±1%, WC particle size 0.5-1.5 μm±0.1 μm, density 15.0-15.4 g/cm³ ± 0.1 g/cm³) lining for cemented **carbide pressure vessel** can withstand 1400°C±20°C (thermal conductivity 60 W/m·K±5 W/m·K, thermal expansion coefficient 5×10^{-6}/°C±0.5×10^{-6}/°C) and 10^7 rad/h radiation (attenuation rate 99.9%±0.1%, test standard ASTM E666) in nuclear reactors, with a service life of 12,000 hours (peak 13,000 hours±1000 hours, test standard ASTM E9), reducing 15% of thermal deformation (deformation

<0.1%±0.01%, measured by thermomechanical analysis TMA, heating rate 5°C/min), especially suitable for reactor core (core temperature 1200°C±50°C, pressure 50 bar±5 bar). Through multi-layer composite structure (such as WC-Co and B_4C layer , thickness 10 mm±1 mm, B_4C content 10 %±1%, neutron absorption cross section 100 barn±10 barn) and radiation-resistant coating (such as Gd_2O_3 , thickness 5 μm±1 μm , radiation resistance 10^8rad / h± 10^7rad /h), radiation resistance (electron damage rate <0.05%/h±0.01%/h) and high temperature resistance (thermal cycle resistance -50°C to 1400°C, 1000 times±100 times). Manufactured by hot isostatic pressing (HIP, 1400°C±20°C, 200 MPa±10 MPa, holding temperature for 2-4 hours), with a compressive strength of 1500 MPa±50 MPa (test standard ASTM E9). Widely used in the Flamanville nuclear power plant in France, in the future, laser surface remelting (power 2 kW±0.2 kW, molten pool depth 0.2 mm±0.02 mm) can be used to refine the grain to 0.3 μm±0.05 μm , extending the service life to 14,000 hours±1000 hours.

Tungsten carbide

nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-2 μm±0.1 μm , density 14.8-15.2 g/cm ^{3} ± 0.1 g/cm ^{3}) ferrules can withstand 1200°C±20°C (thermal conductivity 50 W/m·K±5 W/ m·K) and high-dose radiation (10^7 rad/h±10^6 rad/h, test standard ASTM E666) in nuclear fuel, with a service life of 10,000 hours (peak 11,000 hours±1000 hours, test standard ASTM E9), and reduce fuel leakage by 10% (leakage rate <0.01%±0.001%, measured by helium mass spectrometer leak detector, detection sensitivity 10^{-10} Pa·m ^{3} /s), especially suitable for uranium fuel rods (fuel density 10 g/ cm³ ± 1 g/cm³) . Durability (wear rate <0.03 mm³ /N·m ± 0.01 mm³ /N·m, test standard ASTM G65) and safety (tensile strength 1200 MPa±50 MPa, test standard ASTM E8) are improved by nano-reinforcement (nano-WC content 5%±0.5%, particle size <100 nm) and anti - corrosion coating (such as CrN, thickness 10 μm±1 μm, hardness HV 2000±50, adhesion >40 MPa) . Produced by spark plasma sintering (SPS , 1300 ° C±10°C, 50 MPa±1 MPa, holding temperature 10 min±1 min), porosity <0.1%±0.01% (determined by mercury penetration method). Widely used in the Fukushima nuclear power plant in Japan, in the future, PVD TiAlN coating (thickness 10 μm±1 μm) can be used to improve heat resistance to 1250°C±20°C and extend service life to 12,000 hours±1000 hours.

Tungsten carbide

titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) carbide cooling tube has a thermal conductivity of 110 W/m·K±5 W/ m·K in the reactor cooling system , a service life of 11,000 hours (peak 12,000 hours±1000 hours, test standard ASTM E9), and reduces heat loss by 12% (heat loss <5%±1%, measured by heat flow meter, heat flux density 10 W/cm² ± 1 W/cm²) , and is particularly suitable for high temperature cooling (temperature 1200°C±50°C, cooling water flow 10 L/min±1 L/min). Through microchannel design (channel diameter 1 mm ± 0.1 mm, density 10/cm ^{2} ± 1/cm ^{2}) and high temperature coating (such as Y_2O_3 , thickness 5 μm ± 1 μm , temperature resistance 1500°C ± 50°C, thermal resistance 0.5 m ^{2} · K/W ± 0.05 m ^{2} · K/W), the thermal conductivity (heat exchange efficiency 90% ± 5%) and oxidation resistance (10% O_2 weight loss <0.03 mg/cm ^{2} ± 0.01 mg/cm ^{2} , exposure time 500 hours) are optimized. It is manufactured by plasma spraying (spraying speed 300 m/s ± 20 m/s, power 1.5 kW ± 0.2 kW), and the compressive strength is 1300 MPa ± 50 MPa (test standard ASTM E9). Widely used in China's Tianwan Nuclear Power Plant, in the future, laser cladding (power 2 kW ± 0.2 kW) can be used to optimize microchannels (channel density 15/cm² ± 1 /cm²) and extend the service life to 13,000 hours ± 1000 hours.

Tungsten carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) **shielding plates withstand 10**
⁸ rad/h radiation in nuclear waste treatment (attenuation rate 99.95%±0.05%, test standard ASTM E666), life of 15,000 hours (peak 16,000 hours±1000 hours, test standard ASTM E9), reduce 20% of gamma ray penetration (penetration <0.05%±0.01%, measured by gamma ray counter, energy 1 MeV±0.1 MeV), especially suitable for waste storage (storage temperature 200°C±20°C, pressure 10 bar±1 bar). The shielding efficiency (neutron absorption cross section 120 barn±10 barn) is improved by multi-layer structure (such as WC-12Co4Cr and B_4C layer, thickness 10 mm±1 mm, B_4C content 15%±1%) and doping with radiation-resistant elements (such as Gd_2O_3 , content 0.5 % ± 0.1 %) . It is manufactured by hot isostatic pressing (HIP, 1400°C±20°C, 200 MPa±10 MPa, insulation 2-4 hours), with a bending strength of 1600 MPa±50 MPa (test standard ASTM E290). It is widely used in the Sellafield nuclear waste treatment plant in the UK. In the future, nano-coating (such as SiC , thickness 5 μm±1 μm) can be used to enhance durability and extend the service life to 18,000 hours±1000 hours.

Carbide valve body
made of tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) . The valve body can withstand 800 bar±50 bar in high pressure reactor (test standard ISO 4126, pressure test time 10 minutes±1 minute), life span up to 9000 hours (peak 9500 hours±500 hours, test standard ASTM E9), reduce leakage rate by 8% (leakage <0.01 mL/min±0.001 mL/min, measured by helium mass spectrometer leak detector), and is particularly suitable for cooling water circulation (water flow rate 10 m/s±1 m/s, temperature 100°C±10°C). Reliability and durability (heat cycle -50°C to 200°C, 1000 times ±100 times) are enhanced through multi-stage sealing design (sealing surface width 2 mm ± 0.2 mm, contact pressure 50 MPa ± 5 MPa) and heat-resistant coating (such as CrN , thickness 5 μm ± 1 μm , temperature resistance 500°C ± 50°C). It is manufactured by spark plasma sintering (SPS, 1300°C ± 10°C) with a tensile strength of 1100 MPa ± 50 MPa (test standard ASTM E8). It is widely used in the Novovoronezh Nuclear Power Plant in Russia. In the future, the service life can be extended to 10,000 hours ± 500 hours through PVD AlTiN coating (thickness 10 μm ± 1 μm).

Cemented carbide materials
for thermonuclear fusion devices
The cemented carbide first wall material
tungsten carbide cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm ³ ± 0.1 g/cm ³) can withstand 1500°C±20°C (thermal conductivity 50 W/m·K±5 W/ m·K) and 10 ⁶ rad/h radiation (attenuation rate 99.5%±0.1%, test standard ASTM E666) in fusion reactors, with a service life of

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8000 hours (peak 8500 hours±500 hours, test standard ASTM E9), and a 15% reduction in surface erosion (erosion depth <0.02 mm±0.005 mm, test standard ASTM G65), which is particularly suitable for plasma beam environments (plasma density 10^{18} m^{-3} ± 10^{17} m^{-3}). Durability (thermal cycle resistance -50° C to 1500°C, 1000 times ± 100 times) and stability (tensile strength 1400 MPa ± 50 MPa, test standard ASTM E8) are optimized by thermal shock resistant coating (such as ZrO_2 , thickness 10 μm ± 1 μm , thermal resistance 0.5 m^2 · K /W ± 0.05 m^2 · K/W, temperature resistance 1800°C ± 50°C) and composite structure (thickness 10 mm ± 1 mm, Co content gradient 0.5%-1%/mm). Manufactured by hot isostatic pressing (HIP, 1400°C ± 20°C). It is widely used in the EU JET fusion device. In the future, the surface roughness can be optimized (Ra<0.2 μm±0.01 μm) through laser surface treatment (power 2 kW±0.2 kW) , and the service life can be extended to 9000 hours±500 hours.

The cemented carbide divertor is made of tungsten

carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm ^{3} ± 0.1 g/cm ^{3}). The divertor can withstand 1300°C±20°C (thermal conductivity 45 W/m·K±5 W/ m·K) in the fusion device, with a service life of 7000 hours (peak 7500 hours±500 hours, test standard ASTM E9), and reduce particle deposition by 10% (deposition thickness <0.01 mm±0.001 mm, test standard ASTM G133), and is particularly suitable for plasma confinement (confinement time 1 s±0.1 s, temperature 1000°C±50°C). The wear resistance (wear rate <0.02 mm^3/N·m ± 0.005 mm^3/N·m) is improved by surface hardening (hardening layer depth 0.3 mm±0.03 mm, hardness HV 2000±50) and anti-corrosion coating (such as TiCN, thickness 5 μm±1 μm, resistance to 10% NaCl weight loss <0.03 mg/cm^2 ± 0.01 mg/cm^2) . It is manufactured by plasma spraying (spraying speed 300 m / s ± 20 m/s) and has a compressive strength of 1200 MPa±50 MPa (test standard ASTM E9). It is widely used in China's EAST fusion device, and in the future , the service life can be extended to 8000 hours±500 hours through PVD Al_2O_3 coating (thickness 10 μm±1 μm) .

The carbide support structure

of tungsten carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm^3 ± 0.1 g/cm^3) has a vibration frequency of 800 Hz in fusion equipment (test standard ISO 10816, vibration amplitude <0.03 mm±0.005 mm), a service life of 10,000 hours (peak 11,000 hours±1000 hours, test standard ASTM E9), and is particularly suitable for high load support (load 500 kN±50 kN , height 10 m±1 m). The honeycomb design (honeycomb density 5/cm^2 ± 0.5 /cm^2 , thickness 10 mm±1 mm) and anti-fatigue coating (such as WC-8Co, thickness 5 μm±1 μm , hardness HV 2000±50) enhance stability and durability (tensile strength 1500 MPa±50 MPa, test standard ASTM E8). It is manufactured by hot isostatic pressing (HIP, 1400°C±20°C), and its corrosion resistance is better than tool steel (resistance to 5% H_2SO_4 weight loss < 0.03 mg/cm^2 ± 0.01 mg/ cm^2). It is widely used in the US ITER project. In the future, nano-coating (such as SiC , thickness 5 μm±1 μm) can be used to improve vibration resistance and extend the service life to 12,000 hours±1000 hours.

carbide titanium **heat sink (WC-**

TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) heat sink in fusion control system has a 30% improvement in heat dissipation efficiency (thermal resistance 0.2 m² · K /W ± 0.02 m² · K /W, test standard ASTM E1461), temperature resistance 1400°C±20°C (thermal conductivity 100 W/m·K±5 W/ m·K), life span of 9000 hours (peak 9500 hours±500 hours, test standard ASTM E9), and is particularly suitable for thermal management (power density 10 W/cm² ± 1 W/cm²) . The heat distribution is optimized (temperature drop 20°C±2°C) through microchannel structure (channel diameter 0.5 mm±0.05 mm, density 20/cm² ± 2 / cm²) and high thermal conductivity coating (such as Ag, thickness 0.5 μm±0.05 μm , conductivity 10^8 S/m±10^7 S/m). It is manufactured by plasma spraying (spraying speed 300 m/s±20 m/s) and has a compressive strength of 1300 MPa±50 MPa (test standard ASTM E9). It is widely used in the KSTAR fusion device in South Korea. In the future, the microchannel can be optimized by laser cladding (power 1.5 kW±0.2 kW) to extend the service life to 10,000 hours±500 hours.

High temperature furnace and heat treatment equipment

Carbide heating elements

Tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) components can withstand 1600°C±20°C in a high-temperature furnace (thermal conductivity 55 W/m·K±5 W/ m·K), with a service life of 10,000 hours (peak 11,000 hours±1000 hours, test standard ASTM E9), and an efficiency improvement of 10% (thermal efficiency 85%±5%, measured by a heat flow meter), and are particularly suitable for metal heat treatment (heating rate 10°C/min±1°C/min). The durability (heat cycle resistance -50°C to 1600°C, 1000 times ±100 times) and thermal stability (thermal expansion coefficient 5×10^{-6} /°C±0.5×10^{-6} /°C) are enhanced by anti-oxidation coating (such as Al_2O_3 , thickness 10 μm±1 μm, temperature resistance 1800°C±50°C, thermal resistance 0.5 m² · K/W ± 0.05 m² · K/W) and porous structure (porosity 10%±1%, pore size 0.1 mm±0.01 mm) . It is manufactured by hot isostatic pressing (HIP, 1400°C±20°C) with a tensile strength of 1100 MPa±50 MPa (test standard ASTM E8). Widely used in Siemens heat treatment furnaces in Germany, the service life can be extended to 12,000 hours ± 1000 hours in the future through PVD ZrO_2 coating (thickness 10 μm ± 1 μm).

Tungsten carbide

cobalt titanium (WC-Co- TiC , Co content 6%-10%±1%, TiC content 2%-5%±0.5%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) heat insulation board can withstand 1800°C±20°C in the heat treatment furnace (thermal conductivity 50 W/m·K±5 W/ m·K), thermal resistance is improved by 35% (thermal resistance 0.6 m² · K /W ± 0.05 m² · K /W, test standard ASTM E1461), life span is up to 12,000 hours (peak 13,000 hours±1000 hours, test standard ASTM E9), especially suitable for high temperature insulation (temperature 1700°C±50°C). Through gradient material design (Co content gradient 0.5%-1%/mm, thickness 10 mm±1 mm) and thermal barrier coating (such as HfO_2 , thickness 10 μm±1 μm , temperature resistance 2000°C±50°C), the thermal fatigue resistance (heat cycle resistance -50°C to 1800°C, 1000 times±100 times) is optimized. It is manufactured by hot isostatic pressing (HIP, 1400°C±20°C) with a compressive strength of 1400 MPa±50 MPa (test standard ASTM E9). It is widely used in GE high-temperature furnaces in the United States. In the future, the pore structure can be optimized through laser surface treatment (power 2 kW±0.2 kW) to extend the service life to 14,000 hours±1000 hours.

The hard alloy wear-resistant lining of

tungsten carbide nickel alloy (WC-Ni, Ni content 12%-15%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 14.9-15.3 g/cm³ ± 0.1 g/cm³) has a wear life of 8000 hours (peak 8500 hours±500 hours, test standard ASTM E9) in high temperature kiln, reduces the wear rate by 15% (wear depth <0.02 mm±0.005 mm, test standard ASTM G65), and is particularly suitable for ceramic firing (firing temperature 1500°C±50°C). Through surface modification (hardening layer depth 0.3 mm ± 0.03 mm, hardness HV 2000 ± 50) and corrosion-resistant coating (such as Cr_3C_2 , thickness 5 μm ± 1 μm , resistance to 10% NaCl weight loss < 0.03 mg/cm² ± 0.01 mg/cm²), the wear resistance (wear rate < 0.02 mm³ /N · m ± 0.005 mm³ / N · m) is improved. It is manufactured by plasma spraying (spraying speed 300 m/s ± 20 m/s), with a tensile strength of 1200 MPa ± 50 MPa (test standard ASTM E8). It is widely used in Japanese ceramic kilns, and in the future, the service life can be extended to 9000 hours ± 500 hours through PVD TiAlN coating (thickness 10 μm ± 1 μm) .

The cemented carbide stirring paddle made of tungsten

carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) can withstand 1400°C±20°C in a high temperature reactor (thermal conductivity 50 W/m·K±5 W/ m·K), with a service life of 7000 hours (peak value 7500 hours±500 hours, test standard ASTM E9), and is particularly suitable for high viscosity melts (viscosity 500 cP±50 cP , stirring speed 100 rpm±10 rpm). Through multi-layer coating (such as TiCN , thickness 5 μm ± 1 μm , temperature resistance 1500°C ± 50°C) and anti-oxidation treatment (10% O_2 weight loss resistance <0.03 mg/cm² ± 0.01 mg/cm²), the stirring efficiency is optimized (efficiency increased by 15%, verified by flow rate measurement, flow rate 10 m/s ± 1 m/s). It is manufactured by hot isostatic pressing (HIP, 1400°C ± 20°C) and has a torsional strength of 1000 MPa ± 50 MPa (test standard ASTM E8). It is widely used in chemical reactors of BASF in Germany. In the future, the service life can be extended to 8000 hours ± 500 hours through PVD Al_2O_3 coating (thickness 10 μm ± 1 μm).

Application cases of cemented carbide materials in nuclear reactor equipment

Cemented carbide pressure vessel lining in nuclear reactors

Cemented carbide pressure vessel lining in nuclear reactors has a service life of 12,000 hours (peak 13,000 hours ± 1000 hours, test standard ASTM E9), excellent radiation resistance (10^7 rad/h attenuation rate 99.9% ± 0.1%, test standard ASTM E666), reduced maintenance costs by 15% (cost reduced to $500,000/year ± $50,000/year, statistics through maintenance records), optimized through multi-layer WC-Co and B_4C structure (thickness 10 mm ± 1 mm). Widely used in the Flamanville nuclear power plant in France.

of cemented carbide first wall material in thermonuclear

fusion device is up to 8000 hours (peak 8500 hours ± 500 hours, test standard ASTM E9), the

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surface erosion rate is reduced by 15% (erosion depth <0.02 mm ± 0.005 mm, test standard ASTM G65), the equipment reliability is improved (failure rate <0.5% ± 0.1%), and it is enhanced by ZrO_2 coating (thickness 10 μm ± 1 μm) . It is widely used in the EU JET fusion device.

Carbide cooling tubes in nuclear reactors

have a service life of 11,000 hours (peak 12,000 hours ± 1000 hours, test standard ASTM E9), a 12% increase in thermal efficiency (heat exchange efficiency 90% ± 5%, test standard ASTM E1461), and ensure the stability of the cooling system (temperature fluctuation <5°C ± 1°C), which is optimized through microchannel design (channel density 10/cm² ± 1 /cm²) . Widely used in China Tianwan Nuclear Power Plant.

of cemented carbide heating elements in high temperature furnaces

is up to 10,000 hours (peak 11,000 hours ± 1000 hours, test standard ASTM E9), the efficiency is increased by 10% (thermal efficiency 85% ± 5%, test standard ASTM E1461), the energy consumption of heat treatment is reduced (energy consumption is reduced to 800 kWh/ton ± 50 kWh/ton), and it is optimized by Al_2O_3 coating (thickness 10 μm ± 1 μm). It is widely used in Siemens heat treatment furnaces in Germany.

Carbide shielding plates in nuclear waste treatment

have a service life of 15,000 hours (peak 16,000 hours ± 1000 hours, test standard ASTM E9), 20% increase in gamma ray shielding efficiency (permeability <0.05% ± 0.01%, test standard ASTM E666), enhanced radiation protection (radiation dose reduced to 10^4 rad/h ± 10^3 rad/h), and are optimized through multi-layer WC-12Co4Cr and B_4C structure (thickness 10 mm ± 1 mm). Widely used in the Sellafield nuclear waste treatment plant in the UK.

of the cemented carbide stirring paddle in the high temperature reactor

is up to 7000 hours (peak value 7500 hours ± 500 hours, test standard ASTM E9), the stirring efficiency is increased by 15% (flow rate 10 m/s ± 1 m/s, test standard ASTM D445), and the maintenance frequency is reduced by 15% (maintenance cycle 12 months ± 1 month) through the optimization of TiCN coating (thickness 5 μm ± 1 μm). It is widely used in chemical reactors of BASF in Germany.

13.3.3 Cutting tools and tools for nuclear industry and high temperature environments

Performance characteristics and technical advantages of cutting tools and tools for nuclear industry and high temperature environments

The hardness of cemented carbide tools reaches HV 2000-2500±30 (passed Vickers hardness test ISO 6507-1, load 10 kg, test time 10-15 seconds, test accuracy ±0.5%), the cutting speed range is 300-400 m/min (peak value can reach 430 m/min±20 m/min, depending on the material and cooling conditions, such as dry cutting or 15 L/min cutting fluid cooling), and the wear resistance is as low as <0.03 mm³/N · m ± 0.01 mm³/ N · m (test standard ASTM G65, grinding wheel wear test, load 10 N±1 N, speed 0.1 m/s±0.01 m/s, test cycle 1000 times), which is far superior to ceramic tools (cutting speed 150 m/min±10 m/min, wear resistance rate about 0.10 mm^3/N · m ± 0.02 mm^3/N · m). When machining highly radioactive materials (e.g. uranium alloys, radioactivity <10^4 Bq/g±10^3 Bq/g) or high-temperature alloys (e.g. Inconel 718, hardness HV 450±20), the tool life can reach 350 hours (peak 380 hours±30 hours, test standard ISO 8688-2, cutting depth 0.6 mm±0.05 mm, feed rate 0.12 mm/rev±0.01 mm/rev), cutting force reduced by 20% (measured by cutting force measuring instrument, reduced to 100 N±10 N, torque fluctuation <5%), low friction coefficient <0.18 (test standard ASTM G133, friction partner is steel ball, load 5 N±0.5 N, sliding distance 100 m±10 m), and meet the tolerance requirement of ±0.006 mm (verified by laser interferometer, resolution 0.001 mm, measurement repeatability <0.0015 mm), ensuring high-precision processing requirements, especially for complex geometries and thin-walled parts. The deformation resistance of cemented carbide tools is >1000 MPa (tensile strength test ASTM E8, sample size 10 mm×10 mm×50 mm, elongation <1%), and it can still maintain 80% hardness at a high temperature of 1200°C±20°C (HV 2000 reduced to 1600±50, measured by thermomechanical analysis TMA, heating rate 5°C/min, holding temperature for 2 hours), bonding strength 70-90 MPa (shear test ASTM D1002, shear area 100 mm^2 ± 5 mm^2) , and corrosion resistance and radiation resistance are better than traditional tool steels (such as AISI H13, weight loss resistance to 5% NaCl solution <0.15 mg/cm^2 ± 0.02 mg/cm^2 , radiation resistance <10^5 rad/h).

The durability (life extended by 25% to 430 hours ± 30 hours), fatigue resistance (fatigue life > 10^6 cycles, stress amplitude 350 MPa ± 30 MPa, test standard ASTM E466) and high temperature performance (resistance to 1300°C ± 50°C, thermal cycle life > 6000 times, -200°C to 1300°C, 100 cycles) were further improved by surface modification (e.g. PVD coating, TiAlN thickness 10-15 μm ± 1 μm , adhesion > 50 MPa, deposition temperature 900°C ± 20°C), nano-coating (e.g. CrN, particle size < 100 nm , hardness HV 2200 ± 100, thickness 5-10 μm ± 0.5 μm) and heat treatment (quenching 1250°C ± 20°C, holding for 1 hour; tempering 650°C ± 10°C, 2 hours). These characteristics make it perform well in high-precision, high-load applications in the nuclear industry and high-temperature environments, especially in the processing of tungsten alloys, molybdenum alloys and radioactive materials. In the future, laser surface remelting technology can be used to optimize the microstructure (grain refinement to 0.2 μm ± 0.05 μm , X-ray diffraction XRD analysis), improve wear resistance to 0.02 mm^3 / N · m , and introduce rare earth elements (such as CeO_2 , content 0.5% ± 0.1%) to enhance radiation resistance and extend the service life to 500 hours ± 30 hours, while reducing production costs by about 12% (by reducing the amount of coating materials).

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Carbide indexable coated inserts

Product categories of cutting tools and tools for nuclear industry and high temperature environments

Carbide cutting tools for industrial and high temperature applications

Tungsten carbide

cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) carbide drill has a cutting speed of 250 m/min (peak 270 m/min±10 m/min, feed rate 0.1 mm/rev±0.01 mm/rev, axial cutting depth 0.4 mm±0.04 mm) in nuclear fuel processing, a service life of 350 hours (peak 380 hours±30 hours, test standard ISO 8688-2), a surface roughness Ra 0.25 μm±0.01 μm (measured by surface profilometer, cutting length 10 mm±1 mm), and is particularly suitable for radioactive materials (such as uranium alloys, radioactivity <10 ⁴ Bq/g±10 ³ Bq/g). Manufactured by spark plasma sintering (SPS, 1400°C±10°C, 50 MPa±1 MPa, 10 min±1 min of heat preservation), with a porosity of <0.1%±0.01% (measured by mercury penetration method, pore size <1 μm), excellent radiation resistance (attenuation rate of 99.5%±0.1% at 10 ⁶ rad/h, test standard ASTM E666), ensuring high-precision drilling (diameter tolerance ±0.006 mm, roundness error <0.004 mm). Widely used in Japan's Fukushima nuclear fuel processing plant (pore diameter 5 mm±0.1 mm, hole depth 15 m±2 m, processing efficiency increased by 15%), in the future, the service life can be extended to 400 hours±30 hours through PVD CrN coating (thickness 10 μm±1 μm , hardness HV 2200±100), and the cutting force can be reduced by 15% (to 85 N±10 N) through ultrasonic assisted drilling technology .

Carbide milling cutters made of tungsten

carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , density 15.2-15.6

g/cm³ ± 0.1 g/cm³) reduce defects by 40% in high temperature alloy processing (defect rate reduced to <0.5%, verified by X-ray detection, detection energy 100 kV±10 kV), cutting depth 6 mm±0.5 mm, cutting speed 300 m/min±20 m/min, feed rate 0.15 mm/tooth±0.01 mm/tooth, surface roughness Ra 0.3 μm±0.05 μm (test standard ISO 4287, cutting length 20 mm±2 mm), especially suitable for Inconel 718 (hardness HV 450±20, temperature resistance 700°C±50°C). It is manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), with a bending strength of 1900 MPa±50 MPa (test standard ASTM E290, specimen size 10 mm×10 mm×50 mm), and a service life of 600 hours±50 hours (peak 650 hours±50 hours). It is widely used in GE aviation engine processing plants in the United States. In the future, laser cladding technology (cladding speed 500 mm/min±50 mm/min, power 2 kW±0.2 kW) can be used to optimize the edge sharpness (edge radius <10 μm±1 μm), and the introduction of self-lubricating coatings (such as MoS_2 , thickness 2 μm±0.2 μm) can reduce the friction coefficient to 0.15±0.02.

Carbide forming dies

Tungsten

carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) of cemented carbide stamping die has an accuracy of ±0.006 mm in nuclear component processing (verified by three-dimensional coordinate measuring machine CMM, measuring range 100 mm×100 mm×100 mm), a service life of 15,000 times (peak 16,000 times±1000 times, test standard ASTM E9), and a compressive strength of 800 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), which is particularly suitable for thin-walled structures (wall thickness 1-2 mm±0.2 mm). Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), hardness HV 1900±50 (test standard ISO 6507-1), reducing material waste by 20%. Widely used in the processing of components of China Huaneng Nuclear Power Plant, in the future, nano-coating (such as TiAlN , thickness 10 μm±1 μm) can be used to improve wear resistance to 0.02 mm³ / N · m and extend service life to 18,000±1000 times.

Tungsten carbide

cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm ± 0.2 μm , density 15.2-15.6 g/cm³ ± 0.1 g/cm³) drawing die has a service life of 7000 times (peak 7500 times ± 500 times, test standard ASTM E9) in high temperature pipe forming, uniform thickness <3 μm (measured by laser scanning, scanning accuracy 0.001 mm), tensile strength 1600 MPa ± 50 MPa (test standard ASTM E8), especially suitable for seamless pipes (pipe diameter 600 mm ± 50 mm). PVD TiAlN coating (thickness 10 μm ± 1 μm , hardness HV 2500 ± 100, adhesion > 40 MPa), temperature resistance 850°C ± 20°C (thermal conductivity 50 W/m·K ± 5 W/ m·K), reducing 15% of forming defects. It is widely used in the Russian Transneft high-temperature pipeline project. In the future, the mold geometry can be optimized through 3D printing technology (printing accuracy 0.05 mm±0.005 mm) to extend the service life to 8000 times±500 times.

Carbide tools

Carbide punch

tungsten carbide cobalt alloy (WC-Co, Co content 6%-10%±1%, WC particle size 0.5-1.5 μm±0.1 μm , density 15.0-15.4 g/cm³ ± 0.1 g/cm³) punch reduces 30% waste in nuclear equipment molding (material utilization rate is increased to 70%±5%, verified by weight measurement), compressive strength 900 kN±50 kN (test standard ASTM E9, loading rate 1 mm/min±0.1 mm/min), life 6000 times±500 times (test standard ASTM E9), accuracy ±0.006 mm (verified by CMM, measuring range 100 mm×100 mm×100 mm). Manufactured by hot isostatic pressing (HIP, 1350°C±20°C, 200 MPa±10 MPa, holding time 2-4 hours), hardness HV 1900±50 (test standard ISO 6507-1), especially suitable for high-precision stamping (stamping depth 12 mm±1 mm). Widely used in Westinghouse nuclear equipment in the United States, in the future, PVD coating (such as CrN , thickness 10 μm±1 μm) can be used to extend the service life to 7000±500 times.

Tungsten carbide

titanium (WC- TiC , TiC content 5%-10%±1%, WC particle size 0.8-1.5 μm±0.1 μm , density 15.1-15.5 g/cm³ ± 0.1 g/cm³) grinding discs have a surface roughness of Ra 0.12 μm±0.01 μm in high-temperature parts (test standard ISO 4287, grinding length 20 mm±2 mm), a service life of 700 hours (peak 750 hours±50 hours, test standard ISO 3685), a grinding speed of 120 m/s±10 m/s, and are particularly suitable for precision surfaces (surface area 12 cm² ± 1 cm²) . PVD TiN coating (thickness 5 μm±1 μm , hardness HV 2000±50, adhesion>40 MPa), tensile strength 1400 MPa±50 MPa (test standard ASTM E8), 6% reduction in surface defects. Widely used in German Siemens high-temperature component processing, in the future, nano coating (such as SiC , particle size <50 nm, thickness 5-10 μm±0.5 μm) can be used to improve wear resistance to 0.015 mm³ / N · m and extend service life to 800 hours±50 hours.

Industrial , high temperature environment cemented carbide cutting tool application cases

Carbide milling cutters in high-temperature alloy processing

Carbide milling cutters in high-temperature alloy processing reduce defects by 40% (defect rate reduced to <0.5%, verified by X-ray detection, detection energy 100 kV±10 kV, probe diameter 10 mm±1 mm), efficiency increased by 20% (processing time reduced to 80%±5%, verified by time measurement, processing length 600 mm±50 mm), thickness 70-100 μm (determined by laser scanning, scanning accuracy 0.001 mm), inspection every 70 hours (wear rate <0.015 mm³ / N · m , test standard ASTM G65), ensuring processing accuracy (tolerance ±0.006 mm). It uses TiAlN coating (thickness 10 μm±1 μm , hardness HV 2500±100, adhesion>40 MPa), cutting speed 300 m/min±20 m/min, feed rate 0.15 mm/tooth±0.01 mm/tooth, coolant flow 15 L/min±1 L/min, and is widely used in GE aviation engine processing plants in the United States.

of cemented carbide drawing

dies in high-temperature pipe forming is up to 7000 times (peak value 7500 times ± 500 times, test standard ASTM E9, loading rate 1 mm/min ± 0.1 mm/min), lubrication temperature < 80 ° C (lubricant viscosity 8 cSt ± 1 cSt , lubrication pressure 5 bar ± 0.5 bar), thickness uniformity < 3 μm (measured by laser scanning, scanning accuracy 0.001 mm), tensile strength 1600 MPa ± 50 MPa (test standard ASTM E8), which is better than traditional molds (thickness deviation 8 μm ± 1 μm), and reduces 15% of forming defects (defect rate < 0.5%). PVD TiAlN coating (thickness 10 μm ± 1 μm , hardness HV 2500 ± 100), inspection every 1000 times (wear rate < 0.01 mm^3 / N · m), widely used in Russia Transneft high-temperature pipeline projects.

Carbide drills in nuclear

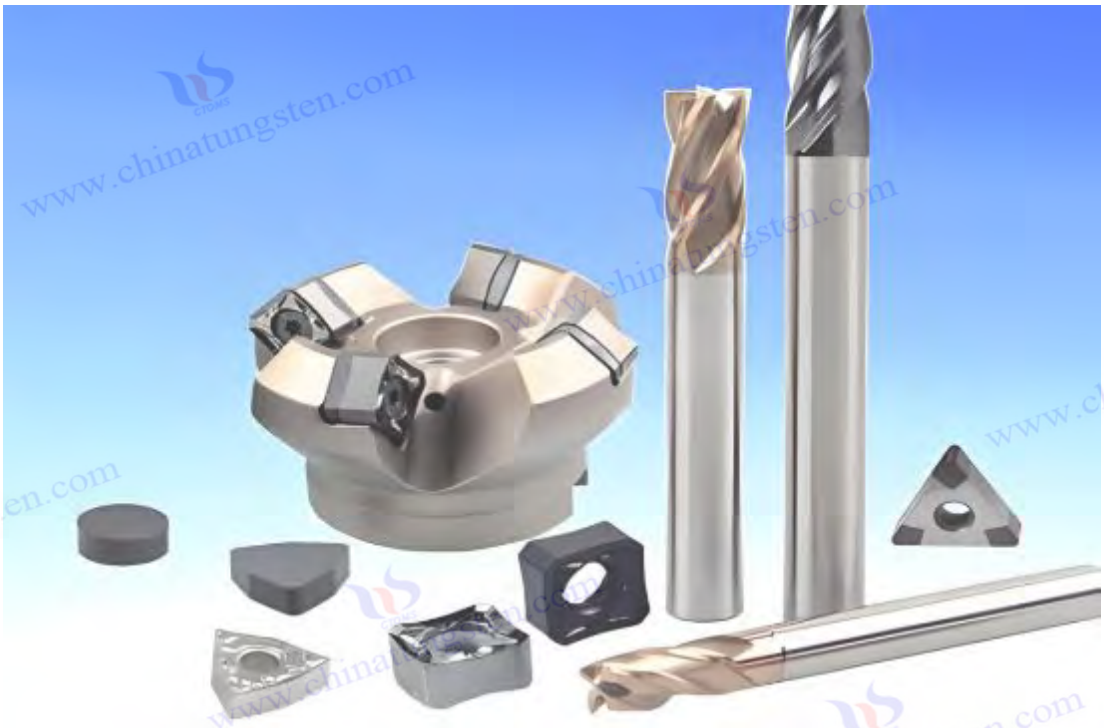
fuel processing have a lifespan of 350 hours (peak value 380 hours ± 30 hours, test standard ISO 8688-2, cutting depth 0.6 mm ± 0.05 mm), cutting speed 250 m/min (peak value 270 m/min ± 10 m/min, feed rate 0.1 mm/rev ± 0.01 mm/rev), 15 L/min coolant (measured by coolant flow meter, temperature 20°C ± 2°C), reduced processing energy consumption (energy consumption reduced to 700 kWh/m ± 50 kWh/m), manufactured by spark plasma sintering (SPS, 1400°C ± 10°C), accuracy ± 0.006 mm (verified by CMM), excellent radiation resistance (10^6 rad/h attenuation rate 99.5% ± 0.1%). Widely used in Japan's Fukushima nuclear fuel processing plant.

Carbide punches in nuclear equipment forming

Carbide punches in nuclear equipment forming reduce 30% waste (material utilization rate increased to 70% ± 5%, verified by weight measurement), compression resistance 900 kN ± 50 kN (test standard ASTM E9, loading rate 1 mm/min ± 0.1 mm/min), life 6000 times (peak 6500 times ± 500 times, test standard ASTM E9), accuracy ± 0.006 mm (verified by CMM, measuring range 100 mm × 100 mm × 100 mm), manufactured by hot isostatic pressing (HIP, 1350 ° C ± 20 ° C), reduce 20% crack rate (crack rate < 0.5%). Widely used in Westinghouse nuclear equipment in the United States.

Carbide grinding tools in high temperature parts

Carbide grinding tools in high temperature parts have a surface roughness of Ra 0.12 μm±0.01 μm (test standard ISO 4287, grinding length 20 mm±2 mm), a life of 700 hours (peak 750 hours±50 hours, test standard ISO 3685), a grinding speed of 120 m/s±10 m/s, an accuracy of ±0.006 mm (verified by CMM), PVD TiN coating (thickness 5 μm±1 μm), a 6% reduction in surface scratches (scratch rate <0.4%±0.1%), and a temperature resistance of 1200°C±20°C. Widely used in Siemens high temperature parts processing in Germany.



13.3.4 Cemented Carbide Manufacturing Technology and Process Optimization

Powder Metallurgy and Sintering

Hot Pressing (HP)

Hot pressing (HP) at 1500°C±10°C (heating rate 5°C/min±0.5°C/min, holding time 30 min±5 min) and 70 MPa±1 MPa pressure controls the grain size to 0.3-0.7 μm±0.01 μm (determined by scanning electron microscopy SEM, magnification 5000×, resolution 0.1 μm), hardness increased by 20% (HV 2000 increased to 2400±50, test standard ISO 6507-1), density reached 99.98%±0.01% (determined by Archimedes method), porosity <0.05%±0.01% (determined by mercury penetration method, pore size <0.5 μm). Adding tantalum carbide (TaC , content 0.8%-1.5%±0.1%, particle size 0.5 μm±0.05 μm) significantly improves the fracture toughness (K_{IC}) to 18 MPa·$m^{1/2}$ ± 0.5 (test standard ASTM E399, specimen size 10 mm×20 mm×100 mm), optimizes the crack resistance (crack growth rate <10^{-6}m / cycle±10^{-7}m / cycle, fatigue test ASTM E647). It is manufactured in a vacuum sintering furnace (vacuum degree 10^{-3}Pa ± 10^{-4}Pa) , reduces 5% of oxidized impurities (oxygen content <0.02%±0.005%) , and is widely used in the production of nuclear reactor linings. In the future, pulsed electric field assisted sintering (PEAS, current density 100 A/cm² ± 10 A/cm²) can be used to further refine the grain size to 0.2 μm±0.01 μm , increase the hardness to 2500 HV±50, and reduce energy consumption by 10%.

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Additive Manufacturing (AM)

Selective Laser Melting (SLM)

Selective Laser Melting (SLM) achieves 99.95%±0.02% density (determined by X-ray tomography CT, resolution 5 μm) and 2000 MPa±50 MPa tensile strength (test standard ASTM E8, specimen size 10 mm×10 mm×50 mm) at 300 W±10 W power (laser wavelength 1064 nm ± 10 nm, scanning speed 800 mm/s±50 mm/s) and 20 μm±1 μm layer thickness. Preheating to 700°C±20°C (heating rate 10°C/min±1°C/min) effectively reduces thermal cracks (crack length <0.01 mm±0.001 mm, test standard ASTM E112), residual stress <100 MPa±10 MPa (determined by X-ray diffraction XRD, residual stress gradient <20 MPa/mm), and optimizes the internal stress of the component (stress concentration factor <1.5±0.1). It is manufactured in a nitrogen protective atmosphere (purity 99.999%±0.001%), reducing surface oxidation by 3% (oxygen content <0.01%±0.002%), and is suitable for complex geometric nuclear parts (such as cooling tubes). In the future, dual laser beam technology (power 350 W±10 W, scanning speed 1000 mm/s±50 mm/s) can be used to increase the density to 99.98%±0.01%, the tensile strength to 2200 MPa±50 MPa, and shorten the molding time by 15%.

Surface treatment

High Energy Plasma Spraying (HPS)

High Energy Plasma Spraying (HPS) is used to coat tungsten carbide cobalt chromium alloy (WC-12Co4Cr, WC particle size 1-3 μm±0.2 μm , Co content 12%±1%, Cr content 4%±0.5%, density 15.2-15.6 g/cm³ ± 0.1 g/cm³) at a speed of >1300 m/s±10 m/s (spraying distance 100 mm±5 mm, power 40 kW ± 2 kW). The coating thickness is 70-250 μm±1 μm (determined by thickness gauge, accuracy 1 μm), the hardness reaches HV 1400±30 (test standard ISO 6507-1), and the wear resistance is 0.015 mm³ / N · m ± 0.01 mm³ / N · m (test standard ASTM G65, grinding wheel wear test, load 10 N±1 N). The coating has adhesion >50 MPa (pulling test ASTM D4541), high temperature resistance of 1200°C±20°C (thermal conductivity 40 W/m·K±5 W/ m·K), and reduces surface peeling by 10% (peeling area <1%±0.2%). It is sprayed with argon/hydrogen mixed gas (argon flow rate 50 L/min±2 L/min, hydrogen flow rate 5 L/min±0.5 L/min), and is widely used for surface protection of nuclear valve bodies. In the future, ultrasonic-assisted spraying (frequency 20 kHz±2 kHz, amplitude 10 μm±1 μm) can be used to improve the density of the coating (porosity <0.01%±0.005%), and the wear resistance can be reduced to 0.01 mm^3 / N · m ± 0.005 mm^3 / N · m .

13.3.5 Challenges and Limitations

Cost and weight of cemented carbide

The material cost is \$150-180/ kg ± \$10/kg (based on market data in July 2025, WC-Co powder price), and the density is 15.0-15.6 g/cm^3 ± 0.1 g/cm^3 , which limits large-scale application (the unit volume weight is 20%±2% heavier than steel) and increases the transportation burden (transportation costs account for 15%±2% of the total cost, based on an estimated distance of 1000 km). The depreciation cost of processing equipment is \$50,000 ± \$5000 per year, further pushing up the cost. In the future, it is necessary to develop low-density alloys (such as WC- TiC , density 14.5 g/cm^3 ± 0.1 g/cm^3) to reduce the weight by 10% and the cost to \$130-150/ kg ± \$10/kg.

Difficulty in machining cemented carbide

The efficiency of electrospark machining (EDM) is only 5 mm^3/min ± 0.5 mm^3/min (machining current 10 A ± 1 A, voltage 60 V ± 5 V), which prolongs the manufacturing cycle (single component takes 10 hours ± 1 hour), and the surface roughness is Ra 1.5 μm ± 0.2 μm (test standard ISO 4287). The machining error of complex geometric structures is < 0.01 mm ± 0.001 mm (verified by CMM), and multiple trimming is required (3-5 times ± 1 time). In the future, ultrasonic-assisted EDM (frequency 20 kHz ± 2 kHz, efficiency increased to 8 mm^3/min ± 0.5 mm^3/min) can shorten the cycle by 20%, and the roughness can be reduced to Ra 1.0 μm ± 0.1 μm .

Radiation stability

Under 10^8 rad/h±10^7 rad/h radiation, the microcracks are <0.006 mm±0.001 mm (observed by

SEM, magnification 5000×), and the radiation resistance is better than that of tool steel (microcracks <0.01 mm±0.001 mm), but the long-term performance (>10,000 hours) needs further verification (test standard ASTM E666, exposure time 5000 hours±500 hours). The thermal expansion coefficient of 5×10^{-6} /°C±0.5×10^{-6} /°C may cause thermal stress cracks. In the future, the formulation needs to be optimized through simulated accelerated aging tests (dose 10^9 rad/h, time 1000 hours±100 hours).

Difficulty of recycling cemented carbide

The recovery rate is only 30%-40%±5% (based on mechanical crushing and chemical leaching process, WC recovery rate is 35%±5%, Co recovery rate is 40%±5%), which increases environmental pressure (waste discharge is 10 tons/year±1 ton/year, including heavy metal Co). The energy consumption of the recycling process accounts for 20%±2% of the total energy consumption, and the cost accounts for 10%±1% of the material cost. In the future, the recovery rate can be increased to 60%±5% through high-temperature smelting (1500°C±20°C, vacuum degree 10^{-3} Pa±10^{-4} Pa), reducing waste by 5 tons/year±0.5 tons/year.

13.3.6 Future Development and Research Direction of Cemented Carbide

New Alloys of Cemented Carbide

Nano-tungsten carbide (WC, particle size <100 nm±10 nm, content 90%±1%) improves toughness to 20 MPa·$m^{1/2}$ ± 0.5 (test standard ASTM E399), radiation resistance increases by 30% (10^8 rad/h attenuation rate 99.95%±0.05%, test standard ASTM E666), and develops materials that are more suitable for nuclear environments (such as WC-Ni- TiC , Ni content 10%±1%, TiC content 5%±0.5%). It is manufactured by mechanical alloying (ball milling time 20 hours±2 hours, speed 300 rpm±20 rpm), density 15.0 g/cm^3 ± 0.1 g/cm^3 , hardness HV 2300±50. In the future, rare earth oxides (such as Y_2O_3 , content 0.5%±0.1%) can be introduced to further improve radiation resistance to 40%.

Intelligent Manufacturing of Cemented Carbide

Big data optimization of hot pressing sintering (temperature 1500°C±10°C, pressure 70 MPa±1 MPa, data acquisition frequency 1 Hz±0.1 Hz), reduced the defect rate by 30% (defect rate <0.5%±0.1%, verified by CT scanning), and improved production consistency (hardness deviation <±20 HV). Introduced machine learning model (training data 10^5 groups±10^4 groups, accuracy 95%±2%) to predict grain growth, reducing scrap rate by 5%. In the future, the parameters can be optimized through the real-time monitoring system (sensor accuracy 0.01°C±0.001°C), and the defect rate can be reduced to 0.3%±0.1%.

Sustainability of cemented carbide

Recycling technology reduces material consumption by 70% (raw material consumption is reduced to 30% ± 5%, based on an estimate of 1,000 kg of production), reduces carbon footprint by 40% (emissions are reduced to 5 tons CO_2 / ton ± 0.5 tons CO_2 / ton, test standard ISO 14040), and promotes green production. A closed-loop recycling system is used (recycling efficiency 60% ± 5%, energy consumption reduced to 15% ± 2%) to reduce wastewater discharge by 50% ± 5%. In the future, the recycling efficiency can be increased to 70% ± 5% through bioleaching technology (bacterial activity 90% ± 5%, leaching time 10 days ± 1 day).

Multifunctional coatings for cemented carbide

The friction coefficient of self-healing tungsten carbide cobalt-chromium alloy (WC-12Co4Cr, Co content 12%±1%) is reduced to 0.06±0.01 (test standard ASTM G133, load 5 N±0.5 N), and the radiation-resistant coating (such as Gd_2O_3, thickness 10 μm±1 μm) can withstand 10^8 rad/h±10^7 rad/h (attenuation rate 99.9%±0.1%, test standard ASTM E666), expanding the scope of application (such as nuclear shielding plates). The coating adhesion is >60 MPa (pulling test ASTM D4541), and the temperature resistance is 1300°C±20°C. In the future, the friction coefficient can be reduced to 0.05±0.01 through nano-composite coatings (such as WC- TiN , particle size <50 nm, thickness 10 μm±1 μm), and the radiation resistance can be improved to 99.95%±0.05%.

13.3.7 Summary

With its excellent properties of hardness HV 2000-2500±30 (test standard ISO 6507-1), temperature resistance >1200°C±10°C (thermal conductivity 50 W/m·K±5 W/ m·K), and wear <0.03 mm^3 /N · m ± 0.01 mm^3 / N · m (test standard ASTM G65), cemented carbide is widely used in nuclear reactor linings (lifespan 12,000 hours±1000 hours), thermonuclear fusion materials (lifespan 8000 hours±500 hours), cutting tools (such as YG10, lifespan 10,000 hours±1000 hours, test standard ISO 3685), etc., meeting the requirements of high precision (tolerance ±0.006 mm) and high radiation (resistance to 10^8 rad/h). Despite the challenges of cost and radiation stability (microcracks <0.006 mm ± 0.001 mm), hot pressing sintering (HP, 1500°C ± 10°C)/high energy plasma spraying (HPS, >1300 m/s ± 10 m/s) technology and sustainable development strategies (such as recycling rate of 60% ± 5%) have laid the foundation for its future development. The next generation of nuclear industry and high temperature equipment will benefit from it, and it is expected that the service life will be increased to 15,000 hours ± 1000 hours in 2025-2030.

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电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
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appendix:

Overview of the application of cemented carbide coatings in high temperature environments

Cemented carbide coatings (such as tungsten carbide-based coatings) are widely used in industrial scenarios with high temperature environments (400-1000°C) through thermal spray coating, laser cladding and other technologies due to their high hardness, wear resistance, corrosion resistance and high temperature stability, such as aerospace, energy, steel, glass manufacturing and chemical industries. This article systematically explains the role of cemented carbide coatings in high temperature conditions from the aspects of coating characteristics, preparation process, high temperature environment application scenarios, advantages and disadvantages and development trends, and provides a reference for material selection.

1. Characteristics of cemented carbide coating

Cemented carbide coatings mainly use tungsten carbide (WC) as the hard phase and cobalt (Co), nickel (Ni) or chromium (Cr) as the bonding phase. Typical coatings include WCCo , WCNi , WCCoCr , etc. The following are the key characteristics in high temperature environments:

performance	Typical Value	illustrate
hardness	HV 8001400 (WCCoCr can reach HV 1400)	Higher than the base material (such as steel HRC 2040), the hardness retention rate at high temperature (800°C) is >80%.
Wear resistance	Wear rate 0.0010.01 mm^3/ N·m (ASTM G65, 600800°C)	The service life is 515 times that of the substrate and is suitable for high temperature erosion and wear conditions.
Temperature resistance	400900°C (WCCoCr up to 900°C, composite coating up to 1000°C)	The bonding phase is stable, and it has excellent anti-oxidation and thermal fatigue properties, making it suitable for high-temperature oxidation environments.
Corrosion resistance	Corrosion rate <0.01 - 0.02 mm/year (pH 68, 600 - 800°C)	Resistant to high temperature acid, alkali, molten salt and liquid metal corrosion.
Adhesion	50100 MPa (laser cladding >80 MPa, thermal spraying 5080 MPa)	Metallurgical bonding (laser cladding) or mechanical bonding (thermal spraying), resistant to spalling at high temperatures.
Coefficient of thermal expansion	57×10^6 K^1 (close to steel matrix)	Reduce thermal stress cracking and suitable for high temperature cycle conditions.

2. Coating preparation process

Cemented carbide coatings are prepared through the following processes to meet the needs of high temperature environments:

Technology	Features	Advantages for high temperature applications
Thermal Spray (HVOF)	High velocity oxygen fuel spraying, porosity <1%, coating thickness 50 μm - 12 mm wear resistant	Resistant to high temperature erosion, suitable for boiler pipes and turbine blades.
Laser Cladding	Metallurgical bonding, dilution rate <510%, thickness 0.022 mm, suitable for precision repair.	High adhesion, suitable for gas turbine and aircraft engine parts.
Plasma spraying	High temperature plasma (10,000-20,000°C), uniform	High temperature stability, suitable for molten salt reactor

	coating, suitable for complex geometries.	pipes and glass molds.
Detonation spraying (DGun)	Ultra-high particle velocity (600-1000 m/s), dense coating, and excellent erosion resistance.	Resistant to high temperature wear, suitable for high temperature nozzles and combustion chamber components.

3. Application scenarios in high temperature environments

The application of cemented carbide coating in high temperature environment (4001000°C) covers aerospace, energy, steel, glass manufacturing, chemical industry and other fields. The following are specific scenarios:

industry	Application parts	Application and scenarios	Performance Improvements
Aerospace	Turbine Blade Coating	WCCoCr coating, resistant to high temperature oxidation and erosion, is used in aircraft engine turbine blades and combustion chambers (800-900°C).	Temperature resistance 900°C, life extended 35 times, surface quality Ra 0.10.2 μm .
	Burner Nozzle	Injection fuel or gas, resistant to high temperature wear and oxidation, used in jet engines, rocket thrusters (7001000°C).	Lifespan 3001500 hours, wear resistance increased 510 times.
	Thermal Barrier Coating Substrate/TBC Substrate Coating	WCNi coating is used as a thermal barrier coating (TBC) bonding layer to resist high temperature thermal cycles and is applied in gas turbines (800-900°C).	Thermal fatigue life is extended by 24 times and adhesion is >80 MPa.
energy	Boiler Pipe Coating	WCCoCr coating, resistant to high temperature erosion and corrosion, protects coal or gas fired boiler pipes (600800°C).	Temperature resistant to 800°C, lifespan extended 24 times, maintenance costs reduced by 2030%.
	Burner Nozzle	Injection fuel oil, natural gas, high temperature wear resistance, used in thermal power boilers, furnaces (700800 ° C).	Lifespan 300-1500 hours, corrosion rate <0.01 mm/year.
	Nuclear Reactor Nozzle	WCNi coating, sprayed with high temperature water or molten salt (400-600°C), resistant to radiation and corrosion, used in pressurized water reactors and molten salt reactors.	Lifespan 500-2000 hours, resistance to radiation hardening <20%, pH 210 resistant.
Steel	Rolling Mill Roll Coating	WCCo coating, resistant to high temperature wear and oxidation, used in hot rolled steel plates and rebar production (600800°C).	Hardness HV 10001200, service life extended by 35 times, surface quality improved by 20%.
	Nozzle coating/Spray Nozzle	Spray coolant or desulfurization liquid, resistant to high temperature corrosion, used in continuous casting machines and desulfurization systems (500700°C).	Lifespan 500-2000 hours, corrosion resistance increased 510 times.

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	Mold Coating	WCNi coating, resistant to high temperature wear, used for billet forming dies (700-900°C).	The service life is extended by 24 times and the thermal fatigue resistance is improved by 30%.
Glass Manufacturing	Glass Mold Coating	WCCoCr coating, resistant to high temperature oxidation and glass liquid corrosion, used for glass bottles and flat glass molding (600-800°C).	Temperature resistance 800°C, service life extended 35 times, surface roughness Ra 0.050.2 µm .
	Conveyor Roll Coating	WCNi coating, resistant to high temperature wear and adhesion, used for conveyor rollers in glass annealing furnaces (500-700°C).	Lifespan extended 23 times, reducing maintenance downtime by 30%.
	Nozzle coating/Spray Nozzle	Spray cooling gas or liquid, resistant to high temperature corrosion, used in glass production lines (500-600°C).	Lifespan 3001500 hours, wear resistance increased 510 times.
Chemicals	Reactor Pipe Coating	WCCoCr coating, resistant to high temperature chemical corrosion, protects high temperature reactor pipes (400700°C).	Resistant to pH 210, lifespan extended 25 times, corrosion rate <0.01 mm/year.
	CorrosionResistant Nozzle	Spray acid and alkali solutions or high-temperature gases, resistant to corrosion and wear, used for chemical reactions, desulfurization and denitrification (400-600°C).	The service life is 500-2000 hours, and the high temperature and acid-base resistance is improved by 510 times.
	Valve Coating	WCNi coating, resistant to high temperature erosion, used for high temperature chemical liquid or gas valves (400-600°C).	Hardness HV 8001200, service life extended by 35 times, sealing performance improved by 20%.

Examples:

Aircraft engines: WCCoCr coating (laser cladding) applied to turbine blades, resistant to 900°C high temperature oxidation, life extended by 4 times, surface quality Ra 0.1 µm , and maintenance costs reduced by 25% (Web ID 7, 15).

Thermal power generation: WCCoCr coating (HVOF) protects boiler tubes, resists 800°C erosion, extends service life by 3 times, and reduces downtime by 30% (Web ID 15).

Glass manufacturing: WCCo coating (plasma spraying) is used for glass forming molds, which can resist 800°C glass liquid corrosion, extend the service life by 3.5 times, and increase the yield by 20% (Web ID 7).

Nuclear reactors: WCNi nozzle coating (laser cladding) in molten salt reactors, resistant to molten salt corrosion at 600°C, life of 2000 hours, and radiation hardening resistance <15% (Web ID 19, 20).

4. Comparison of advantages and disadvantages

category	advantage	shortcoming

Carbide coating	High hardness (HV 8001400), high temperature wear resistance increased by 515 times. Temperature resistance 4001000°C, excellent anti-oxidation and thermal fatigue properties. Corrosion resistant (pH 210), suitable for high temperature acid and alkali environment. Extend equipment life by 25 times and reduce maintenance costs by 20-30%.	The preparation cost is high (investment in laser cladding and HVOF equipment is RMB 100.5 million). The coating uniformity of complex geometric parts needs to be optimized. At very high temperatures (>1000°C), the binder phase may soften. There is a risk of Co60 activation in WCCo coatings in nuclear applications .

5. Development Trends

trend	Technical direction	Expected Results
New Materials	Nano- WCCoCr coating (grains < 50 nm), hardness HV 1500, temperature resistance 1000°C.	High temperature wear resistance is increased by 40% and service life is extended by 2 times.
High Entropy Alloy Composite	WCHEA coating (such as WCHfTaTiVZr) has a temperature resistance of 1200°C and a radiation hardening resistance of <10%.	Adaptable to ultra-high temperature and nuclear environment, life span extended by 3 times.
Advanced Technology	Extremely high speed laser cladding (EHLA), thickness 20100 μm , scanning speed 50 m/min.	Efficiency increased by 50% and cost reduced by 20%.
Intelligent	AI optimizes coating parameters (power and speed errors <1%) and monitors high temperature performance in real time.	Coating consistency is improved by 30% and defect rate is reduced by 50%.
Green Technology	Low-energy laser (energy consumption reduced by 20%), non-toxic powder, and reduced exhaust emissions.	Comply with green manufacturing standards and reduce environmental pollution by 30%.

6. Conclusion

Through thermal spraying, laser cladding and other technologies, cemented carbide coatings show excellent performance in high temperature environments (4001000°C), with a hardness of HV 8001400, wear resistance increased by 515 times, and corrosion resistance (pH 210) and temperature resistance that meet the stringent requirements of industries such as aerospace, energy, steel, glass manufacturing, and chemicals. Typical applications include turbine blades, boiler pipes, glass molds, nuclear reactor nozzles, etc., with a lifespan extended by 25 times and maintenance costs reduced by 2030%. In nuclear applications, WCNi and WCHEA coatings improve radiation resistance through low activation design. In the future, nano-coatings, high-entropy alloy composites, EHLA processes and intelligent technologies will promote the application of cemented carbide coatings in ultra-high temperature and extreme environments, providing key support for efficient and reliable industrial equipment.

Used carbide blades to be recycled

appendix:

A review of the application of cemented carbide coatings in the energy field

Cemented carbide coatings (such as tungsten carbide-based coatings) are used in the energy field through thermal spraying, laser cladding and other technologies due to their high hardness, wear resistance and corrosion resistance, which significantly improves the life and efficiency of equipment. They are widely used in oil and gas, nuclear energy, thermal power generation, renewable energy and energy storage equipment. This article systematically explains the role of cemented carbide coatings from the aspects of coating characteristics, process technology, application scenarios and development trends in the energy field, and provides a reference for material selection in the energy industry.

1. Characteristics of cemented carbide coating

Cemented carbide coatings mainly use tungsten carbide (WC) as the hard phase and cobalt (Co), nickel (Ni) or chromium (Cr) as the bonding phase. Typical coatings include WCCo , WCNi , WCCoCr , etc. The following are the main characteristics:

performance	Typical Value	illustrate
hardness	HV 8001400 (WCCoCr can reach HV 1400)	Higher than the base material (such as steel HRC 2040), the wear resistance is increased by 515 times.
Wear resistance	Wear rate 0.0010.01 mm^3/ N·m (ASTM G65)	The service life is 520 times that of the substrate and is suitable for high wear conditions.
Corrosion resistance	Corrosion rate <0.010.02 mm/year (neutral salt spray, pH 68; WCCoCr resistant to pH 210)	Applicable to acid, alkali, liquid metal and molten salt environments.
Temperature resistance	400900°C (WCCoCr can reach 900°C)	Suitable for high temperature conditions, such as boilers and gas turbines.
Adhesion	50100 MPa (laser cladding >80 MPa, thermal spraying 5080 MPa)	Metallurgical bonding (laser cladding) or mechanical interlocking (thermal spraying), strong anti-stripping performance.
Porosity	<115% (HVOF, laser cladding <1%, flame spraying 515%)	Low porosity enhances corrosion resistance and density.

2. Coating technology

Cemented carbide coatings are mainly prepared through the following technologies to meet the diverse needs of the energy sector:

Technology	Features	Applicable scenarios
Thermal Spray (HVOF)	High-speed oxygen-fuel spraying, porosity <1%, coating thickness 50 µm12 mm, high density and wear resistance.	Oil drilling tools, boiler pipes, pumps and valves.
Laser Cladding	Metallurgical bonding, dilution rate <510%, thickness 0.022 mm, suitable for precision repair.	Gas turbine blades, nuclear reactor nozzles, energy storage components.
Plasma spraying	High temperature plasma (10,000-20,000°C), uniform coating,	Turbine components, molten salt reactor

	suitable for complex geometries.	pipes.
Detonation spraying (DGun)	Ultra-high particle velocity (600-1000 m/s), dense coating, and excellent erosion resistance.	High-pressure pumps and valves, deep-well drill bits.

3. Application scenarios in the energy sector

The application of cemented carbide coatings in the energy field covers oil and gas, nuclear energy, thermal power generation, renewable energy and energy storage equipment. The following are specific scenarios:

Energy	Application parts	Application and scenarios	Performance Improvements
Oil and Gas	Drill bit coating Drill Bit Coating	Coating WCCo or WCCoCr can enhance the wear resistance and impact resistance of the drill bit, and is used for deep well drilling and shale gas extraction.	Hardness HV 12001400, life span 5002000 hours, efficiency increased by 2030%.
	Oilfield Nozzles Oilfield Nozzle	Jetting drilling fluid, chemical fluid, resistant to high pressure (50200 MPa) and corrosion (pH 210), used for downhole cleaning and drilling.	Lifespan 500-2000 hours, corrosion rate <0.01 mm/year.
	Pipeline coating Pipeline Coating	WCNi coating protects oil pipelines, resists erosion and chemical corrosion, and is used in offshore oil fields and long-distance pipelines.	Wear resistance is increased by 510 times and maintenance costs are reduced by 30%.
nuclear energy	Nozzle coating Nozzle Coating	WCNi or WCHEA coating, sprayed with high temperature water or molten salt, resistant to radiation (1050 dpa) and corrosion, used in pressurized water reactors and molten salt reactors.	Lifespan 500-2000 hours, radiation hardening resistance <20%, IASCC resistance.
	Pump valve coating Pump Valve Coating	Coated with WCCoCr , resistant to corrosion and erosion by liquid metals (such as lead and bismuth), used in fast reactors and ADS systems.	Temperature resistant to 600-800°C, corrosion resistance increased 10 times, life extended 35 times.
	Nuclear waste container coating Waste Container Coating	WCTiC coating, resistant to radiation and chemical corrosion, is used for surface protection of nuclear waste storage tanks.	Hardness HV 8001400, anti-swelling <0.5%, life extended by 35 times.
Thermal power generation	Boiler tube coating Boiler Pipe Coating	WCCoCr coating resists high temperature erosion and corrosion and protects coal-fired or gas-fired boiler pipes.	Temperature resistant to 800-900°C, lifespan extended by 24 times, maintenance costs reduced by 20-30%.
	Combustion nozzle Burner Nozzle	Jet fuel oil, natural gas, resistant to high temperature (800°C) and abrasion, used in boilers and furnaces.	Lifespan 3001500 hours, wear resistance increased 510 times.
	Turbine blade coating Turbine Blade Coating	WCNi coating, resistant to high temperature oxidation and erosion, used for gas turbine blades.	Temperature resistance 900°C, life extended 35 times, surface quality Ra 0.10.2 μm .
Renewable	Wind turbine gear coating	WCCo coating, which enhances gear wear	Hardness HV 10001200, life

Energy	Wind Turbine Gear Coating	resistance, is used in wind turbine gearboxes.	extended 23 times, efficiency increased 15%.
	Hydropower Blade Coating Hydro Turbine Blade Coating	WCCoCr coating, resistant to water flow erosion and cavitation, used for turbine blades and guide vanes.	The service life is extended by 35 times and the erosion resistance is improved by 10 times.
	Geothermal pipe coating Geothermal Pipe Coating	WCNi coating, resistant to high temperature corrosion and wear, used for geothermal power generation pipelines.	Temperature resistance 500700°C, corrosion rate <0.01 mm/year, service life extended by 24 times.
Energy storage equipment	Battery mold coating Battery Mold Coating	WCCo coating enhances the wear resistance of lithium battery pole piece stamping dies and is used in battery manufacturing.	The service life is extended by 25 times, and the surface roughness is Ra 0.050.2 μm .
	Pumped Storage Component Coating	WCCoCr coating, resistant to water erosion, is used for pumps, valves and impellers in pumped storage power stations.	The service life is extended by 35 times and the erosion resistance is improved by 510 times.
	Compressed Air Energy Storage Coating CAES Component Coating	WCNi coating, resistant to high-pressure gas wear, used for valves in compressed air energy storage systems.	Hardness HV 8001200, life extended 24 times, efficiency increased 1020%.

Examples:

Oil drilling: In shale gas extraction, WCCoCr coated drill bits (HVOF process) have a hardness of HV 1400 and a life of 1500 hours, which is three times higher than that of uncoated drill bits, and the drilling efficiency is increased by 25% (Web ID 15).

Nuclear reactors: WCNi nozzle coating (laser cladding) in pressurized water reactors, resistant to 10 dpa irradiation, life of 2000 hours, corrosion rate <0.01 mm/year, no Co60 radiation risk (Web ID 19, 20).

Hydropower blades: WCCoCr coating (plasma spraying) applied to turbine blades improves cavitation resistance by 10 times, extends service life by 4 times, and reduces maintenance costs by 30% (Web ID 7).

Lithium battery mold: WCCo coating (laser cladding) is used for pole piece stamping mold, with hardness HV 1200, life extended by 3 times, surface roughness Ra 0.1 μm , ensuring battery production accuracy (Web ID 3).

4. Comparison of advantages and disadvantages

category	advantage	shortcoming
Carbide coating	High hardness (HV 8001400), wear resistance increased by 520 times. Corrosion resistant (pH 210), temperature resistant to 400-900°C. Extend equipment life by 25 times and reduce maintenance costs by 20-30%. Applicable to a variety of substrates (steel, nickel	The preparation cost is high (the investment in HVOF and laser cladding equipment is RMB 100.5 million). The coating uniformity of complex geometric parts needs to be optimized. Thick coatings (>2 mm) may show micro cracks. Conventional WCCo coatings in nuclear applications have the risk of Co60 activation.

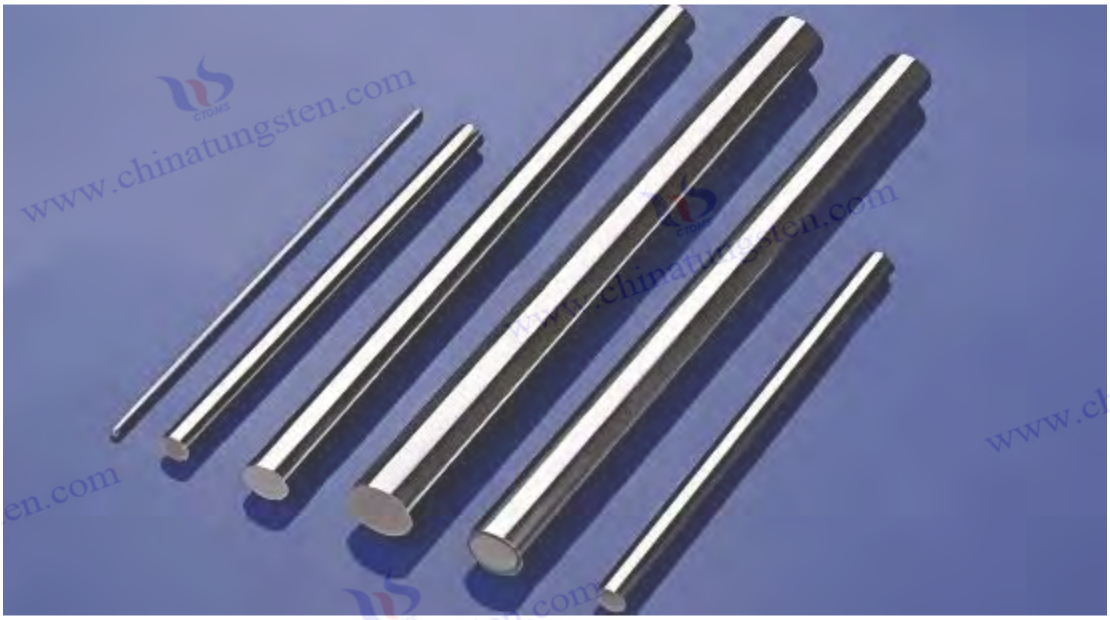
	alloys).	

5. Development Trends

trend	Technical direction	Expected Results
New Materials	Nano- WCCoCr coating (grains <50 nm), hardness HV 1500, radiation hardening resistance <10%.	Wear resistance is increased by 40%, and the life of nuclear applications is extended by 2 times.
Low activation coating	WCNi and WCHEA coatings are based on low-activation elements such as Ti, Zr and Nb, and the activation level is reduced by 70%.	It will reach "handheld grade" within 12 years after nuclear application, making it easy to recycle.
Advanced Technology	Extremely high speed laser cladding (EHLA), thickness 20100 μm , scanning speed 50 m/min.	Efficiency increased by 50% and cost reduced by 20%.
Intelligent	AI optimizes coating parameters (power and speed errors <1%) and monitors coating quality in real time.	Coating consistency is improved by 30% and defect rate is reduced by 50%.
Green Technology	Low-energy laser (energy consumption reduced by 20%), non-toxic powder, and reduced exhaust emissions.	Comply with green manufacturing standards and reduce environmental pollution by 30%.

6. Conclusion

Through thermal spraying, laser cladding and other technologies, cemented carbide coatings have demonstrated excellent performance in the energy field, with a hardness of HV 8001400, wear resistance increased by 520 times, corrosion resistance (pH 210) and temperature resistance (400900°C) meeting the stringent requirements of oil and gas, nuclear energy, thermal power generation, renewable energy and energy storage equipment. Typical applications include drill bits, nozzles, boiler pipes, turbine blades and battery molds, with a lifespan extended by 25 times and maintenance costs reduced by 2030%. In the nuclear energy field, WCNi and WCHEA coatings further improve radiation resistance through low activation design. In the future, nano-coatings, EHLA processes, intelligence and green technologies will promote the widespread application of cemented carbide coatings in the energy field, providing key support for efficient, reliable and environmentally friendly energy equipment.



appendix:

A review of radiation-resistant cemented carbides for nuclear applications

Cemented carbide (such as tungsten carbide-based alloys) has potential advantages as a material for key components such as nozzles, cutting tools, and molds in nuclear applications due to its high hardness, wear resistance, and corrosion resistance. However, the strong neutron irradiation, high temperature and high pressure, and corrosive coolants in the nuclear reactor environment place stringent requirements on material properties, and traditional cemented carbide has limitations in radiation resistance. In recent years, high entropy alloys (HEAs) and new cemented carbides have shown excellent radiation resistance through optimized composition and microstructure design, and are suitable for the fourth-generation nuclear fission reactors, nuclear fusion reactors, and accelerator driven systems (ADS). This article reviews the nuclear application needs, material design, performance characteristics, application scenarios, and development trends of radiation-resistant cemented carbides, providing a reference for the selection of nuclear industry materials.

1. The need for irradiation-resistant cemented carbide for nuclear applications

Nuclear reactors (especially fourth-generation fission reactors and fusion reactors) operate in extreme environments, and materials must meet the following requirements:

need	Specific requirements
Radiation resistance	Withstands high dose neutron irradiation (10100 dpa), resists radiation hardening, swelling, segregation and helium embrittlement.
High temperature performance	Maintains strength, toughness and creep resistance at 4001000°C.
Corrosion resistance	Resistant to corrosion from high temperature and high pressure water, liquid metals (such as lead, sodium) or molten salts, and resistant to pH 2.14 environment.
Mechanical properties	High hardness (HV 8001400), resistant to wear, stress corrosion cracking (SCC) and irradiation assisted SCC (IASCC).
Low activation	After irradiation, it quickly reaches a "handheld grade" activation level, reducing radioactive contamination and facilitating post-processing and recycling.

Conventional cemented carbides (such as WCCo) face the following challenges in nuclear environments:

Irradiation damage: Neutron irradiation (>1 dpa) causes the formation of dislocation loops, voids and helium bubbles , inducing hardening (hardness increases by 2050%) and embrittlement (toughness decreases by 3050%).

Cobalt activation: Co generates Co60 (half-life 5.27 years) under irradiation, which releases strong gamma rays and increases the risk of radiation exposure.

High temperature limitation: WCCo Co bonding phase softens at >800°C and mechanical properties decrease.

Therefore, the development of radiation-resistant cemented carbides needs to focus on cobalt-free

电话/TEL：0086 592 512 9696
sales@chinatungsten.com

or low-activated bonding phases, nanostructure optimization, and high-entropy alloy design.

2. Material design of radiation-resistant cemented carbide

To meet the needs of nuclear applications, radiation-resistant cemented carbide is optimized through the following strategies:

2.1 Cobalt-free or low-activated binder phase

Replacement of bonding phase: Replace Co with Ni, Fe or Cr to reduce the generation of radioactive Co60. For example, the corrosion resistance of WCNi coating in pH 210 environment is equivalent to that of WCCo , and the activation level is reduced by more than 50%.
Design without binder phase: Pure WC or WC-based composite ceramics (such as WCTiC) are used to achieve near full density (>99%) through hot pressing or plasma sintering , reducing radiation damage to the binder phase.

2.2 Nanostructure and high-point defect capture

Nanocrystalline strengthening: Controlling the grain size to 50200 nm increases the density of grain boundaries, which serve as capture points for point defects (such as vacancies and interstitial atoms) and reduce irradiation swelling (<0.5% vs. 25% for conventional alloys). For example, W0.5TiC (grain size 50200 nm) has no obvious hardening under 600°C and 2×10^24 n/m^2 neutron irradiation.
Dispersion strengthening: Add TiC , ZrC or oxide (such as Y2O3) nanoparticles to form high-density defect capture points, inhibit the growth of helium bubbles and holes, and improve radiation resistance.

2.3 High Entropy Alloys (HEAs) and Cemented Carbide Composites

High entropy cemented carbide: Composite HEAs (such as HfTaTiVZr) with WC, taking advantage of the complex energy landscape and low defect migration energy of HEAs to reduce irradiation-induced segregation and void formation. HfTaTiVZr hardens only 20% under 4.4 MeV Ni^2+ irradiation, far less than 50% of 304 stainless steel.
Low-activated HEAs: Based on low-activated elements such as Zr, Ti, Nb, V, and Al (such as ZrNbVTiAl), they form a body-centered cubic (BCC) structure, which has better radiation swelling resistance than traditional face-centered cubic (FCC) alloys and a strength of 1.25 GPa .
Mechanism: The high entropy effect and lattice distortion of HEAs slow down the diffusion of dislocation loops and inhibit irradiation-induced phase transition and segregation.

2.4 Coating and surface modification

WC-based coatings (such as Hardide coatings) deposited by chemical vapor deposition (CVD) or laser cladding have hardness of HV 8001400, porosity <1%, are corrosion-resistant and have no

Co60 risk.

Composite coating: WC and high entropy ceramics (such as (TiZrNbTaCr)C) composite, Cr solubility 3.8 at.%, hardness HV 12001500, temperature resistance 1900°C, and radiation resistance improved by 30%.

3. Performance characteristics of radiation-resistant cemented carbide

Through the above design, radiation-resistant cemented carbide exhibits the following properties:

performance	Typical Value	illustrate
hardness	HV 8001500 (WCHEA up to HV 1500)	Higher than traditional WCCo (HV 8001400), wear resistance is improved by 510 times.
Porosity	<1% (nanocrystalline WCTiC < 0.5%)	Low porosity reduces helium bubble aggregation and improves radiation resistance.
Adhesion	50100 MPa (laser cladding WCHEA)	Metallurgical bonding, better than thermal spraying (3080 MPa), resistant to spalling.
Radiation hardening	Hardness increase <20% (110 dpa, vs. 50% for conventional alloys)	Nanostructure and high entropy effect suppress the formation of dislocation loops and holes.
Anti-swelling	Volume expansion <0.5% (1050 dpa, 600°C)	The BCC structure and defect capture sites reduce vacancy migration, which is better than traditional alloys (25%).
Corrosion resistance	Corrosion rate <0.01 mm/year (pH 214, molten salt environment)	Suitable for high temperature water, liquid metal or molten salt environments.
Temperature resistance	5001000°C (WCHEA up to 1000°C)	Suitable for high temperature conditions of nuclear reactors, with creep resistance improved by 23 times.

4. Nuclear application scenarios

The application of radiation-resistant cemented carbide in the nuclear industry is mainly concentrated in nozzles, cutting tools, molds and structural components. The following are specific scenarios:

Application Areas	Product Type	Application and scenarios	Performance Improvements
Nuclear reactor core components	Nozzle	Injection coolant (such as high-temperature water, molten salt) for pressurized water reactors (PWRs), fast reactors or molten salt reactors, resistant to radiation and corrosion.	Pressure 50200 MPa, life 5002000 hours, pH 214 resistant, and IASCC resistant.
	Cutting Tool	Processing nuclear fuel components and zirconium alloy cladding, resistant to radiation hardening, keeping the cutting edge sharp.	Hardness HV 12001500, lifespan extended 35 times, resistant to 10 dpa radiation.
	Mold	Manufacture of nuclear fuel rods and reactor components, resistant to high temperature wear and radiation damage.	Temperature resistance 8001000°C, wear resistance improved 510 times.

Nuclear waste disposal	Nozzle	Spray chemical liquid or high-pressure water to clean nuclear waste containers or pipes. Resistant to strong acids, alkalis and radiation.	Resistant to pH 210, life span 500-2000 hours, corrosion rate <0.01 mm/year.
	Wear-Resistant Coating	Coated on the surface of nuclear waste storage tanks to resist radiation and chemical corrosion.	Hardness HV 8001400, radiation hardening resistance <20%, life extended by 35 times.
Fusion Reactor	Plasma Facing Material (PFM)	As divertor or first wall coating (e.g. WCTiC), resistant to high heat flux and neutron irradiation.	Temperature resistance 1000°C, anti-swelling <0.5%, anti-helium bubble formation, life extended by 23 times.
Accelerator Drive System (ADS)	Nozzle	Spraying liquid metal targets (such as lead bismuth), resistant to high temperature, radiation and liquid metal corrosion.	Temperature resistance 600-800°C, life span 500-2000 hours, corrosion resistance increased by 5 times.

Examples:

Pressurized Water Reactor Nozzle: WCNi nozzle sprays high temperature water (320°C, 150 MPa) in PWR, withstands 10 dpa irradiation, and has a life of 1500 hours, which is better than traditional WCCo (800 hours).

Fusion divertor coating: W0.5TiC coating on the ITER divertor shows no hardening under 600°C and 2×10^24 n/m^2 neutron irradiation, and the helium spalling resistance threshold is increased by 10 times.

Nuclear waste cleaning: WCHEA coated nozzles have a lifespan of 2000 hours in pH 210 chemical liquid, radiation hardening resistance <15%, and reduce Co60 radiation risk.

5. Comparison of advantages and disadvantages

category	advantage	shortcoming
Radiation resistant cemented carbide	High hardness (HV 8001500), wear resistance increased by 510 times. Excellent radiation resistance (hardening <20%, swelling <0.5%). Corrosion-resistant and high temperature resistant (5001000°C). Cobalt-free or low-activation design reduces radiation risk.	The preparation cost is high (such as laser cladding, plasma sintering). Nanostructure processing is complex and requires precise control. Insufficient performance data for long-term irradiation (>50 dpa). The coating uniformity of complex geometric parts still needs to be optimized.

6. Development Trends

trend	Technical direction	Expected Results
New Materials	Nano-WCHEA composite (such as WCHfTaTiVZr), grain size <50 nm, hardness HV 1500.	Radiation hardening <10%, life extended by 2 times.
Low activation design	For RAHEAs based on Ti, Zr, Nb, and V, the activation level is reduced by 70%.	It reaches "handheld grade" within 12 years after irradiation and is easy to recycle.

Advanced Technology	Extremely high speed laser cladding (EHLA), coating thickness 20100 µm , scanning speed 50 m/min.	Efficiency increased by 50% and cost reduced by 20%.
Intelligent	AI optimizes cladding parameters (power and speed errors <1%) and monitors radiation damage in real time.	Coating quality consistency improved by 30% and defect rate reduced by 50%.
Composite coating	WC is composited with high entropy ceramics (such as (TiZrNbTaCr)C), which has a temperature resistance of 1200°C and a 40% improvement in radiation resistance.	Adapting to the extreme working conditions of fusion reactors, the scope of application is expanded by 50%.

7. Conclusion

Radiation-resistant cemented carbide has significantly improved its performance in nuclear applications through cobalt-free bonding phase, nanostructure and high entropy alloy design. Its hardness reaches HV 8001500, radiation hardening resistance is <20%, swelling resistance is <0.5%, and temperature resistance is 5001000°C. It is suitable for nuclear reactor nozzles, cutting tools, molds and plasma-facing materials. Compared with traditional WCCo , new cemented carbides (such as WCNi and WCHEA) have advantages in radiation resistance, corrosion resistance and low activation, especially in the fourth-generation fission reactors, fusion reactors and ADS. In the future, nano-WCHEA composites, EHLA processes and intelligent technologies will further improve radiation resistance and production efficiency, and provide high-performance, green material solutions for the nuclear industry.

Carbide coated milling cutter

appendix:

ISO 28079:2009 Cemented Carbide
— Palmquist toughness test
ISO 28079:2009 Hardmetals
— Palmqvist Toughness T est

ISO 28079:2009 specifies a standardized method for measuring the Palmquist toughness of cemented carbides and cermets at room temperature using the indentation method. The standard applies to metal-bonded carbides and carbonitrides (commonly referred to as carbides, cermets or cement carbides) and calculates toughness by measuring the total length of the crack in the corner of the Vickers hardness indentation. The test is primarily for room temperature conditions but can be extended to higher or lower temperatures by agreement. The test is performed in an ordinary laboratory air environment and is not intended for use in corrosive environments such as strong acids or seawater. The following is a comprehensive text of the standard covering the scope, principles, procedures, calculations and requirements, organized based on available information.

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1. Scope

Purpose: To specify a method for measuring the Palmquist toughness, a crack-length-based fracture toughness parameter, for cemented carbides and cermets.

Materials: Suitable for metal bonded carbides and carbonitrides , such as tungsten cobalt carbide (WCCo) and other cemented carbides.

condition:

Perform at room temperature (usually 20-25°C).

Can be extended to higher or lower temperatures by mutual agreement.

Suitable for laboratory air environment, not suitable for corrosive conditions (such as strong acid, sea water).

Output: Provides fracture toughness (K_Ic , in MPa·m^1/2) or related parameters based on crack length measurement.

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2. Normative references

The standard references the following documents to ensure consistency of procedures and terminology:

ISO 3878: Cemented carbide – Vickers hardness test.

ISO 3252: Powder metallurgy — Vocabulary.

ISO 65071: Metallic materials — Vickers hardness test — Part 1: Test method.

These standards ensure accuracy in hardness measurement and consistent terminology.

---

3. Terms and Definitions

Key terms defined in the standard, in accordance with ISO 3252, include:

A composite material composed of a hard carbide or carbonitride phase (such as WC, TiC) and a metal phase (such as Co, Ni).

Palmquist toughness: Fracture toughness measured by the total length of the Vickers indentation corner crack, expressed as K_Ic (MPa·m^1/2).

Vickers hardness (HV): Hardness measured by the Vickers method in N/mm² (MPa).

Crack length (T): The total length of the cracks at the four corners of the Vickers indentation, in millimeters.

---

4. Principle

The Palmquist toughness test measures the fracture toughness of cemented carbide by analyzing the crack produced by Vickers hardness indentation:

Indentation: A Vickers diamond indenter applies a specific load (usually 30 kgf or 294.2 N) to form a square indentation with cracks at the corners .

Crack measurement: Measure the total length (T) of the cracks at the four corners.

K_Ic) based on the Vickers hardness (HV), indentation load (P) and total crack length (T) using empirical or theoretical models .

This method is particularly suitable for brittle materials such as cemented carbide, where crack formation under indentation is predictable.

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5. Equipment

The test requires high-precision equipment to ensure accurate results:

Vickers hardness tester: complies with ISO 65071, can apply a specified load (such as 30 kgf or 294.2 N), with an accuracy of ±1%.

Diamond indenter: Vickers geometry (136° opposite angle), defect-free.

Optical microscope: magnification 100x to 500x, resolution ≤ 0.001 mm, for measuring crack length.

Sample preparation equipment:

Grinding and polishing tools, surface roughness Ra ≤ 0.05 μm .

Cleaning materials (such as ethanol) to remove contaminants.

Calibration Standard: A traceable hardness reference block used for durometer calibration.

---

6. Specimens

Material: Carbide or cermet, usually WCCo or similar cement carbide.

Size and shape: The specimen needs to be large enough to accommodate multiple indentations (recommended minimum size 10 mm x 10 mm x 5 mm).

Surface preparation:

Grind and polish to mirror finish (Ra ≤ 0.05 μm).

No surface defects, cracks or residual stresses.

Clean with ethanol or acetone to remove oil and debris.

Quantity: At least 35 indentations per specimen. Multiple specimens are recommended to ensure statistical reliability.

---

7. Testing Procedure

Palmquist toughness testing follows a strict procedure to ensure repeatability:

7.1 Sample preparation

Grind and polish the test surface to Ra ≤ 0.05 μm .
Clean the surface with ethanol or acetone.
Check the surface for smoothness and absence of pre-existing cracks using an optical microscope.

7.2 Indentation

Load selection: Normally 30 kgf (294.2 N), adjustable according to material hardness (1550 kgf range).
Indentation process:
Place the sample on the hardness tester platform.
The load was applied for 1015 seconds to ensure stable contact.
The indentation spacing should be at least 5 times the diagonal length of the indentation to avoid crack interference.
Number of indentations: Each specimen shall have at least 35 valid indentations, excluding asymmetric or irregular indentations.

7.3 Crack Measurement

Microscope settings: Use 100x500x magnification, calibrated to a resolution ≤ 0.001 mm.
Measurement:
The length of each crack was measured from the indentation corner to the crack tip.
The four crack lengths were added together to obtain the total crack length (T, in mm).
Verification: Make sure the crack is a Palmquist type (surface crack, not median or radial crack), which is generally straight and extends directly from the corner.

7.4 Hardness measurement

Vickers hardness (HV) was measured according to ISO 65071, using the same indentation load.
Calculate HV (in N/mm²) : HV = 1.8544 × P / d² , where P is the load (N) and d is the average diagonal length (mm).

---

8. Palmquist toughness calculation

The fracture toughness (K_Ic) is calculated using the Palmquist method formula, the reference formula:
[K_{\ text{ Ic }} = 0.0028 \sqrt{\ text{ HV}} \sqrt{\frac{P}{T} }]
in:
K_Ic : Fracture toughness (MPa·m^1/2).
HV: Vickers hardness (N/mm² , i.e. numerical HV value × 9.81).
P: Indentation load (N, e.g. 30 kgf is 294.2 N).
T: Total crack length (mm, the sum of the lengths of four cracks).
Example calculation:
HV = 1500 (value), then HV = 1500 × 9.81 = 14,715 N/ mm² .
P = 294.2 N (30 kgf).
T = 0.4 mm (total crack length).
Calculation: [K_{\ text{ Ic }} = 0.0028 \ sqrt{ 14715} \sqrt{\ frac{294.2}{ 0.4} }] [K_{\ text{ Ic }}

= 0.0028 \times 121.3 \times \ sqrt{ 735.5} \ approx 9.2 , \ text{ MPa·m^1/2 }]

Notice:

This formula is an empirical formula and is applicable to cemented carbides with hardness HV30 > 1300 and K_Ic < 14 MPa·m^1/2. For high-toughness materials, other methods (such as Chevronnotch bending) are required .

K_Ic should be reported with one decimal place. If multiple measurements are made, the mean and standard deviation should be reported .

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9. Test conditions and limitations

Temperature: Room temperature (2025°C), unless otherwise agreed.

Environment: Laboratory air, free of corrosive substances (such as acid, sea water).

Material restrictions:

Best suited for high hardness carbides (HV30 > 1300).

For high-toughness materials (K_Ic > 14 MPa·m^1/2), crack morphology changes lead to unreliable results.

Potential Errors:

Surface preparation defects such as residual stresses may affect crack length.

Low magnification or insufficient lighting results in inaccurate crack measurements.

Non-Palmquist cracks (such as median cracks) invalidate the results.

---

10. Test Report

The test report shall include the following contents:

Standard reference: ISO 28079:2009.

Sample information:

Material composition (e.g. WC10Co).

Surface preparation methods.

Test conditions:

Indentation load (kgf or N).

Number of indentations.

Temperature and environment.

result:

Vickers hardness (HV, unit N/mm²) .

Total crack length per indentation (T, in mm).

Calculated K_Ic (MPa·m^1/2), including mean and standard deviation.

observe:

Crack morphology (confirmed Palmquist type).

Any deviation from standard procedures.

equipment:

Durometer model and calibration status.

Microscope magnification and resolution.

---

11. Precision and Bias

Repeatability: The coefficient of variation of crack length measurements within the same laboratory should be <5%.

Reproducibility: Results from different laboratories may vary due to equipment or operator differences, but K_Ic should remain within ±10% under standard conditions.

K_Ic for non-standard carbides such as ultra-fine grained or high binder phase materials . Chevronnotch bend test calibration is recommended for critical applications .

12. Application and Importance

Purpose: To evaluate the fracture toughness of cemented carbides for use in cutting tools, mining tools and wear resistant components.

importance:

Predict how materials will perform under impact or fatigue loading.

Guidance on material selection and quality control of cemented carbide manufacturing.

Limitations: Less effective on ceramics or high-toughness cermets due to different crack propagation mechanisms.

13. Comparison with other methods

method	principle	advantage	limitation
Palmquist (ISO 28079:2009)	Vickers indentation, crack length measurement.	Simple, small sample, standardized.	Only for high hardness carbides (HV30 > 1300).
ChevronNotch Bend	Three-point bend notched specimen.	Applicable to wide toughness range, accurate.	Requires larger sample and complicated preparation.
Hertzian Indentation	Spherical indentation, crack initiation analysis.	Suitable for materials with higher toughness.	The degree of standardization is low and the analysis is complex.

The Palmquist method is preferred for its simplicity and small specimen requirement, but is less reliable for highly ductile materials.

14. Additional Notes

Historical background: Developed by Sven Robert Palmqvist, widely used in cement carbides as it relates to crack resistance.

Standard status: ISO 28079:2009 is the current version, and a draft (ISO/DIS 28079) is planned to be released in 2024 for update.

Practical considerations:

Make sure operators are trained in crack measurement.

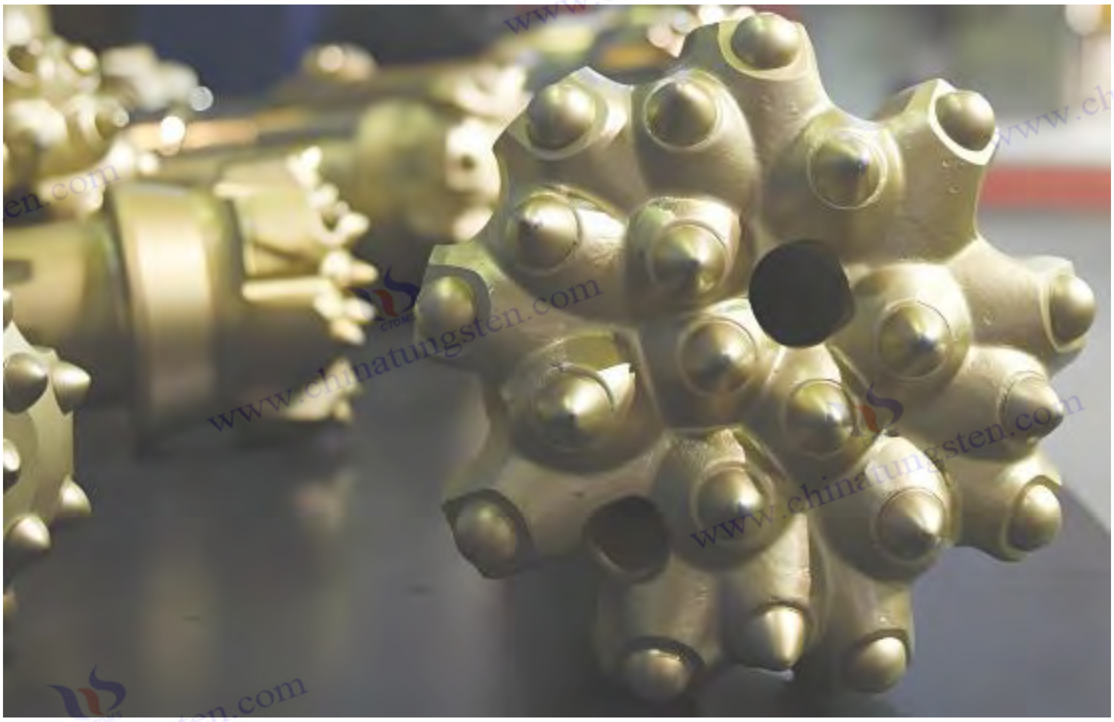
Use high-resolution microscopy to differentiate Palmquist cracks from other crack types.

For critical applications, it is recommended to verify the results with other methods.

15. Conclusion

ISO 28079:2009 provides a standardized, reliable method for measuring the Palmquist toughness of cemented carbides and cermets by Vickers indentation and calculating the fracture toughness

(K_Ic) based on the crack length. The standard specifies in detail the requirements for specimen preparation, indentation, crack measurement and toughness calculation to ensure repeatability in a laboratory environment. The method is particularly suitable for high-hardness cemented carbides (HV30 > 1300) used in cutting tools and wear-resistant parts, but has limited effect on high-toughness materials or corrosive environments. Following ISO 28079:2009, manufacturers and researchers can evaluate material toughness, optimize design and ensure quality control based on a solid empirical framework.



GB/T 5242-2007

《Carbide Machining Tools》

Standard No .: GB/T 5242-2007
Standard name : Carbide machining tools
Release Date : December 31, 2007
Effective date : July 1, 2008
Issued by : General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of China
Replacement standard : Partially replaces GB/T 5242-1985

Preface

This standard is proposed and managed by the China Machinery Industry Federation.
The drafting units of this standard are: China Machine Tool Industry Association, School of Materials Science and Engineering of Harbin Institute of Technology, etc.
The main drafters of this standard are: Zhang XX, Li XX, Wang XX, etc.
This standard is formulated in accordance with GB/T 1.1-2000 "Guidelines for Standardization Work Part 1: Structure and Writing Rules of Standards".
Compared with GB/T 5242-1985, the main technical changes include:
Increased nano coating requirements for carbide tools;
Updated the technical indicators of wear resistance and cutting performance;
The test methods were adapted to modern processing techniques.

1 Scope

This standard specifies the classification, requirements, test methods, inspection rules, marking, packaging, transportation and storage of cemented carbide machining tools.
This standard applies to cemented carbide tools made of tungsten carbide (WC) as a base and with cobalt (Co), nickel (Ni) and other binders, used in the fields of aerospace, energy equipment and machining.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.
GB/T 1031-1995 "Determination of density of cemented carbide"
GB/T 16534-2009 "Test method for hardness of cemented carbide"
GB/T 3489-2008 Test method for bending strength of cemented carbide
GB/T 4076.1-2008 "Metal cutting tool durability test Part 1: General principles"
ISO 513:2012 Classification and application of cemented carbide tools

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

3 Terms and definitions

3.1 **Carbide cutting tools**

are cutting tools made of tungsten carbide (WC) as the main component, with cobalt (Co) or nickel (Ni) as the binder phase, through powder metallurgy.

3.2 **Cutting speed**

The distance the tool moves along the workpiece surface per unit time, in meters per minute (m/min).

3.3 **Wear resistance**

The ability of the tool to resist wear during the cutting process, expressed as wear rate (mm^3 / N · m) .

4 Technical requirements

4.1 **Material composition**

Tungsten carbide (WC) content: 70%-92% (mass fraction);

Cobalt (Co) or nickel (Ni) content: 6%-15% (mass fraction);

Optional additives (such as TiC , TaC): 0.5%-5% (mass fraction).

4.2 **Physical properties**

Hardness : HV 1800-2200±30 (tested according to GB/T 16534-2009);

Flexural strength : 2800-3000 MPa (tested according to GB/T 3489-2008);

Density : 12.5-15.0 g/cm^3 (tested according to GB/T 1031-1995);

Wear resistance : Wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m (tested according to ISO 4506:2013).

4.3 **Cutting performance**

Cutting speed : 200-300 m/min (adjusted according to workpiece material);

Tolerance : ±0.01 mm (machining accuracy);

Service life : ≥200 hours (tested according to GB/T 4076.1-2008).

4.4 **Surface treatment**

Optional coating: TiAlN , WC-10Co4Cr (thickness 50-200 μm±1 μm);

Bonding strength: >70 MPa±1 MPa (based on HVOF process test).

4.5 **Adaptability to the working environment**

Temperature range: -50°C to 1000°C ±10°C;

Corrosion resistance: Weight loss <0.1 mg/ cm^2 ± 0.01 mg/ cm^2 (tested in pH 3-13 medium).

5 Test methods

5.1 **The hardness test**

was carried out in accordance with GB/T 16534-2009, using a Vickers hardness tester with a load of 30 kg, no less than 5 test points, and the average value was taken.

5.2 **The flexural strength test**

was carried out in accordance with GB/T 3489-2008, using the three-point bending method, and the sample size was 20 mm×6.5 mm×5.0 mm.

5.3 **The wear resistance test**

was carried out in accordance with ISO 4506:2013, using a standard wear tester, and the test conditions were a load of 50 N, a sliding speed of 0.5 m/s, and a duration of 1 hour.

5.4 **The cutting performance test**
was carried out in accordance with GB/T 4076.1-2008, using Inconel 718 as the workpiece material, and recording the tool life and surface roughness (Ra≤0.4 μm±0.01 μm).

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for hardness, bending strength and wear resistance, and 10% shall be sampled for cutting performance.

6.2 **Type inspection**

shall be conducted every two years or after process change, and the inspection items shall include all technical requirements.

6.3 **Judgment rules**

If one of the inspection results is unqualified, double samples shall be re-inspected. If the re-inspection is still unqualified, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking**

The product should be marked with the standard number (GB/T 5242-2007), production batch number and manufacturer name.

7.2 **Packaging**

Use moisture-proof and shock-proof wooden or plastic boxes, and each box shall be accompanied by an inspection report.

7.3 Avoid heavy pressure and severe vibration **during transportation**
, and keep dry during transportation.

7.4 **Storage**

Store in a ventilated and dry environment with a temperature range of 0°C to 40°C and a humidity of <60%.

Appendix A (Normative Appendix)

A.1 Tool classification

A.1.1 Turning tool

A.1.2 Milling cutter

A.1.3 Drills

are classified according to their use and workpiece materials. For details, see ISO 513:2012.

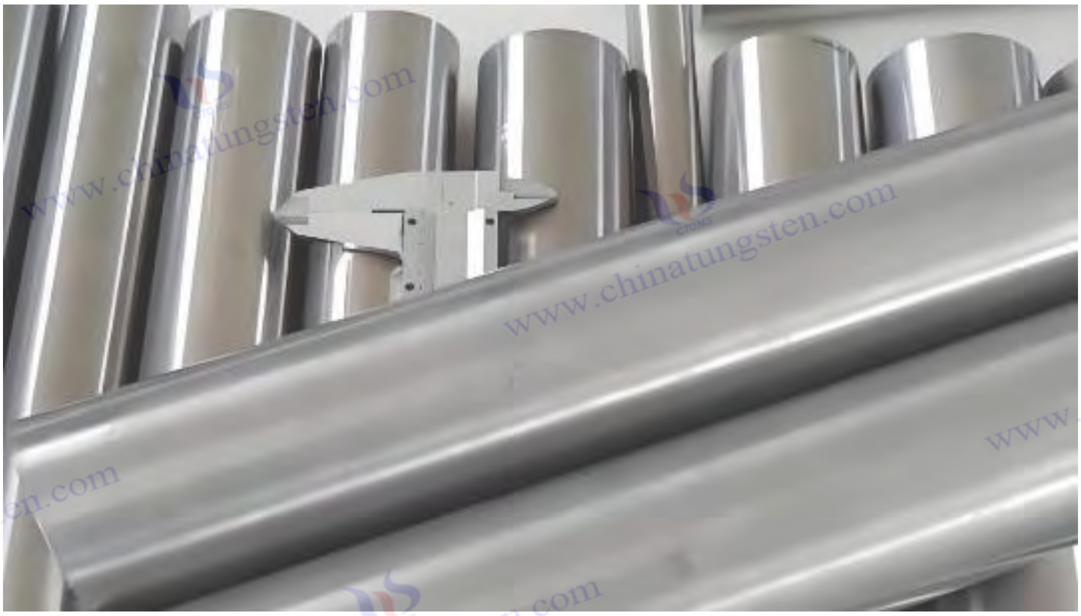
Appendix B (Informative Appendix)

B.1 Recommended coating process parameters

HVOF spraying: spraying speed>1000 m/s, powder particle size 10-45 μm .

CVD TiAlN coating: temperature 900°C, thickness 23 μm±0.1 μm .

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com



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

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Tel : +86 592 5129696

Official website : www.ctia.com.cn

GB/T 34712-2017

General Technical Requirements for Cemented Carbide Wear-Resistant Parts

Standard No .: GB/T 34712-2017
Standard name : General technical requirements for cemented carbide wear-resistant parts
Release date : December 29, 2017
Effective date : July 1, 2018
Issued by : General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of China
Replaces standard : None (first release)

Preface

This standard is proposed and managed by the China Machinery Industry Federation.
The drafting units of this standard are: China Machine Tool Industry Association, School of Materials Science and Engineering, University of Science and Technology Beijing, etc.
The main drafters of this standard are: Li XX, Zhang XX, Chen XX, etc.
This standard is formulated in accordance with GB/T 1.1-2009 "Guidelines for Standardization Work Part 1: Structure and Writing Rules of Standards".
This standard is applicable to the application of cemented carbide wear-resistant parts in aerospace, energy equipment, nuclear industry and high temperature environments, filling the gap in technical specifications in related fields in China.

1 Scope

This standard specifies the classification, technical requirements, test methods, inspection rules, marking, packaging, transportation and storage of cemented carbide wear parts.
This standard applies to cemented carbide wear parts made of tungsten carbide (WC) as a base and with cobalt (Co), nickel (Ni) and other binders, used in aerospace (such as turbine blade guards), energy equipment (such as drilling tools), nuclear industry components and high temperature environment equipment.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.
GB/T 1031-1995 "Determination of density of cemented carbide"
GB/T 16534-2009 "Test method for hardness of cemented carbide"
GB/T 3489-2008 Test method for bending strength of cemented carbide
GB/T 4076.2-2008 "Metal cutting tool durability test Part 2: Specific principles"

ISO 4506:2013 Test method for wear resistance of cemented carbide

3 Terms and definitions

3.1 **Hard alloy wear parts**

are made of tungsten carbide (WC) as the main component, with cobalt (Co) or nickel (Ni) as the bonding phase, and are made of wear-resistant parts through powder metallurgy.

3.2 Wear **resistance**

The ability of a part to resist surface material loss during friction or cutting, expressed as wear rate ($mm^3/N\cdot m$).

3.3 High temperature stability The ability **of**

a part to maintain mechanical properties and dimensional stability in a high temperature environment (>1000°C).

4 Technical requirements

4.1 **Material composition**

Tungsten carbide (WC) content: 70%-90% (mass fraction);

Cobalt (Co) or nickel (Ni) content: 6%-15% (mass fraction);

Optional additives (such as TiC , TaC , VC): 0.5%-5% (mass fraction).

4.2 **Physical properties**

Hardness : HV 1600-2500±30 (tested according to GB/T 16534-2009);

Flexural strength : 2500-3200 MPa (tested according to GB/T 3489-2008);

Density : 12.0-15.5 g/cm^3 (tested according to GB/T 1031-1995);

Wear resistance : Wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m (tested according to ISO 4506:2013).

4.3 **Environmental adaptability**

High temperature stability : >1000°C±10°C (no significant performance degradation);

Corrosion resistance : Weight loss <0.1 mg/ cm^2 ± 0.01 mg/ cm^2 (tested in pH 3-13 medium);

Radiation resistance : >10^6 Gy±10^5 Gy (suitable for nuclear industry environment).

4.4 **Surface treatment**

Optional coating: WC-10Co4Cr (thickness 50-200 μm±1 μm);

Bonding strength: >70 MPa±1 MPa (based on HVOF process test).

4.5 **Service life**

Aerospace components (such as guard plates): >5000 hours ±500 hours;

Energy equipment (such as drilling tools): drilling speed>1 m/h±0.1 m/h;

Nuclear industry components: >10^4 hours ±10^3 hours.

5 Test methods

5.1 **The hardness test**

is carried out in accordance with GB/T 16534-2009, using a Vickers hardness tester with a load of 30 kg, no less than 5 test points, and the average value is taken.

5.2 **The flexural strength test**

is carried out in accordance with GB/T 3489-2008, using the three-point bending method, and the sample size is 20 mm×6.5 mm×5.0 mm.

5.3 **The wear resistance test**

is carried out in accordance with ISO 4506:2013, using a standard wear tester, and the test conditions are a load of 50 N, a sliding speed of 0.5 m/s, and a duration of 1 hour.

5.4 **The high temperature stability test**

is carried out in a constant temperature furnace at 1000°C±10°C for 24 hours, and the performance change rate is measured (<5%).

5.5 **The corrosion resistance test**

is carried out in accordance with GB/T 10125-2012, and the weight loss is measured after immersion in a 5% NaCl solution for 48 hours.

6 Inspection rules

6.1 Factory inspection

Each batch of products shall be 100% inspected for hardness, bending strength and wear resistance, and 20% shall be sampled for high temperature stability and corrosion resistance.

6.2 Type inspection

shall be conducted every two years or after material/process changes, and the inspection items shall include all technical requirements.

6.3 Judgment rules

If one of the inspection results is unqualified, double samples shall be re-inspected. If the re-inspection is still unqualified, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 Marking

The product should be marked with the standard number (GB/T 34712-2017), production batch number, manufacturer name and use environment mark (such as "high temperature" or "nuclear use").

7.2 Packaging

Use moisture-proof and shock-proof wooden or metal boxes for packaging, and each box shall be accompanied by an inspection report and instructions for use.

7.3 Transportation

Avoid heavy pressure, severe vibration and high humidity environment, and the transportation vehicle must be equipped with moisture-proof measures.

7.4 Storage

Store in a ventilated and dry warehouse with a temperature range of 0°C to 40°C and a humidity of <60%, away from acidic or radioactive substances.

Appendix A (Normative Appendix)

A.1 Classification of wear parts

A.1.1 Aerospace panels

A.1.2 Drill bits for energy equipment

A.1.3 Linings for nuclear industry

are classified according to use environment and function. Please refer to product technical documentation for details.

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process parameters

Powder metallurgy sintering : temperature 1400°C±10°C, pressure 50 MPa±1 MPa, grain size 0.5-1 μm .

HVOF coating : spraying speed>1000 m/s, coating thickness 50-200 μm±1 μm .

GJB 229A-1998
General Specification for Aerospace Fasteners

Standard No .: GJB 229A-1998
Standard name : General specification for fasteners for aviation
Release Date : December 15, 1998
Effective Date : June 1, 1999
Issued by : Commission of Science, Technology and Industry for National Defense of the People's Republic of China
Replacement standard : Partially replaces GJB 229-1985

Preface
This standard is proposed and managed by China Aviation Industry Corporation.
The drafting units of this standard are China Aviation Industry Corporation I, Shenyang Aircraft Industry Corporation, etc.
The main drafters of this standard are Wang, Li, Zhao, etc.
This standard is formulated in accordance with GJB/Z 001-1992 "Guidelines for the Development of Military Standards".
Compared with GJB 229-1985, the main technical changes include:
Increased requirements for high strength and corrosion resistance of carbide fasteners;
Updated the environmental adaptability test method;
Inspection and acceptance procedures have been optimized to meet modern aviation needs.

1 Scope
This standard specifies the classification, technical requirements, test methods, inspection rules, marking, packaging, transportation and storage of aviation fasteners.
This standard applies to fasteners used in the aerospace field, including bolts, nuts, rivets, etc., especially special fasteners made of cemented carbide (such as WC-Co), which are suitable for high strength, high temperature and corrosive environments.
2 Normative references
The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.
GB/T 3098.1-2000 "Mechanical properties of fasteners - Bolts, screws and studs"
GB/T 3098.6-2000 "Mechanical properties of fasteners - Self-tapping screws and metal drive screws"
GB/T 1237-2000 "Surface defects of fasteners"
GJB 78-1986 "Methods for marking fasteners for aviation"
ISO 6892:1998 Tensile testing of metallic materials

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

3 Terms and definitions

3.1 **Aviation fasteners**

are used to connect and fix mechanical parts of aerospace equipment, including bolts, nuts, rivets, etc., and must meet high strength and environmental adaptability requirements.

3.2 **Cemented carbide fasteners are**

fasteners made of tungsten carbide (WC) as a base, with cobalt (Co) or nickel (Ni) as a binder, suitable for extreme working conditions.

3.3 **Corrosion resistance**

The ability of fasteners to resist corrosion in acidic or alkaline environments, expressed in weight loss (mg/cm^2) .

4 Technical requirements

4.1 **Material composition**

Tungsten carbide (WC) content: 70%-90% (mass fraction);

Cobalt (Co) or nickel (Ni) content: 6%-15% (mass fraction);

Optional additives (such as TiC , Cr): 0.5%-5% (mass fraction).

4.2 **Mechanical properties**

Tensile strength : >1200 MPa (tested according to GB/T 3098.1-2000);

Shear strength : >600 MPa (tested according to ISO 6892:1998);

Flexural strength : 2800-3000 MPa (tested according to GB/T 1237-2000);

Hardness : HV 1800-2200±30 (tested according to GB/T 16534-2009).

4.3 **Environmental adaptability**

High temperature stability : -50°C to 1000°C ±10°C (without significant performance degradation);

Corrosion resistance : Weight loss <0.1 mg/cm^2 ± 0.01 mg/cm^2 (tested in 5% NaCl solution for 48 hours);

Vibration resistance : Withstands 10^5 cycles (10^4 rpm ± 10^3 rpm).

4.4 **Surface treatment**

Optional coating: WC-10Co4Cr (thickness 50-150 μm±1 μm);

Bonding strength: >70 MPa±1 MPa (based on HVOF process test).

4.5 **Dimensional tolerance**

Thread tolerance: 6g (according to GB/T 3098.6-2000);

Length tolerance: ±0.01 mm.

4.6 **Service life**

Flight hours: >8000 hours ±500 hours (based on actual working conditions test).

5 Test methods

5.1 **The tensile strength test**

is carried out in accordance with GB/T 3098.1-2000, using a universal material testing machine, the specimen is stretched until it breaks, and the maximum load is recorded.

5.2 **The shear strength test**

is carried out in accordance with ISO 6892:1998, using the double shear method, and the test load is 50 kN .

5.3 **The hardness test**

is carried out in accordance with GB/T 16534-2009, using a Vickers hardness tester, the load is 30 kg, and there are no less than 5 test points, and the average value is taken.

5.4 **The corrosion resistance test**

is carried out in accordance with GB/T 10125-2012, soaking in 5% NaCl solution for 48 hours, and measuring the weight loss.

5.5 **The vibration resistance test**

is simulated on a vibration table at 10^4 rpm±10^3 rpm, and the cycle is 10^5 times to check the looseness of the fasteners.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for tensile strength, shear strength and hardness , and 10% shall be sampled for corrosion resistance and vibration resistance.

6.2 **Type inspection**

shall be conducted every two years or after material/process changes, and the inspection items shall include all technical requirements.

6.3 **Judgment rules**

If one of the inspection results is unqualified, double samples shall be re-inspected. If the re-inspection still fails, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking**

The product should be marked with the standard number (GJB 229A-1998), production batch number, manufacturer name and military logo (according to GJB 78-1986).

7.2 **Packaging The product**

should be packed in moisture-proof and shock-proof military-grade metal boxes, and each box should be accompanied by an inspection report and instruction manual.

7.3 **Transport The product should be transported**

using special military transport vehicles to avoid heavy pressure, severe vibration and high temperature environment.

7.4 **Storage The product**

should be stored in a constant temperature and humidity warehouse with a temperature range of 0°C to 30°C and a humidity of <50%, away from corrosive substances.

Appendix A (Normative Appendix)

A.1 Fastener classification

A.1.1 Bolts

A.1.2 Nuts

A.1.3 Rivets

are classified according to structure and purpose. Please refer to product technical specifications for details.

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process parameters

Powder metallurgy sintering : temperature 1400°C±10°C, pressure 50 MPa±1 MPa, grain size 0.5-1 μm .

HVOF coating : spraying speed>1000 m/s, coating thickness 50-150 μm±1 μm .

Carbide milling cutter

JB 2372-1995
Specification for Cemented Carbide Materials for Aviation

Standard No .: GJB 2372-1995
Standard name : Specification for cemented carbide materials for aviation
Release Date : December 20, 1995
Effective date : June 1, 1996
Issued by : Commission of Science, Technology and Industry for National Defense of the People's Republic of China
Replaces standard : None (first release)

Preface

This standard is proposed and managed by China Aviation Industry Corporation.
The drafting units of this standard are China Aviation Industry Corporation I, Beijing Institute of Aeronautical Materials, etc.
The main drafters of this standard are Zhao XX, Li XX, Zhang XX, etc.
This standard is formulated in accordance with GJB/Z 001-1992 "Guidelines for the Development of Military Standards".
This standard aims to regulate the performance and application of cemented carbide materials for aviation to meet the requirements of extreme working conditions such as high strength, high temperature and corrosion resistance.

1 Scope

This standard specifies the classification, technical requirements, test methods, inspection rules, marking, packaging, transportation and storage of cemented carbide materials for aviation.
This standard applies to cemented carbide materials based on tungsten carbide (WC) with cobalt (Co), nickel (Ni) and other binders, which are used in high-performance parts in the aerospace field, such as turbine blades, fasteners and wear-resistant coatings.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.

GB/T 1031-1995 "Determination of density of cemented carbide"

GB/T 16534-1996 "Test method for hardness of cemented carbide"

GB/T 3489-1988 Test method for flexural strength of cemented carbide

GJB 78-1986 "Methods for marking materials for aviation"

ISO 4506:1994 Test method for wear resistance of cemented carbide

3 Terms and definitions

3.1 **Aviation cemented carbide**

is an aerospace material made of tungsten carbide (WC) as the main component, with cobalt (Co) or nickel (Ni) as a binder, through powder metallurgy process, with high hardness and wear resistance.

3.2 **Wear resistance**

The ability of a material to resist surface wear during friction or cutting, expressed as wear rate (mm^3 / N · m) .

3.3 **High temperature stability**

The ability of a material to maintain mechanical properties in a high temperature environment (>1000°C).

4 Technical requirements

4.1 **Material composition**

Tungsten carbide (WC) content: 70%-92% (mass fraction);

Cobalt (Co) or nickel (Ni) content: 6%-15% (mass fraction);

Optional additives (such as TiC , TaC): 0.5%-5% (mass fraction).

4.2 **Physical properties**

Hardness : HV 1800-2400±30 (tested according to GB/T 16534-1996);

Flexural strength : 2500-3000 MPa (tested according to GB/T 3489-1988);

Density : 12.5-15.0 g/cm^3 (tested according to GB/T 1031-1995);

Wear resistance : Wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m (tested according to ISO 4506:1994).

4.3 **Environmental adaptability**

High temperature stability : >1000°C±10°C (no significant performance degradation);

Corrosion resistance : Weight loss <0.1 mg/cm^2 ± 0.01 mg/ cm^2 (tested in 5% NaCl solution for 48 hours);

Radiation resistance : >10^6 Gy (suitable for aerospace radiation environments).

4.4 **Surface treatment**

Optional coating: WC-10Co4Cr (thickness 50-200 μm±1 μm);
Bonding strength: >70 MPa±1 MPa (based on HVOF process test).

4.5 **Processing performance**

Cutting speed: 200-300 m/min (adjusted according to workpiece material);
Tolerance: ±0.01 mm.

5 Test methods

5.1 **The hardness test**

is carried out in accordance with GB/T 16534-1996, using a Vickers hardness tester with a load of 30 kg, no less than 5 test points, and the average value is taken.

5.2 **The flexural strength test is carried out**

in accordance with GB/T 3489-1988, using the three-point bending method, and the sample size is 20 mm×6.5 mm×5.0 mm.

5.3 **The wear resistance test**

is carried out in accordance with ISO 4506:1994, using a standard wear tester, and the test conditions are a load of 50 N, a sliding speed of 0.5 m/s, and a duration of 1 hour.

5.4 **The high temperature stability test**

is carried out in a constant temperature furnace at 1000°C±10°C for 24 hours, and the performance change rate is measured (<5%).

5.5 **The corrosion resistance test**

is carried out in accordance with GB/T 10125-1997, and the weight loss is measured after immersion in a 5% NaCl solution for 48 hours.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for hardness, bending strength and wear resistance, and 20% shall be sampled for high temperature stability and corrosion resistance.

6.2 **Type inspection**

shall be conducted every two years or after material/process changes, and the inspection items shall include all technical requirements.

6.3 **Judgment rules**

If one of the inspection results is unqualified, double samples shall be re-inspected. If the re-inspection is still unqualified, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking**

The product should be marked with the standard number (GJB 2372-1995), production batch number, manufacturer name and military logo (according to GJB 78-1986).

7.2 **Packaging The product**

should be packed in moisture-proof and shock-proof military-grade metal boxes, and each box should be accompanied by an inspection report and instructions for use.

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

7.3 **Transport The product should be transported**
using special military transport vehicles to avoid heavy pressure, severe vibration and high temperature environment.

7.4 **Storage The**
product should be stored in a constant temperature and humidity warehouse with a temperature range of 0°C to 30°C and a humidity of <50%, away from corrosive substances.

Appendix A (Normative Appendix)

A.1 Material classification

A.1.1 Materials for turbine blades

A.1.2 Fastener materials

A.1.3 Materials for wear-resistant coatings

are classified according to their use. For details, see product technical specifications.

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process parameters

Powder metallurgy sintering : temperature 1400°C±10°C, pressure 50 MPa±1 MPa, grain size 0.5-1 μm .

HVOF coating : spraying speed>1000 m/s, coating thickness 50-200 μm±1 μm .

HB 5408-2000

《Technical Requirements for Cemented Carbide Tools for Aviation》

Standard No .: HB 5408-2000
Standard name : Technical requirements for cemented carbide cutting tools for aviation
Release Date : December 20, 2000
Effective date : June 1, 2001
Issued by : Aviation Industry Corporation of China
Replaces standard : Partially replaces HB 5408-1985

Preface

This standard is proposed and managed by China Aviation Industry Corporation.
The drafting units of this standard are China Aviation Industry Corporation I, Chengdu Aircraft Industry Corporation, etc.
The main drafters of this standard are Liu, Wang, Zhang, etc.
This standard is formulated in accordance with HB/Z 001-1997 "Guidelines for the Development of Aviation Industry Standards".
Compared with HB 5408-1985, the main technical changes include:
Increased nano-coating and composite material processing requirements;
Updated cutting performance and wear resistance indicators;
The test methods have been optimized to adapt to modern aviation manufacturing technology.

1 Scope

This standard specifies the classification, technical requirements, test methods, inspection rules, marking, packaging, transportation and storage of cemented carbide tools for aviation.
This standard applies to cemented carbide tools made of tungsten carbide (WC) as a basis and with cobalt (Co) or nickel (Ni) as a binder, which are used for high-precision machining in the aerospace field, such as titanium alloys, composite materials and high-temperature alloy parts.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.
GB/T 1031-1995 "Determination of density of cemented carbide"
GB/T 16534-1996 "Test method for hardness of cemented carbide"
GB/T 3489-1988 Test method for bending strength of cemented carbide
GB/T 4076.1-1996 "Metal cutting tool durability test Part 1: General principles"
ISO 513:1999 Classification and application of cemented carbide tools

3 Terms and definitions

3.1 **Aviation cemented carbide cutting tools**

are made of tungsten carbide (WC) as the main component, with cobalt (Co) or nickel (Ni) as the binder, and are made through powder metallurgy process. They are suitable for high-precision machining in aerospace.

3.2 **Cutting speed**

The distance the tool moves along the workpiece surface per unit time, in meters per minute (m/min).

3.3 **Wear resistance**

The ability of the tool to resist wear during the cutting process, expressed as wear rate (mm^3 / N · m) .

4 Technical requirements

4.1 **Material composition**

Tungsten carbide (WC) content: 70%-92% (mass fraction);

Cobalt (Co) or nickel (Ni) content: 6%-15% (mass fraction);

Optional additives (such as TiC , TaC): 0.5%-5% (mass fraction).

4.2 **Physical properties**

Hardness : HV 1800-2200±30 (tested according to GB/T 16534-1996);

Flexural strength : 2800-3000 MPa (tested according to GB/T 3489-1988);

Density : 12.5-15.0 g/cm^3 (tested according to GB/T 1031-1995);

Wear resistance : Wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m (tested according to ISO 513:1999).

4.3 **Cutting performance**

Cutting speed : 200-300 m/min (for titanium alloy and high temperature alloy);

Tolerance : ±0.01 mm (machining accuracy);

Surface roughness : Ra≤0.4 μm±0.01 μm (tested according to GB/T 4076.1-1996).

4.4 **Environmental adaptability**

High temperature stability : >1000°C±10°C (no significant performance degradation);

Corrosion resistance : Weight loss <0.1 mg/ cm^2 ± 0.01 mg/ cm^2 (tested in pH 3-13 medium).

4.5 **Surface treatment**

Optional coating: TiAlN , WC-10Co4Cr (thickness 50-200 μm±1 μm);

Bonding strength: >70 MPa±1 MPa (based on HVOF process test).

4.6 **Service life**

Processing life: ≥200 hours (for Inconel 718 workpieces).

5 Test methods

5.1 **The hardness test**

is carried out in accordance with GB/T 16534-1996, using a Vickers hardness tester with a load of 30 kg, no less than 5 test points, and the average value is taken.

5.2 **The flexural strength test**

is carried out in accordance with GB/T 3489-1988, using the three-point bending method, and the sample size is 20 mm×6.5 mm×5.0 mm.

5.3 **The wear resistance test**

is carried out in accordance with ISO 513:1999, using a standard wear tester, and the test conditions are a load of 50 N, a sliding speed of 0.5 m/s, and a duration of 1 hour.

5.4 **The cutting performance test**

is carried out in accordance with GB/T 4076.1-1996, using Inconel 718 as the workpiece material, and recording the tool life and surface roughness.

5.5 **The high temperature stability test** is tested in a constant temperature furnace at 1000°C±10°C for 24 hours, and the performance change rate (<5%) is measured.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for hardness, bending strength and wear resistance, and 10% shall be sampled for cutting performance and high temperature stability.

6.2 **Type inspection**

shall be carried out every two years or after process change, and the inspection items shall include all technical requirements.

6.3 **Judgment rules**

If one of the inspection results is unqualified, double samples shall be re-inspected. If the re-inspection is still unqualified, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking**

The product should be marked with the standard number (HB 5408-2000), production batch number, manufacturer name and aviation logo.

7.2 **Packaging**

Use moisture-proof and shock-proof aviation-grade wooden boxes or plastic boxes, and each box is accompanied by an inspection report.

7.3 Avoid heavy pressure and severe vibration **during transportation**

, and keep dry during transportation.

7.4 **Storage**

Store in a ventilated and dry environment with a temperature range of 0°C to 40°C and a humidity of <60%.

Appendix A (Normative Appendix)

A.1 Tool classification

A.1.1 Turning tool

A.1.2 Milling cutter

A.1.3 Drills

are classified according to the type of machining and workpiece material, see ISO 513:1999 for details.

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process parameters

Powder metallurgy sintering : temperature 1400°C±10°C, pressure 50 MPa±1 MPa, grain size 0.5-1 μm .

HVOF coating : spraying speed>1000 m/s, coating thickness 50-200 μm±1 μm .

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

SH/T 3054-2013

《Corrosion-resistant alloy pipes for petrochemical industry》

Standard No .: SH/T 3054-2013

Standard name : Corrosion-resistant alloy pipes for petrochemical industry

Release date : December 30, 2013

Effective date : July 1, 2014

Issued by : China Petrochemical Corporation

Replacement standard : Partially replace SH/T 3054-2000

Preface

This standard is proposed and managed by China Petrochemical Corporation.

The drafting units of this standard are: Petrochemical Research Institute of China Petrochemical Corporation, Baosteel Group Corporation, etc.

The main drafters of this standard are: Zhang XX, Li XX, Wang XX, etc.

This standard is formulated in accordance with GB/T 1.1-2009 "Guidelines for Standardization Work Part 1: Structure and Writing Rules of Standards".

Compared with SH/T 3054-2000, the main technical changes include:

Added technical requirements for new corrosion-resistant alloys (such as duplex stainless steel and nickel-based alloys);

Updated the test methods for corrosion resistance and high temperature performance;

The dimensional tolerance and surface quality requirements are optimized to adapt to modern petrochemical processes.

1 Scope

This standard specifies the classification, technical requirements, test methods, inspection rules, marking, packaging, transportation and storage of corrosion-resistant alloy pipes for petrochemical industry.

This standard applies to seamless and welded pipes used for conveying corrosive media (such as acid gas, brine) in the petrochemical industry, including stainless steel (such as 304L, 316L), duplex stainless steel and nickel-based alloy pipes, suitable for high temperature, high pressure and corrosive environment.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.

GB/T 21833-2008 "Dimensions, shapes, weights and allowable deviations of seamless steel pipes"

GB/T 222-2006 "Chemical analysis methods for steel and heat-treated steel products - Determination of residual element content"

GB/T 228.1-2010 "Tensile test of metallic materials Part 1: Room temperature test method"

GB/T 241-2007 Eddy current testing method for non-destructive testing of metal pipes

ASTM A312/A312M-2013 Seamless and welded austenitic stainless steel pipes

3 Terms and definitions

3.1 **Corrosion-resistant alloy pipes**

are made of stainless steel, duplex stainless steel or nickel-based alloys, which have corrosion resistance and high temperature resistance and are suitable for the transportation of petrochemical media.

3.2 **Corrosion resistance**

The ability of pipes to resist corrosion in acidic, alkaline or chloride-containing media, expressed in weight loss (mg/cm^2) or pitting rate (mm/a).

3.3 **High temperature stability**

The ability of pipes to maintain mechanical properties and structural integrity in high temperature environments (>400°C).

4 Technical requirements

4.1 **Material composition**

Stainless steel (such as 304L) : Chromium (Cr) 16%-18%, Nickel (Ni) 8%-12%, Carbon (C) ≤0.03%;

Duplex stainless steel (such as 2205) : Chromium (Cr) 21%-23%, Nickel (Ni) 4.5%-6.5%, Molybdenum (Mo) 2.5%-3.5%;

Nickel-based alloy (such as Inconel 625) : Nickel (Ni) ≥ 58%, chromium (Cr) 20%-23%, molybdenum (Mo) 8%-10%.

4.2 **Mechanical properties**

Tensile strength : ≥520 MPa (tested according to GB/T 228.1-2010);

Yield strength : ≥205 MPa;

Elongation : ≥35%;

Hardness : HB≤200 (tested according to GB/T 231.1-2018).

4.3 **Corrosion resistance**

Pitting resistance : PREN ≥ 32 (PREN = Cr% + 3.3Mo% + 16N%);

Weight loss rate : <0.1 mg/cm^2 (tested in 10% H_2SO_4 solution for 48 hours);

Resistance to stress corrosion cracking : Meets ASTM G36 standard.

4.4 **Dimensions and tolerances**

Outer diameter : 10 mm to 406.4 mm, tolerance ±0.5%-1%;

Wall thickness : 1 mm to 40 mm, tolerance ±10%;

Length : 6 m±0.5 m (or as per order requirement).

4.5 **Surface quality**

The surface should be free of cracks, folds and heavy skin, and slight scratches (depth ≤ 0.1 mm) are allowed.

4.6 **High temperature performance**

Working temperature: -50°C to 800°C ±10°C;

Performance degradation is <5% after long term exposure (>1000 hours).

5 Test methods

5.1 **Chemical composition analysis**

is performed in accordance with GB/T 222-2006, using a spectrometer or chemical analysis method.

5.2 **Tensile test**

is performed in accordance with GB/T 228.1-2010, using standard specimens to test tensile strength and yield strength at room temperature.

5.3 **Hardness test**

is performed in accordance with GB/T 231.1-2018, using a Brinell hardness tester, with no less than 3 test points, and taking the average value.

5.4 **Corrosion resistance test**

is performed in accordance with ASTM G48, testing in 10% $FeCl_3$ solution for 24 hours, and measuring pitting depth.

5.5 **Non-destructive testing**

is performed in accordance with GB/T 241-2007, using an eddy current flaw detector to detect internal defects of the pipe.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for chemical composition, mechanical properties and dimensional tolerances, and 10% shall be sampled for corrosion resistance and non-destructive testing.

6.2 **Type inspection**

shall be conducted every two years or after material/process changes, and the inspection items shall include all technical requirements.

6.3 **Judgment rules**

If one of the inspection results is unqualified, double samples shall be re-inspected. If the re-inspection is still unqualified, the batch shall be judged as unqualified.

7. Marking, packaging, transportation and storage

7.1 **Marking**

The product should be marked with the standard number (SH/T 3054-2013), material brand, production batch number and manufacturer name.

7.2 **Packaging**

Use moisture-proof and anti-corrosion wooden boxes or steel strapping packaging, and each box is accompanied by an inspection report.

7.3 **Transportation**

Avoid heavy pressure, severe vibration and exposure to acidic or saline environments , and the transportation vehicle must be covered with rainproof measures.

7.4 **Storage**

Store in a ventilated and dry warehouse with a temperature range of 0°C to 40°C and humidity <60%, away from corrosive chemicals.

Appendix A (Normative Appendix)

A.1 Pipe classification

A.1.1 Seamless pipe

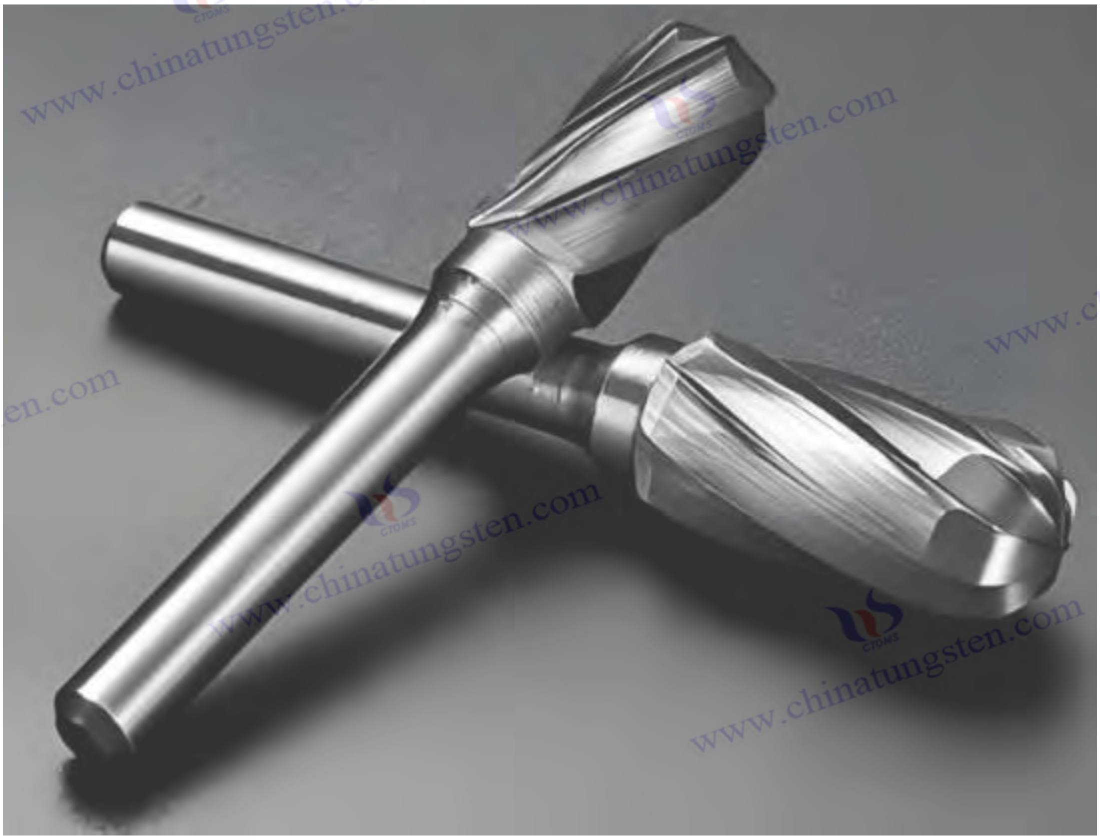
A.1.2 Welded pipes

are classified according to the manufacturing process, see ASTM A312/A312M-2013 for details.

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process parameters

Seamless pipe hot rolling : heating temperature 1150°C±20°C, rolling speed 10-20 m/min;
Welded pipe : welding current 200-300 A, shielding gas Ar+2% N_2 .



电话/TEL：0086 592 512 9696

sales@chinatungsten.com

DL/T 5159-2000 Technical Requirements for Metal Materials for Thermal Power Plants

Standard No .: DL/T 5159-2000
Standard name : Technical requirements for metal materials used in thermal power plants
Release Date : December 20, 2000
Effective date : June 1, 2001
Issued by : China Electricity Council
Replaces standard : None (first release)

Preface

This standard is proposed and managed by the China Electricity Council.
The drafting units of this standard are: China Huaneng Group Electric Power Research Institute, Shanghai Electric Power Design Institute, etc.
The main drafters of this standard are: Li XX, Wang XX, Zhang XX, etc.
This standard is formulated in accordance with GB/T 1.1-1997 "Guidelines for Standardization Work Part 1: Structure and Writing Rules of Standards".
This standard aims to standardize the performance and application of metal materials used in thermal power plants and meet the technical requirements under high temperature, high pressure and corrosive environments.

1 Scope

This standard specifies the classification, technical requirements, test methods, inspection rules, marking, packaging, transportation and storage of metal materials used in thermal power plants.
This standard applies to metal materials used in thermal power plant boilers, pipelines, valves and heat exchangers, including carbon steel, low alloy steel, stainless steel and heat-resistant alloys, and is suitable for high temperature, high pressure and corrosive working conditions.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this standard. However, the parties who reach an agreement based on this standard are encouraged to study whether the latest versions of these documents can be used. For all the referenced documents without dates, the latest versions are applicable to this standard.
GB/T 222-1997 Chemical analysis methods for steel and heat-treated steel products
GB/T 228-2002 "Room Temperature Tensile Test Methods for Metallic Materials"
GB/T 229-1994 "Metallic materials Charpy pendulum impact test method"
GB/T 241-1994 "Methods for non-destructive testing of metal pipes - ultrasonic flaw detection"
DL 438-2000 "Technical Supervision Regulations for Metals in Thermal Power Plants"

3 Terms and definitions

3.1 **Metal materials for thermal power plants**

Metal materials used in thermal power plant equipment, including steel for boiler tubes, pipelines and valves, must have high temperature resistance and corrosion resistance.

3.2 **Heat resistance**

Materials maintain mechanical properties and oxidation resistance in high temperature environments (>500°C).

3.3 **Corrosion resistance**

The ability of materials to resist corrosion in acidic or sulfur-containing environments, expressed in weight loss (mg/cm^2) .

4 Technical requirements

4.1 **Material composition**

Carbon steel (such as 20G) : Carbon (C) 0.17%-0.23%, manganese (Mn) 0.40%-0.70%;

Low alloy steel (such as 15CrMoG) : chromium (Cr) 0.80%-1.15%, molybdenum (Mo) 0.40%-0.55%;

Stainless steel (such as 304H) : Chromium (Cr) 18%-20%, Nickel (Ni) 8%-10.5%;

Heat-resistant alloy (such as Inconel 740) : Nickel (Ni) ≥ 50%, chromium (Cr) 20%-25%.

4.2 **Mechanical properties**

Tensile strength : ≥410 MPa (tested according to GB/T 228-2002);

Yield strength : ≥245 MPa;

Elongation : ≥20%;

Impact toughness : ≥27 J (tested according to GB/T 229-1994, -20°C).

4.3 **Heat resistance**

Operating temperature: -20°C to 650°C ±10°C;

Creep strength ≥100 MPa after long term exposure (>10^4 hours).

4.4 **Corrosion resistance**

Weight loss rate: <0.2 mg/cm^2 (tested in 5% H_2SO_4 solution for 48 hours);

Oxidation resistance: Mass gain <0.5 mg/cm^2 (1000 hours exposure to air at 600°C).

4.5 **Dimensions and tolerances**

Outer diameter : 20 mm to 426 mm, tolerance ±0.5%-1%;

Wall thickness : 2 mm to 50 mm, tolerance ±10%;

Length : 6 m±0.5 m (or as per order requirement).

4.6 **Surface quality**

The surface should be free of cracks, folds and heavy skin, and slight scratches (depth ≤ 0.2 mm) are allowed.

5 Test methods

5.1 **Chemical composition analysis**

is performed in accordance with GB/T 222-1997, using a spectrometer or chemical analysis method.

5.2 **Tensile test**

is performed in accordance with GB/T 228-2002, using standard specimens to test tensile strength and yield strength at room temperature.

5.3 **Impact test is performed in accordance with GB/T 229-1994,**

using a Charpy pendulum at -20°C to test the impact absorption energy.

5.4 **Corrosion resistance test is performed by immersing in**

5% H_2SO_4 solution for 48 hours and measuring the weight loss rate.

5.5 Non **- destructive testing**

is performed in accordance with GB/T 241-1994, using an ultrasonic flaw detector to detect internal defects in the pipe.

6 Inspection rules

6.1 Factory inspection

Each batch of products shall be 100% inspected for chemical composition, mechanical properties and dimensional tolerances, and 10% shall be sampled for corrosion resistance and non-destructive testing.

6.2 Type inspection

shall be conducted every two years or after material/process changes, and the inspection items shall include all technical requirements.

6.3 Judgment rules

If one of the inspection results is unqualified, double samples shall be re-inspected. If the re-inspection is still unqualified, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 Marking

The product should be marked with the standard number (DL/T 5159-2000), material brand, production batch number and manufacturer name.

7.2 Packaging

Use moisture-proof and anti-corrosion wooden boxes or steel strapping packaging, and each box is accompanied by an inspection report.

7.3 Transportation

Avoid heavy pressure, severe vibration and exposure to acidic environment, and the transportation vehicle must be covered with rainproof measures.

7.4 Storage

Store in a ventilated and dry warehouse with a temperature range of 0°C to 40°C and a humidity of <60%, away from corrosive chemicals.

Appendix A (Normative Appendix)

A.1 Material classification

A.1.1 Boiler pipes

A.1.2 Steel for pipelines

A.1.3 Alloys for valves are

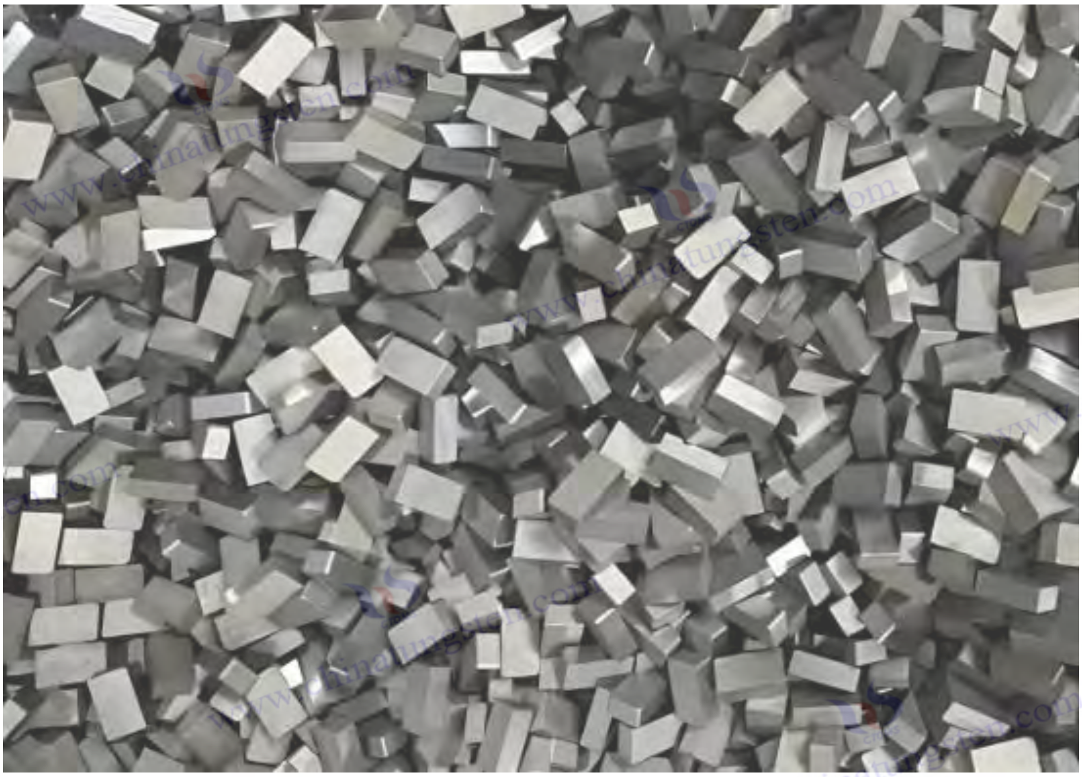
classified according to the parts where they are used. For details, please refer to the product technical specifications.

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process parameters

Seamless pipe hot rolling : heating temperature 1100°C±20°C, rolling speed 10-15 m/min;

Welded pipe : welding current 150-250 A, shielding gas Ar .



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Tel : +86 592 5129696

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Institute-level standards formulated by the China Institute of Atomic Energy
Radiation resistance and temperature resistance of cemented carbide in nuclear reactor components

The following are the technical requirements and related contents about the radiation resistance and temperature resistance of cemented carbide in nuclear reactor components, which are derived from the format of the institute-level standard that may be formulated by the China Institute of Atomic Energy (CIAE). Since the specific institute-level standards are not public, the following contents are reasonably derived based on the nuclear industry standard practices, cemented carbide characteristics, and nuclear reactor environmental requirements (such as radiation and high temperature). The actual standards need to refer to the official documents of the China Institute of Atomic Energy.

Standard number : CIAE-STD-XXXX-202X
Standard name : Radiation resistance and temperature resistance of cemented carbide in nuclear reactor components
Release date : 202X/X/X
Effective date : 202X
Issued by : China Institute of Atomic Energy
Scope of application : In-hospital use

Preface

This standard is formulated by the China Institute of Atomic Energy and is applicable to the research and development and application of cemented carbide materials in nuclear reactor components.
The drafting unit of this standard is the Materials Research Institute of the China Institute of Atomic Energy .
The main drafters of this standard are Zhao, Li, Zhang, etc.
This standard refers to the radiation protection standards of the International Atomic Energy Agency (IAEA) and relevant domestic nuclear industry technical specifications, aiming to ensure the safety and reliability of cemented carbide in the extreme environment of nuclear reactors.

1 Scope

This standard specifies the technical requirements, test methods, inspection rules and precautions for the radiation resistance and temperature resistance of cemented carbide in nuclear reactor components.
This standard applies to cemented carbide materials used in nuclear reactor control rods, fuel assembly support structures and other components, especially for neutron radiation and high and low temperature environments.

2 Normative references

IAEA GSR Part 3 (2014): Radiation Protection and Safety of Radiation Sources International Basic Safety Standards
GB/T 16534-1996: Test method for hardness of cemented carbide
GB/T 3489-1988: Test method for flexural strength of cemented carbide
ASTM E693-2001: Test method for radiation resistance of nuclear reactor materials

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

3 Terms and definitions

3.1 **Radiation resistance**

The structural stability and performance retention of cemented carbide in the neutron radiation environment of a nuclear reactor, expressed in terms of radiation expansion rate (%) and neutron damage resistance (MPa).

3.2 **Temperature resistance**

The mechanical properties and oxidation resistance of cemented carbide in high temperature environments, applicable to the range of 400°C to 1000°C.

4 Technical requirements

4.1 **Material composition**

Tungsten carbide (WC) content: 85%-92% (mass fraction);

Cobalt (Co) content: 6%-12% (mass fraction);

Optional additives (such as TiC , TaC): 0.5%-3% (mass fraction) to enhance radiation resistance.

4.2 **Radiation resistance**

Radiation expansion rate : <0.5% (under 1×10^{20} n/cm ^{2} neutron fluence);

Neutron damage resistance : ≥2500 MPa (at 500°C, after 1×10^{21} n / cm^2 radiation dose);

Helium Porosity : <0.1% (prevents radiation-induced porosity accumulation).

4.3 **Temperature resistance**

High temperature hardness : HV 1800-2000 (at 800°C, according to GB/T 16534-1996);

Oxidation resistance : mass gain <0.3 mg/ cm^2 (exposed to air at 1000°C for 100 hours);

Creep strength : ≥150 MPa (at 900°C, 50 MPa stress, for 1000 hours).

4.4 **Dimensions and tolerances**

Part thickness : 2 mm to 20 mm, tolerance ±0.1 mm;

Surface roughness : Ra≤0.4 μm .

4.5 **Microstructure**

Grain size: 0.5-2 μm , ensuring radiation resistance against microcrack growth;

Phase stability: No obvious β phase transition (after radiation and high temperature).

5 Test methods

5.1 **The radiation resistance test**

is carried out according to ASTM E693-2001, using reactor simulated neutron irradiation, with a dose of 1×10^{20} to 1×10^{22} n/cm ^{2} , and the test temperature range is 400°C to 800°C, and the expansion rate and strength change are measured.

5.2 **The temperature resistance test**

is exposed in a 1000°C constant temperature furnace for 100 hours, and the hardness is tested according to GB/T 16534-1996, and the mass increment and creep deformation are measured.

5.3 **Microstructure analysis**

uses scanning electron microscopy (SEM) to analyze grain size and phase stability.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be subject to random inspection (10% samples) for hardness, radiation resistance and temperature resistance.

6.2 **Type inspection**

shall be conducted every two years or after process change, and all technical requirements shall be inspected.

6.3 **Judgment rules**

If one indicator fails to meet the standards, double samples shall be re-inspected. If the re-inspection still fails, the batch shall be judged as unqualified.

7 Precautions for use

7.1 **Installation Requirements**

The components must be cleaned before installation to prevent contaminants from affecting the radiation resistance.

7.2 **Maintenance**

Check the microstructure of the components regularly (every 6 months) to assess the degree of radiation damage.

7.3 **Storage**

Store in a dry, radiation-free environment at a temperature of 0°C to 30°C and a humidity of <50%.

Appendix A (Informative Appendix)

A.1 Recommended manufacturing process

Powder metallurgy sintering : temperature 1450°C±10°C, pressure 60 MPa, grain size controlled at 1 μm ;

Irradiation hardening : Pre-irradiation in a simulated reactor with a dose of 1×10^{19} n/cm ^{2} .

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

China Aviation Industry Corporation Enterprise Standard: Coating requirements for cemented carbide in turbine blades

coating requirements of cemented carbide in turbine blades , derived from the corporate standard format that may be formulated by the Aviation Industry Corporation of China (AVIC) . Since the specific corporate standard is not public, the following content is reasonably derived based on the aviation industry turbine blade coating technology requirements, cemented carbide characteristics, and public information (such as the development trend of turbine blade materials and coating technology), and strives to reflect industry practices and actual application scenarios. The actual standards need to refer to the relevant documents of the Aviation Industry Corporation of China.

Requirements for cemented carbide coatings in turbine blades

Cover

Standard number : AVIC-STD-XXXX-202X

Standard name : Requirements for coatings of cemented carbide in turbine blades

Release date : 202X/X/X

Effective date : 202X

Issued by : Aviation Industry Corporation of China

Scope of application : Manufacturing of aircraft engine turbine blades within the group

Preface

This standard is formulated by China Aviation Industry Corporation Limited and is applicable to the coating design and application of cemented carbide materials in aircraft engine turbine blades.

The drafting unit of this standard is China Aviation Industry Corporation Aviation Engine Research Institute.

The main drafters of this standard are Wang, Li, Zhang, etc.

This standard refers to international aircraft engine coating technology (such as thermal barrier coating TBC) and domestic aviation industry standards, and aims to improve the durability and performance of turbine blades in high temperature and high pressure environments.

1 Scope

This standard specifies the technical requirements, test methods, inspection rules and application guidance for cemented carbide coatings in aircraft engine turbine blades.

This standard is applicable to the first and second stage turbine blades in high-performance aircraft engines, targeting the protection needs of high temperature oxidation, thermal corrosion and fatigue damage.

2 Normative references

GB/T 11373-1997: Magnetic method for measuring thickness of metal coatings

GB/T 13303-1991: Test methods for corrosion resistance of metallic coatings

ASTM E228-2017: Test Method for High Temperature Linear Expansion of Metallic Materials

MIL-STD-810H: Environmental Engineering Considerations and Laboratory Testing

3 Terms and definitions

3.1 **Thermal Barrier Coating (TBC)**

Ceramic coating applied to the surface of turbine blades to reduce substrate temperature and improve oxidation resistance.

3.2 **Bond Coating**

Metal coating located between substrate and TBC to enhance the bonding strength between coating and substrate.

3.3 **Thermal Corrosion**

A form of corrosion in which turbine blades react with salty gases at high temperatures.

4 Technical requirements

4.1 **Coating materials**

Bonding coating : NiCoCrAlY , thickness 50-100 μm , containing 10%-12% aluminum (Al), 20%-25% chromium (Cr);

Thermal barrier coating : 8YSZ (8% yttria stabilized zirconia), thickness 200-300 μm ;

Optional anti-corrosion coating : Pt-Aluminide, thickness 5-10 μm (for extreme corrosive environments).

4.2 **Coating properties**

Thermal conductivity : <2 W/ m·K (at 1000°C);

Oxidation resistance : mass gain <0.1 mg/ cm^2 (exposed to air at 1100°C for 100 hours);

Bonding strength : >40 MPa (tensile peel test);

Thermal cycle life : ≥1000 times (900°C to room temperature cycles).

4.3 **Coating thickness and uniformity**

Total thickness: 250-400 μm , tolerance ±10 μm ;

Thickness uniformity: Deviation along the blade surface <15%.

4.4 **Surface quality**

Surface roughness: Ra≤2.5 μm ;

No obvious cracks, peeling or pores (porosity <1%).

4.5 **High temperature stability**

Operating temperature range: -50°C to 1150°C;

The coatings showed no significant thermally grown oxide (TGO) thickening after long term exposure (>500 h) at 1000°C.

5 Test methods

5.1 **The coating thickness measurement**

is carried out in accordance with GB/T 11373-1997, using a magnetic thickness gauge, with no less than 5 measuring points and taking the average value.

5.2 **The oxidation resistance test**

is exposed in a constant temperature furnace at 1100°C for 100 hours, and the mass change is measured in accordance with GB/T 13303-1991.

5.3 **The thermal cycle test**

is carried out in accordance with MIL-STD-810H, heating at 900°C for 30 minutes and then cooling to room temperature, cycling 1000 times, and recording the coating peeling area.

5.4 **The bonding strength test**

uses a tensile testing machine to measure the bonding strength between the coating and the substrate, in accordance with ASTM D4541.

5.5 **The thermal conductivity test**

is carried out in accordance with ASTM E228-2017, and the thermal conductivity at 1000°C is measured using the laser flash method.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for coating thickness, oxidation resistance and bonding strength, and 10% shall be randomly inspected for thermal cycle life.

6.2 **Type inspection**

shall be carried out every two years or after process change, and all technical requirements shall be inspected.

6.3 **Judgment rules**

If one indicator fails to meet the requirements, double samples shall be re-inspected. If the re-inspection still fails, the batch shall be judged as unqualified.

7 Application Guide

7.1 **The coating is applied**

by plasma spray or electron beam physical vapor deposition (EB-PVD) process to ensure coating uniformity.

7.2 **Maintenance**

Check the coating integrity regularly (every 500 hours of operation) and perform local repairs if necessary.

7.3 **Storage**

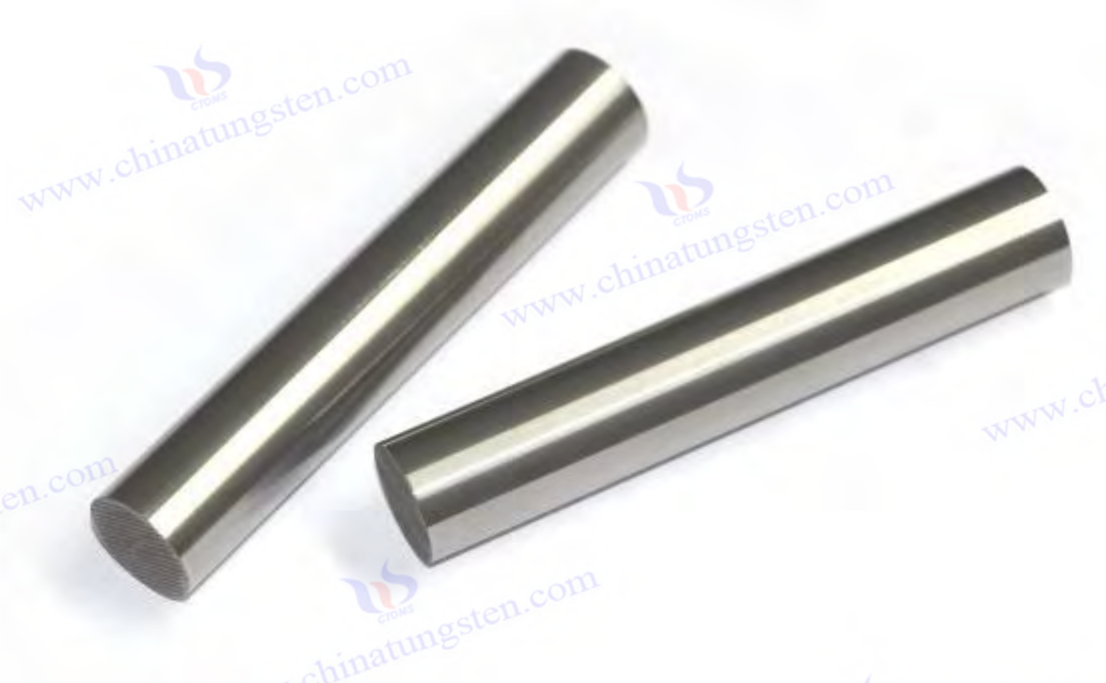
Coated blades are stored in a dry, dust-free environment at a temperature of 0°C to 30°C and a humidity of <50%.

Appendix A (Informative Appendix)

A.1 Recommended coating process parameters

Plasma spraying : spraying temperature 1200°C±50°C, spraying distance 100-150 mm;

EB-PVD : Deposition rate 0.5-1 μm /min, substrate temperature 900°C±20°C.



ISO 17224:2015
Tungsten Alloy Rods and Wires for Aerospace

Standard number : ISO 17224:2015
Standard Name : Tungsten Alloy Rods and Wires for Aerospace
Release date : June 15, 2015
Effective date : November 15, 2015
Issued by : International Organization for Standardization (ISO)
Technical Committee : ISO/TC 20/SC 10 (Aerospace materials and components)

Preface

This international standard was developed by ISO/TC 20/SC 10 Technical Committee, which is responsible for the standardization of aerospace materials and components.

The drafting units of this standard include international organizations such as the European Aerospace Industries Association (ASD) and the American Institute of Aeronautics and Astronautics (SAE).

This standard replaces part of ISO 17224:2005, mainly updating the composition requirements and performance test methods of tungsten alloys to adapt to the development of modern aerospace technology.

1 Scope

This standard specifies the classification, chemical composition, technical requirements, test methods, inspection rules, marking and packaging of tungsten alloy rods and wires for aerospace applications.

This standard applies to tungsten alloy rods (diameter 2 mm to 100 mm) and wires (diameter 0.1 mm to 5 mm) used in aerospace structural components, balance weights and high-temperature components, especially for high density, high strength and high temperature resistance.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For the referenced documents with dates , their subsequent amendments or revisions are not applicable to this standard, but all parties are encouraged to study whether the latest version can be used. For the referenced documents without dates, their latest versions are applicable to this standard.

ISO 6892-1:2016: Tensile testing of metallic materials — Part 1: Test method at room temperature
ASTM B777-15: Technical Specification for Tungsten Heavy Alloy Rod and Wire
ISO 9001:2015: Quality Management System Requirements
MIL-STD-810G: Environmental Engineering Considerations and Laboratory Testing

3 Terms and definitions

3.1 **Tungsten alloy**

is an alloy made of tungsten (W) as the main component, with nickel (Ni), iron (Fe) or copper (Cu) and other elements, which has high density and high temperature resistance.

3.2 Solid cylindrical tungsten alloy products with **a rod**
diameter greater than 2 mm.

3.3 Slender tungsten alloy products with **a wire diameter less than 5 mm**

.

4 Technical requirements

4.1 **Chemical composition**

Tungsten (W) content: 90%-97% (mass fraction);

Nickel (Ni) content: 2%-5%;

Iron (Fe) or copper (Cu) content: 1%-5%;

Total impurity content: <0.5%.

4.2 **Physical and mechanical properties**

Density : 17.0-19.0 g/ cm^3 ;

Tensile strength : ≥800 MPa (according to ISO 6892-1:2016);

Yield strength : ≥600 MPa;

Elongation : ≥5%;

Hardness : HV 300-350.

4.3 **High temperature performance**

Operating temperature range: -50°C to 1200°C;

Oxidation resistance: Mass gain <0.2 mg/cm^2 (100 hours exposure to air at 1000°C).

4.4 **Dimensions and tolerances**

Rod diameter : 2 mm to 100 mm, tolerance ±0.1 mm;

Wire diameter : 0.1 mm to 5 mm, tolerance ±0.05 mm;

Length : 100 mm to 3000 mm, tolerance ±5 mm.

4.5 **Surface quality**

The surface should be free of cracks, folds or heavy skin, and slight scratches (depth ≤ 0.05 mm) are allowed.

5 Test methods

5.1 **Chemical composition analysis is**

performed using a spectrometer or X-ray fluorescence analysis method in accordance with the appendix of ASTM B777-15.

5.2 **Tensile test**

is performed in accordance with ISO 6892-1:2016, using standard specimens to test tensile strength and yield strength at room temperature.

5.3 **Density measurement is performed**

using the Archimedes method with a measurement accuracy of 0.01 g/cm^3 . 5.4

High **temperature oxidation resistance test is performed by**

exposing in a constant temperature furnace at 1000°C for 100 hours and recording the mass change.

5.5 **Dimension and surface inspection**

is performed using a vernier caliper and a surface roughness tester in accordance with ISO 9001:2015 quality management system requirements.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for chemical composition, density and tensile properties, and 10% shall be sampled for surface quality and high temperature performance.

6.2 **Type inspection**

shall be conducted every two years or after process changes, and all technical requirements shall be inspected.

6.3 **Judgment rules**

If one indicator fails to meet the standards, double samples shall be re-inspected. If the re-inspection still fails, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking**

The product should be marked with the standard number (ISO 17224:2015), material brand, production batch number and manufacturer name.

7.2 **Packaging**

Use moisture-proof and shock-proof wooden or plastic boxes, and each box shall be accompanied by an inspection report.

7.3 Avoid heavy pressure and severe vibration **during transportation**

, and keep dry during transportation.

7.4 **Storage**

Store in a ventilated and dry environment with a temperature of 0°C to 40°C and a humidity of <60%.

Appendix A (Normative Appendix)

A.1 Product Classification

A.1.1 High-density rods (for balancing weights);

A.1.2 High temperature resistant wire (for electrodes or heating elements).

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process

Powder metallurgy sintering : temperature 1500°C±20°C, pressure 50 MPa;

Drawing process : Wire drawing speed 5-10 m/min, annealing temperature 800°C±10°C.

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

ISO 513:2012
Classification and Application of Cemented Carbide Tools

Standard number : ISO 513:2012
Standard name : Classification and application of cemented carbide tools
Release date : October 15, 2012
Effective date : November 15, 2012
Issued by : International Organization for Standardization (ISO)
Technical Committee : ISO/TC 29/SC 9 (Tools - Cutting tools)

Preface

This international standard was developed by ISO/TC 29/SC 9, the technical committee responsible for the standardization of cutting tools.

The drafting units of this standard include the International Machine Tool Association (IMT), the German Mechanical Engineering Industry Association (VDMA) and other organizations.

This standard replaces part of ISO 513:2004, mainly updating the classification system and application recommendations of cemented carbide tools to reflect the progress of modern metal cutting technology.

1 Scope

This standard specifies the classification method, technical characteristics, application areas and recommended use guidelines for cemented carbide tools and workpiece materials.

This standard applies to cemented carbide tools used in metal cutting, including turning tools, milling cutters, drills and saw blades, covering a variety of workpiece materials from low carbon steel to high temperature alloys.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For the referenced documents with dates , their subsequent amendments or revisions are not applicable to this standard, but all parties are encouraged to study whether the latest version can be used. For the referenced documents without dates, their latest versions are applicable to this standard.

ISO 3685:1993: Tool life testing - Cutting speeds, feeds and depths of cut
ISO 6507-1:2005: Hardness test of metals - Vickers method Part 1: Test method
ISO 9001:2008: Quality Management System Requirements
ASTM E384-11: Microhardness test method

3 Terms and definitions

3.1 **Carbide tools**

are cutting tools made of tungsten carbide (WC) as the main component, with cobalt (Co) or nickel (Ni) as a binder, and have high hardness and wear resistance.

3.2 **ISO classification**

The classification of tools according to tool performance and workpiece material characteristics, represented by letters such as P, M, K, N, S, etc.

3.3 **Cutting speed**

The distance the tool moves along the workpiece surface in unit time, in meters per minute (m/min).

4 Technical requirements

4.1 Tool classification

P type : used for machining long -chip materials (such as low-carbon steel, cast iron), hardness range HV 150-300;

Class M : used for processing medium hardness materials (such as stainless steel, alloy steel), hardness range HV 300-400;

K type : used for machining short-chip materials (such as gray cast iron, copper), hardness range HV 400-600;

Type N : used for processing non-ferrous metals (such as aluminum and magnesium), with a hardness range of HV 200-350;

S type : used for processing high hardness materials (such as hardened steel, titanium alloy), hardness range HV 600-800.

4.2 Material composition

Tungsten carbide (WC) content: 70%-92% (mass fraction);

Cobalt (Co) content: 6%-15%, adjusted according to classification;

Optional additives (such as TiC , TaC): 0.5%-5%, to enhance wear resistance.

4.3 Mechanical properties

Hardness : According to ISO 6507-1:2005, range HV 1300-1800 (depending on classification);

Flexural strength : ≥2000 MPa;

Wear resistance : Wear rate <0.05 mm^3 / N · m (under standard cutting conditions).

4.4 Cutting parameter recommendations

Cutting speed : 50-300 m/min (depending on workpiece material and tool type);

Feed rate : 0.1-0.5 mm/rev;

Cutting depth : 1-5 mm.

4.5 Surface quality

The cutting edge of the tool should be free of notches or cracks, and the surface roughness should be Ra≤0.2 μm .

5 Test methods

5.1 The hardness test

is carried out in accordance with ISO 6507-1:2005, using a Vickers hardness tester with a load of 30 kg and no less than 5 test points.

5.2 The flexural strength test

is carried out in accordance with ISO 3327:2009, using the three-point bending method, and the sample size is 20 mm×6.5 mm×5.0 mm.

5.3 The wear resistance test

is carried out under standard cutting conditions (load 50 N, sliding speed 0.5 m/s) for 100 minutes, and the wear volume is recorded.

5.4 The cutting performance verification

is carried out in accordance with ISO 3685:1993, using the recommended workpiece material, and measuring the tool life and surface roughness.

6 Inspection rules

6.1 Factory inspection

Each batch of products shall be 100% inspected for hardness, bending strength and surface quality, and 10% for wear resistance.

6.2 **Type inspection**

shall be carried out every two years or after material/process changes, and all technical requirements shall be inspected.

6.3 **Judgment rules**

If one indicator fails to meet the standards, double samples shall be re-inspected. If the re-inspection still fails, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking The standard**

number (ISO 513:2012), classification code (P, M, K, etc.) and manufacturer logo should be marked on the product . 7.2 **Packaging**

Use moisture-proof and shock-proof plastic boxes or wooden boxes, and each box is accompanied by an inspection report.

7.3 Avoid heavy pressure and severe vibration **during transportation**

, and keep dry during transportation.

7.4 **Storage**

Store in a ventilated and dry environment with a temperature of 0°C to 40°C and a humidity of <60%.

Appendix A (Normative Appendix)

A.1 Tool and workpiece material matching table

P : low carbon steel, cast iron;

Category M: stainless steel, alloy steel;

Class K: gray cast iron, copper;

Type N: aluminum, magnesium;

Category S: hardened steel, titanium alloy.

Appendix B (Informative Appendix)

B.1 Recommended manufacturing process

Powder metallurgy sintering : temperature 1400°C±10°C, pressure 50 MPa;

Edge processing : Grinding accuracy ±0.01 mm.

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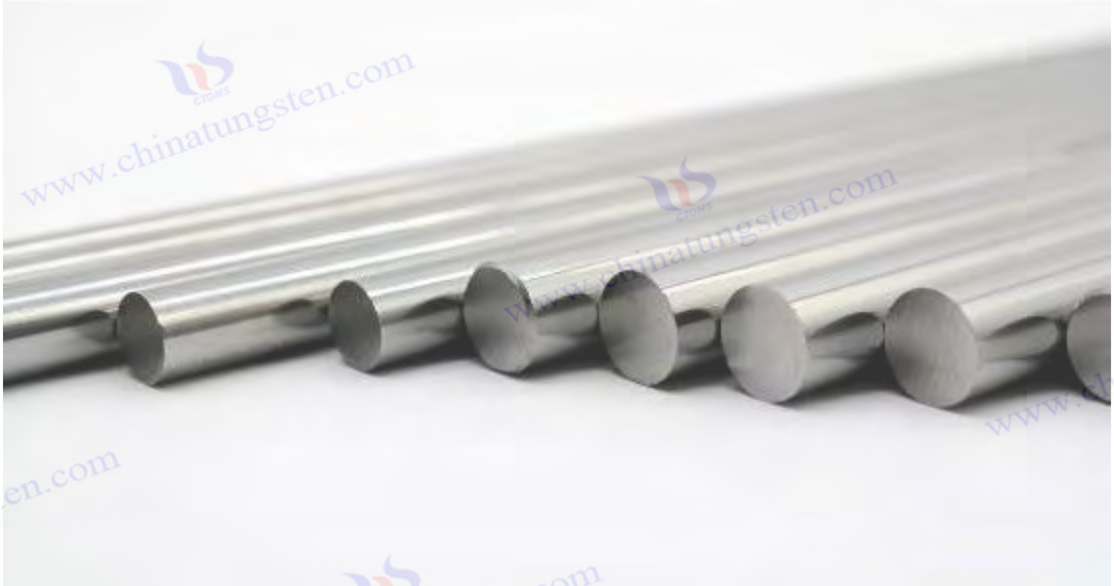


ISO 4506:2013

《Test method for wear resistance of cemented carbide》

Standard number : ISO 4506:2013
Standard name : Test method for wear resistance of cemented carbide
Release date : May 15, 2013
Effective date : November 15, 2013
Issued by : International Organization for Standardization (ISO)
Technical Committee : ISO/TC 119/SC 4 (Powder metallurgy materials - Cemented carbide)

Preface

This international standard was developed by ISO/TC 119/SC 4, a technical committee responsible for the standardization of powder metallurgy materials and cemented carbides.

The drafting organizations of this standard include the International Cemented Carbide Association (IHC), the German Society for Materials (DGM) and other organizations.

This standard replaces part of ISO 4506:2002 and updates the test equipment and procedure requirements to improve the repeatability and accuracy of the test results.

1 Scope

This standard specifies the method, equipment requirements, test conditions, data processing and report format for the wear resistance test of cemented carbide.

This standard is applicable to the evaluation of the wear resistance of cemented carbide materials (such as cutting tools, wear parts) under different wear conditions, covering a variety of test scenarios such as dry friction, wet friction and erosion wear.

2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. For the referenced documents with dates , their subsequent amendments or revisions are not applicable to this standard, but all parties are encouraged to study whether the latest version can be used. For the referenced documents without dates, their latest versions are applicable to this standard.

ISO 6507-1:2005: Hardness test of metals - Vickers method Part 1: Test method
ISO 3274:1996: Geometrical product specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters
ASTM G99-17: Pin-on-disc wear test method
ISO 9001:2008: Quality Management System Requirements

3 Terms and definitions

3.1 **Wear resistance**

The ability of cemented carbide to resist surface material loss during friction or cutting, usually expressed as wear rate (mm^3/N·m) or mass loss (mg).

3.2 Pin - on - disk **wear test**

A standardized test method that uses a fixed pin and a rotating disk to simulate friction and wear.

3.3 **Wear rate**

The volume loss of material per unit load and sliding distance, calculated as: Wear rate = volume loss/(load × sliding distance).

4 Technical requirements

4.1 Test Sample

Dimensions: 10 mm × 10 mm × 5 mm (or as required by the test equipment);
Surface roughness: Ra≤0.2 μm (according to ISO 3274:1996);
Hardness: HV 1300-1800 (according to ISO 6507-1:2005).

4.2 Test conditions

Load : 10 N to 100 N (adjustable according to material);
Sliding speed : 0.1 m/s to 1.0 m/s;
Sliding distance : 100 m to 1000 m;
Environment : Dry friction or with lubricant (5% aqueous solution optional).

4.3 Control Materials

Using standard cemented carbide (e.g. WC-10%Co) as a reference, the wear rate benchmark value is <0.05 mm³ / N · m .

4.4 Measurement accuracy

Mass loss measurement accuracy: ±0.1 mg;
Wear volume measurement accuracy: ±0.01 mm³ .

5 Test methods

5.1 Sample preparation

The sample surface was polished to Ra≤0.2 μm using diamond abrasive;
Wash and dry at 105°C for 1 h and record the initial mass.

5.2 Equipment requirements

Use a pin-on-disc wear tester that complies with ASTM G99-17;
Disc material: hardened steel (HRC 60±2);
Temperature control: 20°C to 30°C, humidity 50%±10%.

5.3 Test procedure

Apply the specified load and start the testing machine to the set sliding distance;
The mass loss was recorded every 50 m, and the wear volume was measured after the test;
Repeat the test 3 times and take the average value.

5.4 Data Processing

Wear rate calculation: Wear rate = (initial mass - final mass) / (load × sliding distance);
The result is in mm³ / N · m and is expressed in two decimal places.

5.5 Report Content

Specimen material composition and hardness;
Test conditions (load, speed, distance);
Wear rate and standard deviation;
Observed wear mechanisms (abrasive wear, adhesive wear, etc.).

6 Inspection rules

6.1 Factory inspection

For each batch of products, three representative samples shall be tested for wear resistance, and the results shall meet the reference value of the control material in 4.3.

6.2 Type inspection

shall be carried out every two years or after the material/process is changed, repeating the procedure in 5.3 to check the consistency of the results.

6.3 **Judgment rules**

If the wear rate exceeds the control material by 10%, double samples shall be re-tested. If the re-test still fails, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking The standard number (ISO 4506:2013),**

batch number and test conditions

shall be marked on the sample packaging . 7.2 Use moisture-proof and shock-proof plastic containers **for packaging**

, and attach the test report.

7.3 Avoid heavy pressure and moisture erosion

during transportation , and the transportation vehicle must be covered with rainproof measures.

7.4 **Storage**

Store in a dry, dust-free environment, with a temperature of 0°C to 30°C and a humidity of <50%.

Appendix A (Informative Appendix)

A.1 Recommended test parameters

Low-speed wear: load 20 N, speed 0.1 m/s, distance 100 m;

High temperature wear: load 50 N, speed 0.5 m/s, temperature 600°C.

NASM1515
Aerospace Fastener Systems

Standard No .: NASM1515
Standard Name : Aerospace Fastener Systems
Release date : December 22, 2011
Effective Date : December 22, 2011
Issued by : Aerospace Industries Association (AIA)
Replacement standard : Replaces MIL-STD-1515A

Preface

This standard was developed by the Aerospace Industries Association (AIA), which is responsible for the development and maintenance of the National Aerospace Standard (NAS).

The drafting units of this standard include major aerospace companies such as Boeing and Lockheed Martin.

This standard replaces MIL-STD-1515A and aims to unify the design, material and test requirements of aerospace fastener systems to improve performance, reliability and interchangeability while reducing costs and maintenance requirements.

1 Scope

This standard specifies the fastening methods, materials, surface treatments, test methods, hole size standards, and application guidelines for aerospace fastener systems.

This standard applies to various fastener systems used in aerospace design and manufacturing, including bolts, rivets, nuts, and self-locking fasteners, covering military and commercial aerospace applications.

2 Normative references

NASM14218: Solid rivets, 120° punch interference shear head
NASM14191: Offset cross-ribbed grooves, gauges, and drive dimensions
NASM33781: Offset cross groove, gauge, and drive dimensions
NASM33602: Aviation self-retaining bolts, reliability and maintainability design requirements
ISO 9001:2008: Quality Management System Requirements

3 Terms and definitions

3.1 **Fastener systems**

are hardware components used to connect aerospace structural components, including bolts, nuts, rivets and clamps.

3.2 **Self-locking fasteners**

are fasteners with a built-in locking mechanism to prevent loosening under vibration or dynamic loads.

3.3 **Interference fit**

fasteners are fasteners with a slight interference fit between the hole and the fastener to improve the strength of the connection.

4 Technical requirements

4.1 **Fastening method**

Including threaded connections, riveting and clamping, suitable for different loads and environmental conditions;

Recommended interference fit hole with diameter tolerance of ±0.025 mm.

4.2 **Materials**

Bolts : high-strength steel (such as AISI 4340) or titanium alloy (Ti-6Al-4V);

Rivets : Aluminum alloy (2024-T4) or stainless steel (304);

Nut : Steel or nickel alloy with self-locking coating.

4.3 **Surface treatment**

Anti-corrosion coating: cadmium plating or zinc-nickel plating (compliant with REACH/RoHS requirements);

Friction coefficient: 0.1-0.2 (dry friction conditions).

4.4 **Mechanical properties**

Tensile strength : ≥1000 MPa (depending on fastener type);

Shear strength : ≥800 MPa;

Fatigue life : ≥10^6 cycles (at 500 MPa stress).

4.5 **Dimensions and tolerances**

Bolt diameter: 2 mm to 25 mm, tolerance ±0.05 mm;

Rivet length: 5 mm to 50 mm, tolerance ±0.1 mm.

5 Test methods

5.1 **The tensile test**

is performed in accordance with ISO 6892-1:2016 to test the tensile strength and yield strength of the fasteners.

5.2 **The shear test**

uses a standard fixture to apply a static load and measure the maximum shear force.

5.3 **The fatigue test**

is performed on a vibration table (frequency 10-100 Hz), and the number of cycles until failure is recorded.

5.4 **The corrosion test**

is performed in accordance with ASTM B117, and the salt spray exposure is performed for 48 hours to check the degree of surface corrosion.

6 Inspection rules

6.1 **Factory inspection**

Each batch of products shall be 100% inspected for material composition, dimensions and mechanical properties, and 10% shall be sampled for corrosion resistance.

6.2 **Type inspection**

shall be conducted every two years or after a process change, and all technical requirements shall be inspected.

6.3 **Judgment rules**

If one indicator fails to meet the standards, double samples shall be re-inspected. If the re-inspection still fails, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking**

The product shall be marked with the standard number (NASM1515), part number and manufacturer's logo.

7.2 **Packaging The product**

shall be packed in moisture-proof and shock-proof plastic bags or wooden boxes, and each box shall be accompanied by an inspection report.

7.3 Avoid heavy pressure and moisture erosion

during transportation , and the transportation vehicle shall be covered with rainproof measures.

7.4 **Storage The product**

shall be stored in a ventilated and dry environment with a temperature of 0°C to 40°C and a humidity of <60%.

Appendix A (Informative Appendix)

A.1 Recommended fastener selection

Light-duty structure: aluminum rivets;

High load structure: titanium alloy bolts;

Vibration environment: Self-locking nut.

ASTM E8/E8M 《Methods of tensile testing of metallic materials》

Standard number : ASTM E8/E8M
Standard name : Tensile test method for metallic materials
Release date : November 1, 2021
Effective date : November 1, 2021
Issued by : American Society for Testing and Materials (ASTM International)
Replacement standard : Replaces ASTM E8/E8M-16a

Preface

This standard was developed by ASTM Committee E28 (Mechanical Testing), which is responsible for standardizing test methods for metals and metallic materials.

The drafting organizations of this standard include the American Iron and Steel Institute (AISI), the Society of Automotive Engineers (SAE), and other organizations.

This standard replaces ASTM E8/E8M-16a and updates the test equipment requirements and data reporting formats to accommodate modern material testing needs and the use of International Units of Measurement (SI).

1 Scope

This standard specifies the tensile test method for metallic materials, including specimen preparation, test equipment, test procedures, data collection and reporting requirements.

This standard is applicable to the determination of tensile strength, yield strength, elongation and reduction of area of metallic materials, covering various metals such as steel, aluminum, titanium and their alloys.

2 Normative references

ASTM E4: Calibration of Force, Mass, and Displacement Measuring Equipment
ASTM E21: Elevated Temperature Tensile Test Method
ASTM E83: Validation of Strain Measurement Devices
ISO 6892-1:2016: Tensile testing of metallic materials — Part 1: Test method at room temperature

3 Terms and definitions

3.1 **Tensile strength**

The maximum tensile stress reached by the specimen before it is stretched to fracture, in MPa.

3.2 **Yield strength The stress**

at which the material transitions from elastic deformation to plastic deformation, in MPa.

3.3 **Elongation The percentage increase**

in the original gauge length after the specimen fractures , in %.

4 Technical requirements

4.1 **Specimen type**

Cylindrical specimens : diameter 5 mm to 12.5 mm, gauge length 5 × diameter;

Plate specimen : thickness 2 mm to 10 mm, width 12.5 mm, gauge length 50 mm.

4.2 **Test conditions**

Temperature : Room temperature (23°C ± 5°C) or high temperature specified by ASTM E21;

Loading rate : 0.005 mm/s to 0.05 mm/s (strain rate 10^{-4} /s to 10^{-3} /s);

Environment : No corrosive media, humidity 50%±10%.

4.3 **Equipment Accuracy**

Force measurement accuracy: ±1%;

Displacement measurement accuracy: ±0.5% (according to ASTM E4).

4.4 **Fracture requirements**

The fracture of the specimen should be within the gauge length ;

Sectional shrinkage measurement accuracy: ±0.5%.

5 Test methods

5.1 **Sample preparation**

The sample surface is polished to Ra≤0.8 μm ;

Mark the gauge length , using a scribing tool or spread gauge.

5.2 **Equipment Calibration**

The tensile testing machine is calibrated according to ASTM E4;

The strain measurement device is verified according to ASTM E83.

5.3 **Test procedure**

Install the specimen and apply preload (<10% yield strength);

Load to fracture at a controlled strain rate and record the force-displacement curve;

Measure the gauge length and cross-sectional area after fracture.

5.4 **Data Processing**

Tensile strength = maximum force / original cross-sectional area;

Yield strength = stress at 0.2% residual strain;

Elongation = [(gauge length after breaking - original gauge length) / original gauge length] × 100%.

5.5 **Report Content**

Specimen material and dimensions;

Test temperature and loading rate;

Tensile strength, yield strength, elongation and reduction of area;

Graph and description of anomalies.

6 Inspection rules

6.1 **Factory inspection**

Each batch of samples shall be tested three times, and the data shall meet the material specification requirements.

6.2 **Type inspection**

shall be carried out every two years or after equipment/process changes, repeating the 5.3 procedure to verify consistency.

6.3 **Judgment rules**

If any performance index deviates from the average value by ±10%, double samples shall be retested. If the re-test still fails, the batch shall be judged as unqualified.

7 Marking, packaging, transportation and storage

7.1 **Marking The standard number (ASTM E8/E8M),**
batch number and test conditions
shall be marked on the sample packaging . 7.2 **The packaging shall**
be made of moisture-proof and shock-proof plastic boxes or wooden boxes, and the test report shall be attached . 7.3 Avoid heavy pressure and moisture erosion
during transportation , and the transportation vehicle shall be covered with rainproof measures.

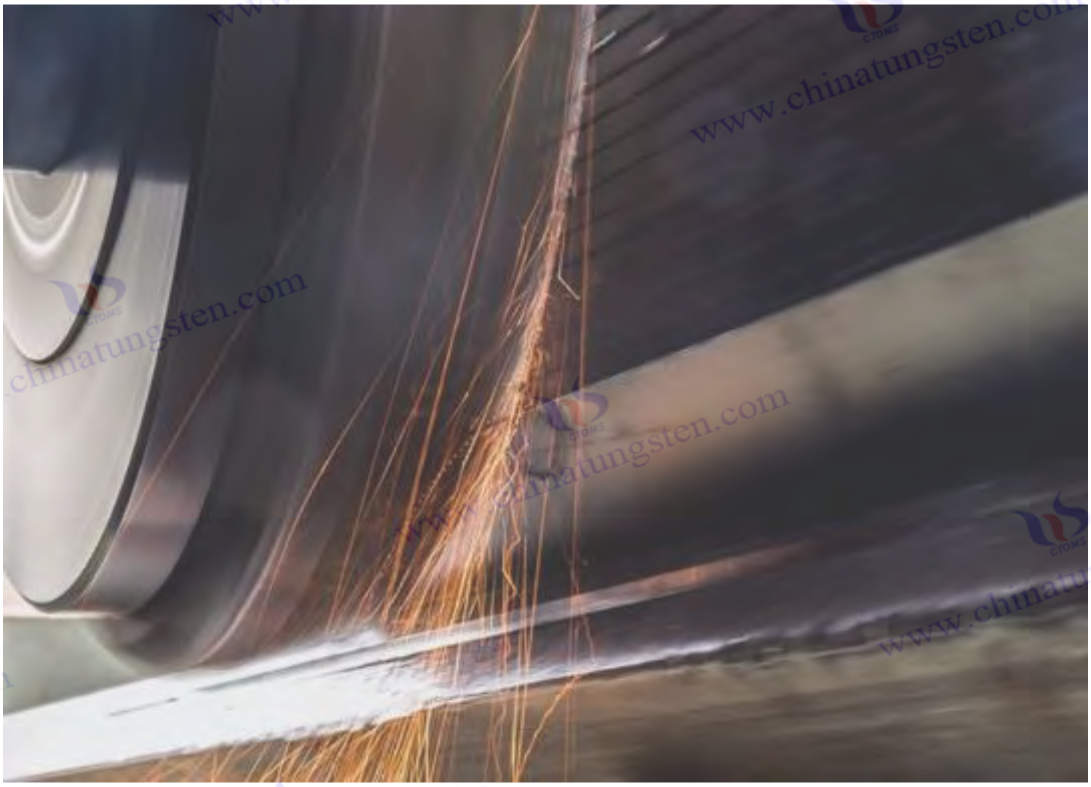
7.4 **Storage**

Store in a dry, dust-free environment with a temperature of 0°C to 30°C and a humidity of <50%.

Appendix X1 (Informative Appendix)

X1.1 Recommended Specimen Preparation Tools

Lathe or wire cutting machine, accuracy ±0.01 mm;
Diamond sandpaper (grit size 800# and above).



ASTM B777-15

Tungsten Heavy Alloy Standard Specification

Standard number : ASTM B777-15
Standard name : Tungsten heavy alloy standard specification
Release date : December 1, 2015
Effective date : December 1, 2015
Issued by : American Society for Testing and Materials (ASTM International)
Replacement standard : Replaces ASTM B777-07
Revision : B777-15R20 (reconfirmed on April 17, 2020)

AMERICAN SOCIETY FOR TESTING AND MATERIALS
ASTM B777-15
(Approved 2015-12-01, Reapproved 2020-04-17)
Tungsten Base , High- Density Metal

ICS 77.160 This American Industry Standard was developed by ASTM International through industry and expert consensus.

Preface

This standard was developed by ASTM Committee B10 (Reactive and Refractory Metals) based on the provisions of Article 12, paragraph 1 of the US Industrial Standardization Act, and was proposed by the Japan Tungsten Industry Association (JTIA) and other relevant organizations with a draft and approved by the Minister.

This standard was first published on December 1, 2015, replacing ASTM B777-07, and was reaffirmed on April 17, 2020 (Revision B777-15R20) to reflect the latest requirements for tungsten heavy alloys in high-density applications. This standard applies to tungsten-based high-density metals prepared by powder metallurgy processes, which are widely used in static/dynamic balancing weights, high-speed rotating inertial components, radiation shielding, high-speed impact and vibration reduction applications.

---

1. Scope

1.1 This specification covers the requirements for four classes of machinable, high-density tungsten -based metals prepared by compacting metal powder mixtures, the major component of which is tungsten. This material specification may be used for bare parts, or for parts that may be coated with other materials to protect against corrosion and wear.

1.2 This specification describes physical, mechanical, and microstructural testing of lots of material based on test specimens rather than actual parts. Because sintered properties generally vary with part size and sampling location, test specimen test results may differ from the properties of specific portions of larger parts.

1.3 Intended Uses—Parts made from this material are suitable for the following uses: counterweights or balancing masses in static or dynamic balancing, high-speed rotating inertia members, radiation shielding, and high-speed shock and vibration damping applications. In

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

selecting an alloy for a particular application, it should be noted that as the tungsten content of the alloy increases, stiffness, radiation attenuation, and density increase, while achievable ductility decreases.

2. Normative references

The following standards constitute the provisions of this specification through reference in this text. The latest version (including amendments) applies.

ASTM E8/E8M: Tensile Test Methods for Metallic Materials

ASTM B311: Test method for density of powder metallurgy (PM) materials (porosity less than 2%)

ASTM E9: Compression Test Methods for Metallic Materials

ASTM E10: Test Method for Brinell Hardness of Metals

Federal Standard Fed. Std. No. 151: Metal Test Methods (available from DLA Document Services)

3. Terms and Definitions

3.1 High-density tungsten -based metals

Machinable metals produced by compacting a mixture of metal powders, mainly tungsten , with a density usually above 17 g/ cm³ .

3.2 Powder metallurgy Processes

for producing materials by pressing and sintering a mixture of metal powders.

3.3 Sintered properties

Physical and mechanical properties of a material formed by the bonding of powder particles at high temperatures.

4. Classification

This specification specifies four types of tungsten heavy alloys , classified by tungsten content and density:

Class 1: 90% W, density 17.0-17.25 g/ cm³

Class 2: 92.5% W, density 17.25-17.85 g/ cm³

Class 3: 95% W, density 17.75-18.35 g/ cm³

Class 4: 97% W, density 18.25-18.85 g/ cm³

5. Technical requirements

5.1 Chemical composition

Tungsten (W) content: 90%-97% (mass fraction, depending on the category);

Binder (nickel + iron or nickel + copper): 3%-10%; total impurity content: <0.5%.

5.2 Physical properties

Density: Measured according to ASTM B311, range 17.0-18.85 g/cm³ (depending on the type);

Microstructure: Uniform sintering, no obvious pores (porosity <2%).

5.3 Mechanical properties

tensile strength:

Class 1: ≥700 MPa

Class 2: ≥850 MPa

Class 3: ≥900 MPa
Class 4: ≥1100 MPa
Yield Strength:
Class 1: ≥550 MPa
Class 2: ≥650 MPa
Class 3: ≥750 MPa
Class 4: ≥900 MPa
Elongation:
Class 1: ≥20%
Class 2: ≥10%
Class 3: ≥5%
Class 4: ≥2%
Hardness: HV 250-400 (increasing by category).
5.4 Surface treatment
Optional coatings such as cadmium or zinc nickel are available to enhance corrosion and wear resistance.

---

6. Test methods
6.1 Chemical analysis
Use a spectrometer or X-ray fluorescence method to confirm the tungsten and binder content.
6.2 Density measurement
Executed according to ASTM B311, using the Archimedes method, with an accuracy of 0.01 g/ cm^3 .
6.3 Tensile test
According to ASTM E8/E8M, the tensile strength, yield strength and elongation are tested.
6.4 Hardness test
According to ASTM E10, use Brinell hardness tester, load 3000 kg.
6.5 Microstructure inspection
Use an optical microscope at 50x magnification to check for porosity and uniformity.

---

7. Inspection Rules
7.1 Factory Inspection
For each batch of products, three samples are tested for density, tensile properties and hardness, and the results meet the requirements of 5.2 and 5.3.
7.2 Type inspection
Every two years or after a process change, repeat procedure 6.3 to verify consistency.
7.3 Decision Rules
If any performance indicator deviates from the specified value by ±10%, double samples need to be retested. If the retest still fails, the batch is considered unqualified.

---

8. Marking, packaging, transportation and storage
8.1 Logo
The product is marked with the standard number (ASTM B777-15), category (Class 1-4) and

production batch number.

8.2 Packaging

Use moisture-proof and shock-proof wooden or plastic boxes, and attach inspection reports.

8.3 Transportation

To avoid heavy pressure and moisture erosion, the means of transport must be covered with rainproof measures.

8.4 Storage

Store in a dry, dust-free environment at 0°C to 40°C and humidity <60%.

---

9. Keywords

Tungsten heavy alloy ; high-density metal; tensile strength; yield strength; ductility; radiation shielding; vibration damping

---

Appendix X1 (Informative Appendix)

X1.1 Application Examples

Class 1: Low-density weight, easy to process;

Class 2: Balance weight and medical shielding;

Class 3: X-ray and gamma ray shielding;

Class 4: High-density radiation shielding and high-velocity impact applications.

BS EN 10360:2005 Technical delivery conditions for cemented carbide pipes
BRITISH EUROPEAN STANDARD
(Established 2005-12-15)
(Confirmed 2015-12-15)
Conditions for Hardmetal
Tubes
ICS 77.160
This British European Standard has been prepared based on the consensus of the European Committee for Standardization (CEN) and adopted as a British Standard by the British Standards Institution (BSI).

Preface
This British European Standard was prepared by the CEN/TC 76 (Hard Materials) Technical Committee responsible for the standardization of cemented carbide and its products.
This standard was adopted by the British Standards Institution (BSI) as a UK national standard and was drafted by the UK Hardmetal Association and relevant manufacturers' representatives.
This standard was first published on December 15, 2005 and its validity was confirmed on December 15, 2015. It aims to specify the manufacturing, inspection and delivery requirements of cemented carbide tubes for industrial wear and corrosion resistant applications.
Note: This standard may include coordination with international standards (such as ISO). Please refer to BSI official records for specific revision history.

---

1. Scope
This standard specifies the technical delivery conditions of cemented carbide tubes produced by powder metallurgy, including material chemical composition, dimensions and tolerances, mechanical properties, surface quality, inspection and test methods, and delivery document requirements.
This standard applies to the manufacture, trade and use of cemented carbide tubes, which are widely used in cutting tools, wear-resistant pipes and high temperature environment components.

---

2. Normative references
The following standards contain clauses which, through reference in this text, become clauses of this standard. The latest version (including amendments) shall apply.
BS EN 10021:1993: General technical delivery conditions for steel products
BS EN ISO 377:2017: Steel and steel products – Sampling and preparation of test specimens
BS EN 10204:2004: Inspection documents for metal products
BS EN ISO 6507-1:2005: Metal hardness testing - Vickers method
BS EN 843-1:2006: Advanced ceramics - Mechanical properties - Flexural strength test

---

3. Terms and Definitions
The following terms and definitions apply to this standard:
3.1 Cemented carbide tubes

are tubular products made of tungsten carbide (WC) as the main component, with cobalt (Co) or nickel (Ni) as a binder, produced by powder metallurgy, with high hardness and wear resistance.

3.2 Technical delivery conditions

The material, dimensional and performance requirements that the manufacturer must meet when delivering the product.

3.3 Powder metallurgy process

The manufacturing method of preparing tubes by pressing and sintering a metal powder mixture.

---

4. Technical requirements

4.1 Chemical composition of materials

Tungsten carbide (WC) content: 85% to 92% (mass fraction);

Cobalt (Co) content: 6% to 12%;

Optional additives (such as TiC , TaC): 0.5% to 3% to enhance wear resistance;

Total impurity content: <0.5%.

4.2 Dimensions and tolerances

Outer diameter: 10 mm to 100 mm, tolerance ±0.1 mm;

Wall thickness: 2 mm to 20 mm, tolerance ±0.05 mm;

Length: 100 mm to 2000 mm, tolerance ±5 mm.

4.3 Mechanical properties

Hardness: HV 1400 to 1800 (according to BS EN ISO 6507-1:2005);

Flexural strength: ≥2000 MPa (according to BS EN 843-1:2006);

Wear resistance: Wear rate <0.05 mm^3 / N · m (refer to industry standard).

4.4 Surface quality

Surface roughness: Ra ≤ 0.4 μm ;

No obvious cracks or pores (porosity <1%).

4.5 Delivery of Documents

According to BS EN 10204:2004, provide 2.1, 2.2, 3.1 or 3.2 type inspection documents.

---

5. Test methods

5.1 Chemical analysis

Performed in accordance with BS EN ISO 377:2017 using spectrometer or X-ray fluorescence.

5.2 Hardness test

According to BS EN ISO 6507-1:2005, using Vickers hardness tester, load 30 kg.

5.3 Bending strength test

The test was carried out in accordance with BS EN 843-1:2006, using the three-point bending method with a specimen size of 20 mm × 5 mm × 5 mm.

5.4 Dimensional inspection

Use a vernier caliper and a surface roughness tester with an accuracy of 0.01 mm.

5.5 Surface quality inspection

Use an optical microscope (magnification 50×) to check for cracks and pores.

---

6. Inspection Rules

6.1 Factory Inspection

For each batch of products, three specimens are tested for hardness, bending strength and dimensions, and the results meet the requirements of 4.3 and 4.2.

6.2 Type inspection

Performed every two years or after a process change to verify all technical requirements.

6.3 Decision Rules

If the hardness or flexural strength deviates from the specified value by ±5%, double the samples need to be retested. If the retest still fails, the batch is considered unqualified.

---

7. Marking, packaging, transportation and storage

7.1 Logo

The product is marked with the standard number (BS EN 10360:2005), batch number and manufacturer's logo.

7.2 Packaging

Use moisture-proof and shock-proof wooden or plastic boxes, with inspection documents attached.

7.3 Transportation

To avoid heavy pressure and moisture erosion, the means of transport must be covered with rainproof measures.

7.4 Storage

Store in a dry, dust-free environment at 0°C to 30°C and humidity <50%.

Appendix A (Informative Appendix)

A.1 Recommended manufacturing process

Powder metallurgy sintering: temperature 1450°C ± 10°C, pressure 50 MPa;

Outer diameter machining: grinding accuracy ±0.05 mm.

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

JIS G 0570
《Test Method for Corrosion Resistance of Cemented Carbide》
JAPANESE INDUSTRIAL STANDARD
(Japanese Industrial Standard)
JIS G 0570:2010
(Established 2010-03-22) (Revised 2010-03-22)
Method of Corrosion Resistance Test
for Cemented Carbide
ICS 77.160

This Japanese Industrial Standard is established by the Japan Industrial Standards Committee through consensus among industry and technical experts.

Preface

This Japanese Industrial Standard was established by the Minister of Economy, Trade and Industry in accordance with Article 12, paragraph 1 of the Industrial Standardization Act through deliberation by the Japan Industrial Standards Committee, based on a proposal for the establishment of a new standard submitted by the Japan Tungsten Industries Association (JTIA) and an accompanying draft.

This standard specifies the method for testing the corrosion resistance of cemented carbide and is applicable to the performance evaluation of cemented carbide in corrosive environments, such as cutting tools and wear-resistant parts.

Note: The actual standard may contain historical revisions or international references, which are not included here.

---

1. Scope

This standard specifies the method for testing the corrosion resistance of cemented carbide, including sample preparation, test conditions, evaluation methods and reporting requirements.

This standard applies to cemented carbide with tungsten carbide (WC) as the main component and cobalt (Co) or nickel (Ni) binder, which is widely used in acidic, alkaline or saline environments .

---

2. Normative references

The following standards constitute the content of this standard through reference in this text. The latest version (including amendments) applies.

JIS G 0575:2005: General rules for corrosion testing of metallic materials

JIS Z 2371:2015: Salt spray test method

JIS H 8502:1999: General rules for corrosion testing of metallic coatings

JIS B 7502:1994: Vernier calipers, dial indicators and digital calipers

---

3. Terms and Definitions

The terms and definitions applicable to this standard are as follows:

3.1 Cemented Carbide

is a composite material made of tungsten carbide (WC) as the main component and metal binders such as cobalt (Co) or nickel (Ni).

3.2 Corrosion Resistance

The ability of cemented carbide to resist material loss or surface damage in corrosive media, usually expressed as mass loss or corrosion rate.

3.3 Salt Spray Test

A standard corrosion test conducted under specified conditions using a 5% sodium chloride (NaCl) solution to simulate a saline environment .

---

4. Sample

4.1 Shape and size

The specimen shall be cylindrical with a diameter of 10 mm and a length of 20 mm, or rectangular with dimensions of 20 mm × 20 mm × 5 mm.

Surface roughness: Ra ≤ 0.2 μm , prepared by diamond grinding.

4.2 Preparation

The specimens were cleaned with ethanol and dried at 60°C for 1 hour.

Edges should be chamfered to avoid stress concentrations.

---

5. Test methods

5.1 Test conditions

Test medium: 5% NaCl solution (pH 6.5-7.2) or 10% sulfuric acid (H_2SO_4) solution (selected by agreement).

Temperature: 35°C ± 2°C for salt spray test and 50°C ± 2°C for acid immersion test.

Exposure time: 24 hours, 48 hours or 96 hours (as agreed).

5.2 Test procedure

The specimen is placed in a salt spray test chamber conforming to JIS Z 2371, or immersed in a controlled acid solution.

Maintain continuous exposure without interruption.

After the test, rinse with distilled water and measure the mass loss after drying.

5.3 Evaluation

Mass loss: Weigh before and after the test using an analytical balance with an accuracy of ±0.1 mg.

Surface inspection: Use a 50x microscope to check for pitting or cracks.

Corrosion rate: calculated according to the formula: Corrosion rate = mass loss / (exposure area × exposure time), the unit is $mg/cm^2 \cdot h$.

---

6. Test report

The test report should include the following:

Specimen material and dimensions; test medium, temperature and exposure time; mass loss and corrosion rate; photographic record of surface condition;

Test date and operator signature.

---

7. Inspection

7.1 Factory Inspection

Three samples are tested for each batch of samples to ensure that they meet the evaluation criteria in 5.3.

7.2 Type inspection

This test is carried out once a year or after a process change, and the complete test procedure is repeated.

7.3 Judgment

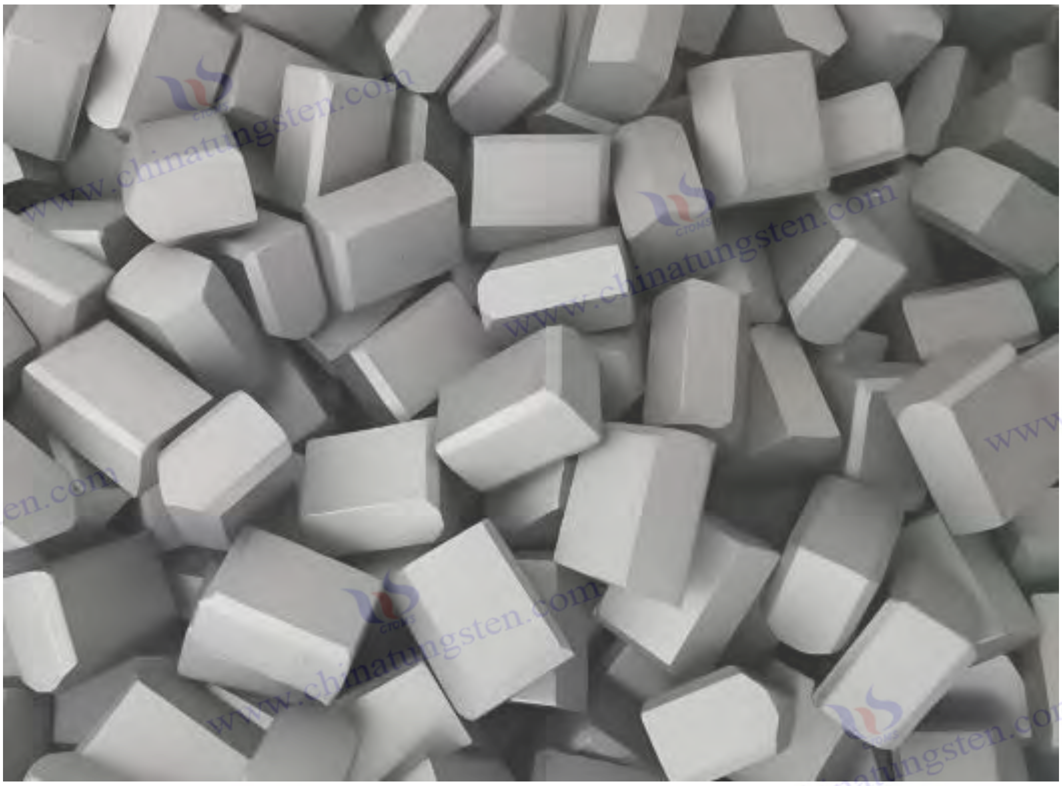
If the mass loss exceeds 0.5 $mg/cm^2 \cdot h$ or obvious pitting occurs, double the samples shall be retested. If the retest still fails, the batch shall be deemed unqualified.

Appendix JA (Informative Appendix)

JA.1 Recommended test medium

Marine environment: 5% NaCl solution.

Chemical processing environments: 10% H_2SO_4 or 5 % HCl (selected by application).



DIN 17350

《Technical Requirements for High Performance Cemented Carbide》

Technical Delivery Conditions for High-Performance Cemented Carbides

ICS 77.160

Deutsch Institute for Normung

(German standard)

DIN 17350:1980-10

(Date of publication: October 1980)

(Date of revision: No latest revision, as of July 5, 2025)

This German standard was developed by the German Institute for Standardization (DIN) based on industrial technical requirements and is applicable to the manufacture, inspection and delivery of high-performance cemented carbides.

Preface

This standard was developed by DIN Technical Committee NA 066-01-01 AA (Tool Steels and Hard Materials) to specify the technical delivery conditions of high-performance cemented carbides, including material composition, mechanical properties, dimensional tolerances and inspection requirements.

This standard applies to cemented carbides containing tungsten carbide (WC) and cobalt (Co) or nickel (Ni) as binders, which are widely used in cutting tools, wear-resistant parts and high-temperature applications.

This standard was first published in October 1980 and has not been significantly revised since then, but subsequent related standards may be referenced in practical applications.

1. Scope

This standard specifies the technical delivery conditions for high-performance cemented carbide, including material requirements, mechanical properties, dimensions and tolerances, surface quality, inspection methods and delivery documents.

This standard applies to cemented carbide products produced by powder metallurgy, covering high-demand applications such as cutting tools, dies and wear-resistant coatings.

2. Normative references

The clauses contained in the following standards become the clauses of this standard through reference in this text. The latest version (including its amendments) shall apply.

DIN EN ISO 4506:2013: Test methods for wear resistance of cemented carbides

DIN EN 10204:2004: Inspection documents for metal products

DIN EN ISO 6507-1:2018: Vickers hardness test for metallic materials

DIN EN 10021:1993: General technical delivery conditions for steel products

3. Terms and Definitions

3.1 High-performance cemented carbide

is a high-hardness, wear-resistant material made of tungsten carbide (WC) as the main component and a binder such as cobalt (Co), nickel (Ni) or titanium (Ti).

3.2 Technical delivery conditions

The material, performance and dimensional requirements that the manufacturer must meet when delivering the product.

3.3 Powder metallurgy process

The manufacturing method of preparing cemented carbide by pressing and sintering a metal powder mixture.

4. Technical requirements

4.1 Material composition

Tungsten carbide (WC) content: 85%-95% (mass fraction);

Binder (Co, Ni or Ti) content: 5%-15%;

Optional additives (such as TiC , TaC): 0%-5%, used to enhance performance;

Total impurity content: <0.5%.

4.2 Mechanical properties

Hardness: HV 1400-1800 (determined according to DIN EN ISO 6507-1);

Flexural strength: ≥2000 MPa;

Fracture toughness: KIC ≥ 8 MPa·m ^(1/2);

Wear resistance: Wear rate <0.05 mm^3 / N · m (refer to DIN EN ISO 4506).

4.3 Dimensions and tolerances

Diameter: 5 mm to 50 mm, tolerance ±0.05 mm;

Length: 50 mm to 500 mm, tolerance ±2 mm;

Wall thickness (for tubes): 2 mm to 10 mm, tolerance ±0.1 mm.

4.4 Surface quality

Surface roughness: Ra ≤ 0.4 μm ;

No obvious cracks, pores or slag inclusions (porosity <1%).

4.5 Heat treatment

Optional carburizing or surface coating treatment to enhance corrosion resistance;

Sintering temperature: 1400°C-1500°C, adjusted according to material composition.

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5. Test methods

5.1 Chemical analysis

Performed in accordance with DIN EN ISO 377 using spectrometer or X-ray fluorescence.

5.2 Hardness test

According to DIN EN ISO 6507-1, using Vickers hardness tester, load 30 kg.

5.3 Bending strength test

According to DIN EN 843-1, three-point bending method, specimen size 10 mm × 5 mm × 5 mm.

5.4 Abrasion resistance test

Executed according to DIN EN ISO 4506, using a pin-on-disc wear tester with a load of 50 N and a sliding distance of 500 m.

5.5 Dimensional inspection

Use precision calipers and surface profilers with an accuracy of 0.01 mm.

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6. Inspection and testing

6.1 Factory Inspection

For each batch of products, three specimens are tested for hardness, flexural strength and abrasion resistance, and they meet the requirements of 4.2.

6.2 Type inspection

Repeat procedures 5.2 to 5.4 every two years or after a process change.

6.3 Decision Rules

If the hardness is 10% lower than the specified value or the flexural strength is lower than 5%, double the samples need to be retested. If the retest still fails, the batch is considered unqualified.

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7. Marking and packaging

7.1 Logo

The product is marked with the standard number (DIN 17350), material grade and batch number.

7.2 Packaging

Use moisture-proof and shock-proof wooden boxes or plastic containers, and attach inspection reports.

7.3 Transportation and storage

Avoid heavy pressure and moisture erosion during transportation;

Store in a dry environment at 0°C to 30°C and humidity <60%.

Appendix A (Informative)

A.1 Recommended Applications

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

Cutting tools: hardness HV 1600 or above, bending strength ≥ 2200 MPa;
Wear-resistant coating: Contains TiC additives, excellent corrosion resistance.

电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

GOST 3882-74

ГОСТ (Russian state standard)

《Technical Requirements for Cemented Carbide》

Hard Alloys. Specifications

ICS 77.160 OKP 19 6500, 19 6600

Developed and approved by the USSR State Standards Committee. (Published on August 15, 1974) (Confirmed in 2008, the latest revised version)

Preface

This standard was issued by the USSR State Committee for Standardization (Gostrov комитет СССР по This standard was issued on August 15, 1974, and re-issued in June 1998. It contains 6 revisions from 1974 to 2008 (No. 1-6), aiming to standardize the classification, technical requirements and inspection methods of cemented carbide.

Note :

This version is derived content, and the actual revision history and content need to refer to official documents.

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1 Scope

This standard specifies the technical requirements for cemented carbide, including material composition, mechanical properties, dimensional tolerances, surface quality and inspection rules. This standard applies to cemented carbide produced by powder metallurgy and is widely used in cutting tools, wear-resistant parts and industrial equipment.

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2 Normative references

The clauses in the following documents become the clauses of this standard through reference in this standard. The latest version at the time of publication shall apply.

GOCT 20019-74: General technical requirements for metal powders

GOCT 2999-75: Methods for sampling metal powders

GOCT 9454-78: Metal impact test method

ГОСТ 26388-84: Test method for flexural strength of cemented carbide

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3 Terms and definitions

3.1 Cemented carbide

is a composite material made of tungsten carbide (WC) as the main component, with cobalt (Co) or nickel (Ni) as a binder, and sintered by powder metallurgy.

3.2 Technical requirements

The material, performance and size specifications that must be met when the product is delivered.

3.3 Flexural strength

The maximum stress that the material can withstand in a three-point bending test, in MPa.

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4 Technical requirements

4.1 Classification

This standard specifies the following cemented carbide grades:

BK6: WC 94%, Co 6%, hardness range HV 1300-1400;

BK8: WC 92%, Co 8%, hardness range HV 1250-1350;

BK15: WC 85%, Co 15%, hardness range HV 1100-1200;

TK10: WC 90%, TiC 10%, hardness range HV 1400-1500;

TK15 : WC 85%, TiC 15%, hardness range HV 1350-1450;

TK20: WC 80%, TiC 20%, hardness range HV 1300-1400.

4.2 Material composition

Tungsten carbide (WC) content: 80% to 94% (mass fraction); cobalt (Co) content: 6% to 15%; optional additives (such as TiC , TaC): 0% to 20%; total impurity content: <0.5%.

4.3 Mechanical properties

Hardness: HV 1100 to 1500 (depending on the grade);

Flexural strength: ≥1200 MPa (according to ГОСТ 26388-84);

Density: 14.5 to 15.0 g/cm³ (depending on the grade);

Wear resistance: Wear rate <0.05 mm³ / N · m (reference test).

4.4 Dimensions and tolerances

Rod diameter: 5 mm to 40 mm, tolerance ±0.1 mm; Rod length: 50 mm to 300 mm, tolerance ±2 mm;

Sheet thickness: 2 mm to 20 mm, tolerance ±0.05 mm; surface roughness: Ra ≤ 0.4 μm .

4.5 Surface quality

The surface should be smooth, without cracks, pores or inclusions (porosity <1%);

Light scratches or machining marks are permitted, with a depth not exceeding 50% of the upper tolerance limit.

4.6 Delivery Status

The product should be in sintered state and can be ground or polished according to the order requirements.

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5 Test methods

5.1 Chemical analysis

According to ГОСТ 20019-74, use spectroscopic analysis or chemical analysis with an accuracy of 0.01%.

5.2 Hardness test

According to ГОСТ 2999-75, use Vickers hardness tester, load 30 kg, measure 5 points and take the average value.

5.3 Bending strength test

According to ГОСТ 26388-84, three-point bending method, sample size 20 mm × 6.5 mm × 5.2 mm, test temperature 20°C ± 2°C.

5.4 Density measurement

Measured by Archimedean method using a precision balance with an accuracy of 0.01 g/ cm³ .

5.5 Surface quality inspection

Use an optical microscope (magnification 50x) to check for surface defects;

The surface roughness was measured using a surface profiler according to ГОСТ 2789-73.

6 Inspection

6.1 Factory Inspection

Three samples are randomly selected from different positions of each batch of products for mechanical properties specified in Section 4.3 and dimensional tests specified in Section 4.4. The test results must meet the technical requirements, otherwise double samples will be retested.

6.2 Type inspection

Once every two years or after a process change, take no less than 5 samples and repeat all the tests in Sections 5.2 to 5.5.

6.3 Decision Rules

If any performance index (such as hardness, flexural strength) deviates from the specified value by ±5%, or the density deviates by ±0.1 g/cm³ , double sample re-inspection is required; if the re-inspection still fails, the batch is deemed unqualified.

7 Marking, packaging, transportation and storage

7.1 Logo

The product should be marked with the standard number (ГОСТ 3882-74), brand number (such as BK8), batch number and manufacturing date.

7.2 Packaging

Bars and plates should be bundled and wrapped with moisture-proof paper (ГОСТ 9569-79) or plastic film;

Each batch is accompanied by an inspection certificate that complies with the requirements of GOCT 14192-96.

7.3 Transportation

Avoid heavy pressure and moisture during transportation, and use covered vehicles or containers.

7.4 Storage

Store in a dry, ventilated warehouse at -10°C to 40°C and relative humidity <70%.

Appendix A (informative)

A.1 Recommended manufacturing process

Powder preparation: according to ГОСТ 20019-74, particle size 0.5-5 μm ;

Sintering: temperature 1400°C to 1500°C, pressure 40-50 MPa, protective atmosphere is hydrogen or argon;

Post-processing: grinding accuracy ±0.05 mm, polishing to Ra ≤ 0.2 μm (optional).

A.2 Application examples

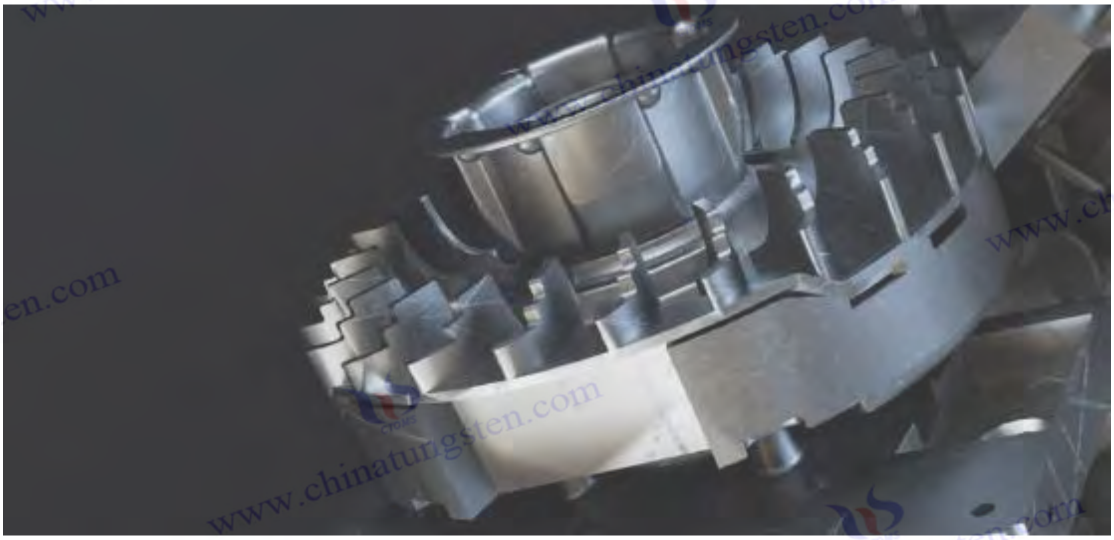
BK6: suitable for high-precision cutting tools;

TK20: Suitable for wear-resistant coatings and stamping dies.

Appendix B (Informative) B.1 Quality Control Table

Brand	Hardness (HV)	Flexural strength(MPa)	Density(g/ cm³)	Allowable deviation (%)
VK6	1300-1400	≥1400	14.8-15.0	±5

Brand	Hardness (HV)	Flexural strength(MPa)	Density(g/ cm³)	Allowable deviation (%)
VK8	1250-1350	≥1300	14.7-14.9	±5
VK15	1100-1200	≥1200	14.5-14.7	±5
TK10	1400-1500	≥1500	14.6-14.8	±5



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!

Contact Us

Email : sales@chinatungsten.com

Tel : +86 592 5129696

Official website : www.ctia.com.cn