Tungsten Cemented Carbide

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

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

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

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

INTRODUCTION TO CTIA GROUP

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

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

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

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

CTIA GROUP® | Hard Technology, Smart Future

The global leader in digital and intelligent services for the tungsten, molybdenum and rare earth industries

Customized processing of cemented 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 88 - 92 ; Accuracy: nozzle hole tolerance ±0.001 mm, surface roughness Ra 0.10.4 μm .

Adaptability: temperature resistance 800 - 1000°C, corrosion resistance pH 210.

Efficiency: Supports high-pressure (0.1500 MPa) injection, with efficiency increased by 20 - 50%.

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 mm
Sandblasting nozzle Sandblasting Nozzle	High wear-resistant design, abrasive blasting	Rust removal of ships, deburring of automobile parts, and concrete cleaning.	Nozzle diameter 2 - 12, length 50 - 200
Water jet nozzle Waterjet Nozzle	High pressure water jet, hard material cutting	Aerospace titanium cutting, automotive composite material cutting, stone processing.	The nozzle diameter is 0.12, the length is 20-100 ,
Spray Nozzle Spray Coating Nozzle	Precise spraying of paint or ceramic coatings	Turbine blade coating, engine coating, electronic circuit board spraying.	The nozzle diameter is 0.55, the length is 30-150 ,
Oilfield Nozzles Oilfield Nozzle	High pressure resistance, corrosion resistance, drilling jetting	Oil drilling fluid injection, downhole cleaning, mining mud injection.	Nozzle diameter 3 - 15, length 50 - 150,
Atomizing nozzle Atomizing Nozzle	Fine atomization spray, liquid dispersion	Agricultural pesticide spraying, chemical liquid atomization, environmental waste gas treatment.	The nozzle diameter is 0.23, the length is 20-100 ,
Combustion nozzle Burner Nozzle	High temperature resistant design, fuel or gas injection	Energy boiler combustion, chemical high temperature reaction, metallurgical furnace injection.	Nozzle diameter 1 - 10, length 30 - 120,
Micro Nozzle Micro Nozzle	Ultra-small nozzle hole, high-precision injection	Medical drug spray, electronic chip cleaning, aviation precision coating.	Nozzle diameter 0.05 - 0.5, length 10 - 50
Corrosion resistant nozzles CorrosionResistant Nozzle	Resistant to strong acid, alkali and chemical environment	Chemical acid and alkali solution injection, environmental protection desulfurization and denitrification, marine engineering seawater injection.	Nozzle diameter 1 - 10, length 30 - 150,
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.:, 05925129595 18750234579 Email: info@ctia.group

CTIA GROUP LTD

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 0.1 - 0.4 μm .

Adaptability: temperature resistance 800 - 1000°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 Dies 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	Specially designed for stamping	Food packaging molds and dairy	The die diameter is 10100 mm, the

FoodGrade Die	of food related parts, in compliance with standards.	processing equipment parts comply with FDA/EU food contact standards.	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

CTIA GROUP LTD

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

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

Part 4: Classification and application fields of cemented carbide

Chapter 14: Emerging Applications and Multifunctionality of Cemented Carbide

Tungsten Cemented Carbide is a composite material with high hardness, wear resistance and toughness, made by powder metallurgy process, with tungsten carbide (WC) as hard phase and cobalt (Co) or other metals (such as nickel Ni, chromium Cr) as bonding phase. Its basic components usually include WC (accounting for 70%-94%), Co (6%-15%), etc. Some advanced formulas may add elements such as TiC , TaC or Pt to optimize performance. With its excellent physical and chemical properties, cemented carbide has become an important material in modern industry and emerging technology fields.

14.0 Properties of cemented carbide

The performance of cemented carbide comes from its unique microstructure and composition design:

High hardness
The hardness range is HV 1600-2500±30. Thanks to the high hardness of WC (close to diamond), it still maintains excellent deformation resistance at high temperatures (up to 1000°C±20°C).
Excellent wear resistance
The wear rate is <0.05 mm³ / N · m ± 0.01 mm³ / N · m . Its wear resistance is 10-20 times that of steel, making it suitable for highly abrasive environments such as cutting tools and abrasive processing.
Electrical conductivity

The resistivity is <10 μΩ·cm±0.1 μΩ·cm , which is close to that of metal conductors and is suitable for electronic applications, especially in scenarios where efficient heat dissipation is required.

Biocompatibility

The cell survival rate is >95%±2% and can be used for in vivo implantation after surface treatment, showing low toxicity and good tissue compatibility.

Catalytic performance

With a MOR (methanol oxidation reaction) current of >450 mA/cm² ± 10 mA/cm² , WC-based catalysts perform well in fuel cells, approaching the catalytic efficiency of precious metal Pt.

Thermal stability

It maintains structural integrity at 800°C±50°C and has a low thermal expansion coefficient (approximately 5×10^{-6}/°C±0.5×10^{-6}/°C), making it suitable for high-temperature processing and energy storage devices.

Mechanical toughness

Flexural strength 600-2000 MPa±50 MPa, hardness and toughness are balanced by adjusting the Co content.

The performance of cemented carbide has been significantly improved through composition optimization (such as Co 6%-15%±1% to control toughness, Pt 0.5%-2%±0.1% to enhance catalytic performance), surface modification (such as PVD/CVD coating thickness of 15 μm±0.1 μm to improve corrosion resistance) and advanced manufacturing processes (such as selective laser melting SLM, laser power 200-400 W±10 W). For example, the conductivity is increased by about 20%±3%, the catalytic efficiency is increased by about 30%±5%, and the porosity is reduced to <2%±0.1%, laying the foundation for multifunctional applications.

14.0 Multifunctional Application of Cemented Carbide

Cemented carbide has shown versatility in emerging fields. With its superior performance (high hardness HV 1600-2000±30, compressive strength>3000 MPa±100 MPa, electrical conductivity resistivity<10 μΩ·cm±0.1 μΩ·cm , corrosion resistance corrosion rate<0.01 mm/year±0.001 mm/year), it is widely used in cutting-edge fields such as electronics, biomedicine, catalytic energy storage and additive manufacturing . In addition, based on the full network search and the latest industry trends, the multifunctional application of cemented carbide has expanded to more fields, including but not limited to the following aspects. This chapter starts from five aspects, systematically analyzing its application and development trends, and providing a theoretical and practical basis for subsequent sections.

Electronic and conductive parts made of cemented carbide

The high electrical conductivity and thermal stability of cemented carbide (withstands temperatures up to 800°C±50°C) make it an ideal choice for electronic molds, heat dissipation substrates, and electrical contact materials, especially in semiconductor packaging (chip lead frames), 5G equipment (high-frequency antenna brackets), and electric vehicle battery connectors. According to

电话/TEL：0086 592 512 9696

sales@chinatungsten.com

online data, cemented carbide (such as WC-Ni) is used in microelectronics processing tools and ultra-high-density circuit board drills due to its low resistivity (<8 μΩ·cm±0.1 μΩ·cm) and excellent oxidation resistance (<0.01%±0.001%), meeting the high precision and durability requirements of 5G base stations (data transmission rates>10 Gbps±1 Gbps) and quantum computing devices (operating temperature<4 K±0.5 K). In addition, WC-based composites combined with graphene (0.2%-1%±0.01%) have enhanced conductivity (>150 S/cm±5 S/cm), and are emerging in flexible electronics (such as wearable sensors, flexibility >90%±2%) and electromagnetic shielding (shielding efficiency >90 dB±2 dB).

Biomedical Applications of Cemented Carbide

The biocompatibility (cytotoxicity <5%±1%), wear resistance (wear rate <0.05 $mm^3/N \cdot m$ ± 0.01 $mm^3/N \cdot m$) and high hardness of cemented carbide support the development of implants (such as hip and knee prostheses) and surgical tools (such as bone saws and drills), combined with surface modification technology (such as hydroxyapatite coating, thickness 5-10 nm±0.1 nm), to meet the high precision (<0.1 mm±0.01 mm) and long-term stability (>10 years±1 year) requirements of medical devices. According to the online data, WC-Co is increasingly used in dental implants (bone integration rate >95%±2%) and spinal fixators (fatigue strength>1200 MPa±50 MPa), and surface nitriding (N content 1%-2%±0.1%) improves antibacterial properties (antibacterial rate>90%±2%). Furthermore, WC- based materials showed potential in biosensors (sensitivity >10^3 ± 10^2) and tissue engineering scaffolds (porosity 20%-30%±1%) due to their high specific surface area (>50 m^2/g ± 5 m^2/g) and bioactivity (cell attachment rate >85%±2%).

Catalysis and energy storage of cemented carbide

The catalytic performance of WC-Pt composites (MOR current >450 mA/cm^2 ± 10 mA/cm^2) is excellent in fuel cells (power density >1 W/cm^2 ± 0.1 W/cm^2) and electrolyzers (hydrogen production >1 L/min±0.1 L/min), promoting the development of clean energy technology, especially in the hydrogen economy (global market >US$200 billion ±US$20 billion, 2025) with great potential. Research data show that tungsten carbide (WC) -based materials have been applied in supercapacitors (specific capacity>200 F/g±10 F/g), lithium-ion battery anodes (specific capacity>500 mAh /g±50 mAh /g) and water electrolysis for hydrogen production (OER current>300 mA/cm^2 ± 10 mA/cm^2) , and WC-Mo doping (Mo 1%-3%±0.1%) improves OER efficiency (current>350 mA/cm^2 ± 10 mA/cm^2) . In addition, the catalytic activity of tungsten carbide (WC) -based materials in CO_2 reduction (conversion rate>80%±2%) and ammonia synthesis (yield>100 mg/h·g±10 mg/ h·g) has attracted attention due to its multiphase structure and high stability (corrosion resistance<0.008 mm/year±0.001 mm/year), supporting the carbon neutrality goal (net zero emissions in 2040±5 years).

Additive Manufacturing of Cemented Carbide

Through 3D printing technologies such as SLM and Binder Jetting, cemented carbide can achieve

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

customized production of complex geometric shapes (precision <0.1 mm±0.01 mm), which is used in aerospace (turbine blades, high temperature resistance>800°C±50°C), mold manufacturing (wear-resistant stamping molds, life>10^6 times±10^4 times) and energy equipment (high temperature valves, pressure>500 MPa±50 MPa), significantly improving manufacturing flexibility (printing speed>100 mm^3 / s ± 10 mm^3 / s). According to the information on the whole network, DED and EBM technologies are used for the repair of large structural parts (interface strength>800 MPa±50 MPa) and gradient material manufacturing (Co content 6%-15%±1% gradient change), and the tensile strength of WC- TiC composite materials in high temperature environment (>1000°C±50°C) is>1300 MPa±50 MPa. Additive manufacturing has also expanded to micro-nano devices (feature size <10 μm±1 μm) and bioprinting (scaffold porosity 20%-40%±1%), promoting personalized medicine and lightweight structural design.

Cemented Carbide for Defense and Extreme Environment Applications

Cemented carbides are increasingly used in defense and extreme environments. WC-Co is used in armor-penetrating warheads (penetration depth >500 mm±50 mm) and ballistic armor (protection level NIJ IV±1) due to its high hardness (HV 1800±30) and impact resistance (impact toughness>20 J/cm^2 ± 2 J/cm^2). WC - TiC - WN composites maintain structural integrity (residual deformation <0.1%±0.01%) at high strain rates (> 10^3 s^{-1} ± 10^2 s^{-1}) .

In deep-sea equipment (pressure > 1000 bar ± 100 bar) and space technology (vacuum < 10^{-6} Pa ± 10^{-7} Pa, temperature -150°C to 200°C ± 10°C), tungsten carbide (WC) -based materials are used as seals and thermal protection coatings (heat resistance > 1200°C ± 50°C) due to their low thermal expansion coefficient (5×10^{-6} /°C ± 0.5×10^{-6} /°C) and corrosion resistance (< 0.005 mm/year ± 0.001 mm/year). In addition, WC shows multifunctional potential as shielding material and target material in the nuclear industry (radiation tolerance > 10^6 Gy ± 10^5 Gy) and high-energy physics experiments (particle beam stability > 99% ± 0.5%) .

Intelligent Manufacturing and Sensor Application of Cemented Carbide

Cemented carbide combined with intelligent manufacturing technology has expanded to the field of sensors and the Internet of Things . According to online data, WC- based materials are used in pressure sensors (sensitivity >10^2 kPa^{-1} ± 10 kPa^{-1}) , temperature sensors (response time <0.1 s±0.01 s) and vibration monitors (frequency range 10 Hz-10 kHz±1 Hz) due to their high conductivity (>100 S/cm±5 S/cm) and mechanical stability (compressive strength >3500 MPa±100 MPa). Integrated nano-coatings (such as SiO_2 , thickness 5-10 nm±0.1 nm) improve environmental adaptability (humidity 50%-95%RH±5%RH). In Industry 4.0, WC-based smart tools (self-diagnosis life > 10^5 times ± 10^4 times) can achieve real-time monitoring (accuracy ± 1%) through embedded sensors, optimize cutting processing (tool wear rate < 0.01 mm^3 /N · m ± 0.001 mm^3 / N · m) and 3D printing parameter adjustment.

This chapter will delve into specific application cases, technical challenges and future prospects in these fields, revealing how cemented carbide can meet increasingly diverse industrial needs through multifunctionality.

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




14.1 Cemented Carbide Electronic and Conductive Components

In the electronics field, cemented carbide has attracted much attention due to its high hardness (HV 1800-2200±30), low resistivity (<10 μΩ·cm±0.1 μΩ·cm), excellent thermal conductivity (>100 W/m·K±5 W/ m·K) and excellent thermal stability (operating temperature can reach 800°C±50°C). It is mainly used in molds and heat dissipation substrates. Molds are used for chip packaging, precision stamping and processing of microelectronic components, with a lifespan of up to 10^6 times±10^5 times; heat dissipation substrates support high-power electronic devices (such as power modules, LEDs and 5G base station components), with a heat dissipation efficiency of more than 90%±2%, and a low thermal expansion coefficient (about 5×10^{-6} /°C±0.5×10^{-6} /°C), ensuring dimensional stability during thermal cycles. The material is mainly based on the WC-Co system (the Co content of cemented carbide is 6%-12%±1%), the grain size of cemented carbide raw materials is controlled at 0.5-2 μm±0.01 μm , and the electrical conductivity and thermal conductivity are optimized by doping Cu (1%-5%±0.5%) or Ni (2%-8%±0.5%). Some high-end formulas add Pt (0.5%-2%±0.1%) to enhance catalytic and conductive properties. The high melting point of cemented carbide (about 2870°C±20°C) makes it have excellent durability in extreme environments, and its corrosion resistance (corrosion resistance index>90%±2% can be achieved through PVD coating) further expands its application range. In 2025, as the electronics industry develops towards high frequency, high power and miniaturization, the demand for cemented carbide in semiconductor manufacturing, electric vehicle power management and smart devices continues to grow.

In the electronics industry, cemented carbide is widely used in the manufacture of molds and heat dissipation substrates due to its excellent hardness (HV 1600-2000±30), wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , high thermal conductivity (thermal conductivity>100

W/m·K±5 W/ m·K) and high temperature resistance (temperature resistance>800°C±50°C). These characteristics enable it to perform well in precision machining and efficient heat dissipation scenarios, especially in the fields of semiconductors, 5G technology and electric vehicles. With the increasing demand for miniaturization and high-density integration of electronic devices, the application prospects of cemented carbide in the electronics industry continue to expand.

14.1.1 Hard alloy molds for the electronics industry

Cemented carbide electronic industry molds are used for precision machining of electronic components. They need to have high precision (machining deviation <0.01 mm ± 0.001 mm), excellent corrosion resistance (corrosion rate <0.01 mm/year ± 0.001 mm/year) and long life (> 10^6 times ± 10^4 times) to meet the high requirements of microelectronic device manufacturing. The material is mainly WC-Co system (Co content 6%-10% ± 1%), and the grain size of cemented carbide raw materials is controlled at 0.5-1 μm ± 0.01 μm . Some surface coatings (such as TiN , thickness 5-15 μm ± 0.1 μm) or CrN (thickness 10-20 μm ± 0.2 μm) are used to further improve wear resistance and oxidation resistance. The mold is optimized by hot isostatic pressing (HIP, 1200°C ± 10°C, 150 MPa ± 1 MPa) or laser surface treatment.

In the electronics industry, cemented carbide molds have become an indispensable core tool in the manufacturing process of electronic components due to their excellent hardness (HV 1600-2000±30), wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , high heat resistance (temperature resistance>800°C±50°C), excellent precision, and excellent conductivity and corrosion resistance. With the rapid development of the electronics industry towards ultra-miniaturization, high performance, intelligence, greenness and multi-functionality, the application scenarios of cemented carbide molds have been significantly expanded, and the market demand has continued to surge. These molds have been rapidly updated through continuous technology iteration, material formulation optimization and innovation of advanced manufacturing processes (such as additive manufacturing , precision surface treatment and intelligent monitoring technology), becoming one of the most important and fastest-growing high-end consumer areas in the cemented carbide industry. Cemented carbide molds are widely used in semiconductor manufacturing, flexible electronic technology, 5G/6G communications, consumer electronics, new energy automotive electronics, Internet of Things equipment, and emerging fields such as quantum computing and smart medical equipment. The market size is expected to reach US$5 billion ± US$500 million, with an annual growth rate of up to 15%-20%, fully reflecting its key position in promoting technological progress and industrial upgrading in the electronics industry.

(1) Carbide lead frame punching die

What is a carbide lead frame punching die?

Carbide lead frame punching dies are high-precision processing tools designed specifically for the semiconductor packaging field. They are mainly used for IC pin forming, LED bracket processing, power module lead forming, and new micro sensor lead manufacturing. Its core material uses WC-8Co formula, and the grain size is precisely controlled at 0.6 μm±0.01 μm . It is prepared by powder metallurgy and hot isostatic pressing (HIP, 1200°C±10°C, 150 MPa±1 MPa) process to ensure material uniformity and high density (porosity <0.5%±0.1%). The TiN coating (thickness 5-10 μm±0.1 μm) is applied to the mold surface through physical vapor deposition (PVD) technology, which significantly reduces the friction coefficient (<0.2±0.02), enhances oxidation resistance (durable temperature up to 600°C±10°C) and reduces adhesion, effectively improving durability (up to 1.2×10^{6} times$\pm10^{4}$ times) and blanking accuracy (<0.005 mm±0.001 mm). By combining laser micromachining, multi-layer coating (such as TiAlN or TiSiN , thickness 10-15 μm±0.2 μm) and adaptive cooling technology, the mold is further optimized to support ultra-fine leads (width <0.01 mm±0.001 mm), high-frequency stability (>10 GHz±1 GHz) and thermal cycle resistance (-40°C to 150°C±10°C), and through digital twin technology, real-time wear monitoring (accuracy ±1%) and parameter optimization are achieved to meet the needs of ultra-high precision and ultra-large-scale production.

Carbide lead frame punching die performance

The mold has high hardness (HV 1800±30), excellent wear resistance (wear rate <0.01 mm^3 / N · m ± 0.001 mm^3 / N · m) , high durability (>1.2×10^{6}times ± 10^{4}times) and extremely high punching accuracy (<0.005 mm±0.001 mm). TiN coating significantly reduces friction (<0.2±0.02), improves oxidation resistance (resistant to 600°C±10°C), and enhances heat cycle stability (-40°C to 150°C±10°C) through multi-layer coating (such as TiAlN , heat resistant>800°C±50°C) and adaptive cooling technology. In addition, digital twin integration enables wear prediction (error <5%±0.5%) and process optimization.

Types of Carbide Lead Frame Punching Dies

Standard mold

Based on WC-8Co, it is suitable for conventional IC pin and LED bracket processing, with an accuracy of <0.005 mm±0.001 mm and a durability of 1×10^{6} times$\pm10^{4}$ times.

High temperature mold

Adding TiC (5%-10%±0.5%) and TiAlN coating (10-15 μm±0.2 μm), heat resistance>800°C±50°C, suitable for power modules such as IGBT packaging.

Ultra-fine mold

Optimized grain size (<0.5 μm±0.01 μm) and laser micromachining support lead width <0.01 mm±0.001 mm, meeting the requirements of 5nm/3nm process and micro LED.

Intelligent mold

Embedded sensors and digital twin modules monitor wear (accuracy ±1%) and adjust parameters in real time for high-frequency (>10 GHz±1 GHz) applications.

Application of Carbide Lead Frame Punching Dies

Carbide lead frame punching dies are widely used in multiple high-tech fields, especially playing a key role in the semiconductor and electronics industries. In the production of high-density integrated circuits, such as the manufacture of 5nm and 3nm process chips , the dies ensure the ultra-high precision and consistency of the lead frames, supporting the mass production of high-end processors and memories. In the field of power semiconductor packaging, the dies are used in the production of IGBT modules, MOSFETs, and SiC and GaN power devices to meet the high reliability requirements of electric vehicles, photovoltaic inverters, and industrial motor drives. Micro LED packaging is another important application area. The high-precision punching technology of the dies supports the manufacture of optical components for micro displays and wearable devices, improving display brightness and resolution.

In addition, molds are widely used in the manufacture of new micro sensors, including MEMS (micro-electromechanical systems) sensors, pressure sensors, and inertial measurement units (IMUs), providing key support for smart devices, IoT nodes, and medical electronics. In the field of automotive-grade electronics, especially in the packaging of autonomous driving chips, radar modules, and on-board computing units, the mold's thermal cycle resistance (-40°C to 150°C±10°C) and high-frequency stability (>10 GHz±1 GHz) ensure the long-term stability and safety of electronic systems. High-performance computing chips and quantum computing devices also rely on the mold's ultra-fine lead processing capabilities (width <0.01 mm±0.001 mm), promoting the development of artificial intelligence accelerators and quantum bit control circuits.

In the field of consumer electronics, molds support the processing of multi-layer lead frames for smartphones, tablets, and gaming devices, improving product thinness and performance. In industrial automation, molds are combined with intelligent manufacturing technology to be used in mass production of precision mechanical parts and connectors, optimizing production efficiency (increase by >20%±2%). Through digital twin technology, molds achieve predictive maintenance and process parameter optimization, reduce downtime (reduction by >15%±2%), and are suitable for extreme environment requirements of aerospace electronics (such as satellite communication modules) and defense electronics (such as radar and missile guidance systems), further expanding their application range.

(2) Carbide chip packaging mold

What is a carbide chip packaging mold ?

Carbide chip packaging molds are high-precision processing tools designed specifically for the field of microelectronic device packaging, mainly used for BGA (ball grid array), QFN (quad flat no-lead package), SIP (system-in-package), 3D IC stacking and wafer-level packaging (WLP). Its core material uses WC-6Co formula, with a grain size accurate to 0.5 μm±0.01 μm . It achieves high density (porosity <0.5%±0.1%) through ultra-fine powder ball milling and sintering processes , and is combined with complex geometric designs (such as microchannel width 0.02-0.05 mm±0.001 mm, depth 0.1 mm±0.005 mm, sidewall verticality <1°±0.1°). A CrN coating (thickness 10-15 μm

± 0.2 μm , using multi-arc ion plating technology) is applied on the mold surface to significantly improve corrosion resistance (corrosion rate <0.008 mm/year ± 0.001 mm/year) and high temperature resistance (>350°C ± 10°C), effectively extending the service life (approximately 8×10^5 times ± 10^4 times). Complex structures (such as internal cooling channels) are customized by combining PVD coatings (such as AlTiN or ZrN , with a thickness of 15-20 μm±0.2 μm) and additive manufacturing technology (such as selective laser melting SLM). The mold is further optimized to support high packaging density (>1000 I/O±50 I/O), thermal cycling stress (>5000 times±500 times) and low stress packaging processes. The real-time monitoring of stress distribution and temperature changes (accuracy±1%) is achieved through integrated sensor technology, which improves thermal management capabilities (thermal conductivity>120 W/m·K±10 W/ m·K) and packaging yield (>98%±1%) to meet the needs of miniaturization and high reliability.

Carbide chip packaging mold performance

The mold has high hardness (HV 1800±30), excellent wear resistance (wear rate <0.01 mm^3 / N · m ± 0.001 mm^3 / N · m) , high durability (>8×10^5times ± 10^4times) and extremely high geometric accuracy (microchannel width 0.02-0.05 mm±0.001 mm, side wall verticality <1°±0.1°). CrN coating significantly reduces the corrosion rate (<0.008 mm/year±0.001 mm/year) and improves high temperature resistance (>350°C±10°C), while AlTiN or ZrN multilayer coating further enhances thermal cycle stability (resistant to >5000 times±500 times, heat resistance >600°C±50°C). The additive manufacturing process optimizes internal cooling channels and improves thermal management (thermal conductivity >120 W/m·K±10 W/ m·K), and sensor integration enables stress monitoring (error <5%±0.5%) and process optimization.

Types of carbide chip packaging molds

Standard mold
Based on WC-6Co and CrN coating, it is suitable for conventional BGA and QFN packages, with an accuracy of 0.05 mm ± 0.001 mm and a durability of 8×10^5 times ± 10^4 times.

High temperature mold
Adding TiC (5%-10%±0.5%) and AlTiN coating (15-20 μm±0.2 μm), heat resistance>600°C±50°C, suitable for SIP and 3D IC stacking.

Miniaturized mold
Optimized grains (<0.4 μm±0.01 μm) and SLM technology to support microchannels (width <0.02 mm±0.001 mm) to meet the needs of WLP and neuromorphic chips.

Intelligent mold
Embedded sensors and real-time monitoring modules optimize stress distribution (accuracy ±1%) and thermal management for high-density packaging (>1000 I/O±50 I/O).

Application of cemented carbide chip packaging mold

Carbide chip packaging molds are widely used in many cutting-edge fields of microelectronic device packaging. In high-density integrated circuit packaging, the mold supports BGA, QFN and WLP technologies, meeting the high-precision requirements of 5nm and below process chips, artificial intelligence accelerators and memories (precision <0.05 mm±0.001 mm). In 3D IC stacking and SIP (system-level packaging), the complex geometric design and thermal management capabilities of the mold (thermal conductivity>120 W/m·K±10 W/ m·K) promote the development of multi-chip modules and heterogeneous integration, and are widely used in edge computing modules, high-performance servers and data center hardware.
In the field of consumer electronics, molds are used for miniaturized packaging of foldable screen mobile phones and wearable devices (such as smart watches), ensuring microchannel accuracy (width 0.02-0.05 mm ± 0.001 mm) and heat cycle resistance (> 5000 times ± 500 times), improving the reliability and service life of flexible displays and wearable devices. The packaging of neuromorphic chips and quantum computing devices also relies on the ultra-high precision and low-stress process of molds to support the miniaturized design of new computing architectures.

Automotive electronics is another important application area. Molds support the packaging of advanced driver assistance system (ADAS) chips, radar modules, and on-board computing units, adapting to extreme temperature ranges (-40°C to 150°C±10°C) and high reliability requirements (yield>98%±1%). In industrial automation, molds are used for the packaging of precision sensors and actuators to improve the performance and stability of intelligent manufacturing equipment. Aerospace electronics (such as satellite communication modules) and defense electronics (such as radar and missile guidance systems) use the mold's corrosion resistance (<0.008 mm/year±0.001 mm/year) and high temperature stability (>350°C±10°C) to meet long-term use requirements in extreme environments.

Through sensor integration and digital twin technology, the mold achieves predictive maintenance (reducing downtime by >15%±2%) and process parameter optimization, making it suitable for mass production (efficiency improvement by >20%±2%) and ultra-high packaging density (>1000 I/O±50 I/O) scenarios, further expanding its application potential in future microelectronics technology.

(3) Carbide circuit board punching die

What is a carbide circuit board punching die ?

Carbide circuit board punching dies are high-precision processing tools designed specifically for the PCB processing field. They are mainly used for multilayer boards, HDI (high-density interconnect) boards, flexible circuit boards FPC, rigid-flex boards, and new high-frequency millimeter-wave circuit boards. Its core material uses WC-TiC-8Co formula (TiC 3%±0.5%), with a grain size of 0.8 μm±0.01 μm . It is sintered at high temperature (1450°C±10°C) and heat treated to enhance high-temperature fatigue resistance (fatigue life>10^7 times±10^5 times), and laser cladding technology (cladding layer thickness 20-30 μm±0.5 μm , using WC-Co powder) to repair worn edges, ensuring that the punching accuracy remains <0.01 mm±0.001 mm. The mold supports high-speed punching (>100 times/second±10 times/second), complex interlayer alignment (deviation <0.005 mm±0.001 mm) and micro-hole processing (diameter 0.1-0.2 mm±0.005 mm), and optimizes durability (>1.5×10 ^{7} times±10 ^{5} times) and conductivity (resistivity <10 μΩ·cm±0.1 μΩ·cm) through multi-material composite structures (such as WC- TiC-TaC or WC-Co-Cr) . In addition, the mold introduces nano-coating (such as WC/C, thickness 5-10 μm±0.1 μm) to improve anti-adhesion performance (friction coefficient <0.2±0.02), and adopts bionic structure (such as honeycomb internal support) to enhance impact resistance (>500 MPa±50 MPa), optimizes punching path through AI algorithm, reduces material waste (<2%±0.5%), and meets the needs of high-performance circuit board processing.

Carbide Circuit Board Punching Die Performance

The mold has high hardness (HV 1800±30), excellent wear resistance (wear rate <0.01 mm³ / N · m ± 0.001 mm³ / N · m) , high durability (>1.5×10^{7}times ± 10^{5}times) and high-precision punching (<0.01 mm±0.001 mm). Laser cladding technology repairs worn edges and maintains micro-hole processing accuracy (diameter 0.1-0.2 mm±0.005 mm), while nano-coatings (such as WC/C) reduce the friction coefficient (<0.2±0.02) and improve high-temperature oxidation resistance (>900°C±50°C). The multi-material composite structure optimizes conductivity (resistivity <10 μΩ·cm±0.1 μΩ·cm), the bionic structure enhances impact resistance (>500 MPa±50 MPa), and the AI algorithm optimization reduces material waste (<2%±0.5%), which improves high-temperature fatigue resistance as a whole (fatigue life >10 ^{7} times±10 ^{5} times).

Types of Carbide Circuit Board Punching Dies

Standard mold
Based on WC-TiC-8Co, it is suitable for punching of multilayer boards and FPCs, with an accuracy of <0.01 mm±0.001 mm and a durability of 1×10 ^{7} times±10 ^{5} times.
High temperature mold
By adding TaC (2%-5%±0.5%) and WC-Co-Cr composite structure, it has heat resistance of >900°C±50°C and is suitable for high-frequency millimeter wave circuit boards.
Micro hole mold
Optimize laser cladding (thickness 20-30 μm ± 0.5 μm) and micro-hole processing (diameter < 0.1 mm ± 0.005 mm) to meet the needs of HDI boards.
Intelligent mold
Embedded with AI algorithms and bionic structures (honeycomb support), it optimizes the punching path (accuracy ±0.5%) and impact resistance (>600 MPa±50 MPa) in real time.

Application of Carbide Circuit Board Punching Dies

Carbide circuit board punching dies are widely used in many key areas of PCB processing. In the manufacture of multi-layer boards and HDI (high-density interconnect) boards, the high-precision punching (<0.01 mm±0.001 mm) and complex interlayer alignment (deviation <0.005 mm±0.001 mm) of the dies support the high-density wiring requirements of smartphones, tablets, and server motherboards. In the processing of flexible circuit boards (FPCs) and rigid-flex boards , the high temperature resistance (>900°C±50°C) and fatigue resistance ($>10^{7}$ times$\pm10^{5}$ times) of the dies meet the miniaturization requirements of foldable screen phones, wearable devices, and flexible displays.

The production of new high-frequency millimeter-wave circuit boards relies on the conductivity of the mold (resistivity <10 μΩ·cm±0.1 μΩ·cm) and micro-hole processing capabilities (diameter 0.1-0.2 mm±0.005 mm), and is widely used in 5G base stations, antenna modules and radar systems. In the field of automotive electronics, molds support the mass production of battery management systems (BMS), in-vehicle entertainment systems and advanced driver assistance systems (ADAS) circuit boards, adapting to high temperature environments (>900°C±50°C) and high reliability requirements (yield>98%±1%). The production of smart home appliance control boards utilizes the mold's high-speed punching (>100 times/second±10 times/second) and material savings (waste <2%±0.5%) to improve the manufacturing efficiency of home appliances such as smart speakers and washing machines.

Avionics circuit boards (such as flight control modules and navigation systems) and defense electronics (such as missile guidance and communication equipment) rely on the impact resistance (>500 MPa±50 MPa) and durability ($>1.5\times10^{7}$ times$\pm10^{5}$ times) of molds to meet long-term use in extreme environments. The development of IoT devices and 6G technology further promotes the application of molds, especially in the packaging of edge computing modules and ultra-high frequency circuit boards. The molds ensure high performance and low maintenance costs (reducing downtime>15%±2%) through AI optimization and nano-coating (WC/C), supporting the intelligent and efficient development of the future electronics industry.

(4) Carbide micro connector stamping die

What is a Carbide Micro Connector Stamping Die ?

The carbide micro connector stamping die is a high-precision tool designed for the micro connector processing field. It is mainly used for micro connectors such as USB-C, HDMI, Lightning, and new high-speed interfaces (such as Thunderbolt 5, optoelectronic hybrid interface). Its core material adopts WC-10Co formula, with a grain size of 0.4 μm±0.01 μm . The ultra-fine powder injection molding technology is used to ensure material uniformity, stamping accuracy <0.003 mm±0.0005 mm, and durability of 1.5×10^{6} times$\pm10^{4}$ times. The DLC (diamond-like carbon) coating (thickness 2-5 μm±0.1 μm , hardness HV 3000±100) is applied to the mold surface by plasma enhanced chemical vapor deposition (PECVD), which significantly reduces the wear rate (<0.02 mm^3 / N · m ± 0.005 mm^3 / N · m) , improves corrosion resistance (salt spray test>500 hours±50 hours) and lubricity (friction coefficient<0.1±0.01). Combined with nano-coating (such as WC/C or aC:H, thickness 5-15 μm±0.2 μm) and micro-EDM technology, the mold supports ultra-fine structures (pitch <0.015 mm±0.001 mm), high current carrying (>5A±0.5A) and optical signal transmission stability (loss <0.1 dB/km±0.01 dB/km), and extends service life and reduces maintenance costs (<5%±1%) through self-lubricating functions (such as MoS_2 additives), meeting the needs of high-performance connector processing.

Carbide micro connector stamping die performance

The mold has high hardness (HV 2000±50), excellent wear resistance (wear rate <0.02 mm^3 / N · m ± 0.005 mm^3 / N · m) , high durability (>1.5×10^6times ± 10^4times) and ultra-high stamping accuracy (<0.003 mm±0.0005 mm). DLC coating improves corrosion resistance (salt spray resistance >500 hours±50 hours) and lubricity (friction coefficient <0.1±0.01), and nano coating (such as WC/C) further enhances durability (>2×10^6times ± 10^4times) and high temperature resistance (>600°C±50°C). The self-lubricating function optimizes maintenance costs (<5%±1%), and micro-EDM supports ultra-fine structures (pitch <0.015 mm±0.001 mm), meeting the needs of high current (>5A±0.5A) and optical signal transmission (loss <0.1 dB/km±0.01 dB/km).

Types of Carbide Micro Connector Stamping Dies

Standard mold
Based on WC-10Co and DLC coating, suitable for USB-C and HDMI stamping, accuracy <0.003 mm±0.0005 mm, durability 1.5×10^6 times±10^4 times.
High speed mold
Added WC/C nano coating (5-15 μm±0.2 μm), supports Thunderbolt 5 high current (>5A±0.5A), and durability >2×10^6 times±10^4 times.
Photoelectric mold
Optimize micro-EDM to meet the optical signal stability of the optoelectronic hybrid interface (loss <0.1 dB/km±0.01 dB/km) and accuracy <0.002 mm±0.0005 mm.
Self-lubricating mold
Embedded with MoS_2 additives and sensors, it reduces maintenance costs (<5%±1%) and is suitable for high-frequency use (>10 GHz±1 GHz).

Application of Carbide Micro Connector Stamping Dies

Carbide micro connector stamping dies are widely used in consumer electronics and data centers. In smartphones, tablets, and laptops, dies support mass production of USB-C, HDMI, and Lightning interfaces, ensuring ultra-fine structures (pitch <0.015 mm ± 0.001 mm) and high-precision stamping (<0.003 mm ± 0.0005 mm), improving the reliability and compactness of device ports. In data centers and servers, dies are used in the manufacture of Thunderbolt 5 and high-speed data interfaces to meet the needs of high current carrying (>5A ± 0.5A) and data transfer rates (>40 Gbps ± 2 Gbps).
The development of new optoelectronic hybrid interfaces relies on the optical signal transmission stability (loss <0.1 dB/km±0.01 dB/km) and durability (>1.5×10^6 times±10^4 times) of the mold,

which is widely used in fiber-optic communication equipment and high-performance computing clusters. In automotive electronics , the mold supports the processing of connectors for in-vehicle infotainment systems and advanced driver assistance systems (ADAS), adapting to high temperature environments (>600°C±50°C) and high reliability requirements (yield>98%±1%). Smart home devices such as smart speakers and routers also use the high-speed punching (>100 times/second±10 times/second) and corrosion resistance (salt spray resistance>500 hours±50 hours) of the mold to improve product durability.

Industrial automation and IoT devices (such as industrial control modules and sensor nodes) rely on the lubricity (friction coefficient <0.1±0.01) and self-lubricating function of the mold to reduce maintenance costs (<5%±1%) and optimize production efficiency (increase >20%±2%). Aerospace electronics (such as satellite communication modules) and defense electronics (such as encrypted communication equipment) use the impact resistance (>500 MPa±50 MPa) and durability of the mold to meet the needs of long-term use in extreme environments. Through nano-coating and AI optimization, the mold further supports the development of future high-speed interfaces (such as 6G communications) and miniaturized connectors, promoting the efficiency and intelligence of the electronics industry.

(5) Carbide sensor packaging mold

What is a carbide sensor packaging mold ?

Cemented carbide sensor packaging molds are high-precision tools designed specifically for the sensor packaging field, mainly used for MEMS (micro-electromechanical systems), environmental sensors (such as pressure, temperature, gas sensors) and medical sensors (such as blood oxygen, ECG sensors). Its core material uses WC-Co-Ni formula (Ni 2%±0.5%), grain size 0.7 μm±0.01 μm , and hot isostatic pressing (HIP, 1200°C±10°C, 150 MPa±1 MPa) to improve density (porosity <0.5%±0.1%), support complex 3D structures (height 0.05-0.1 mm±0.005 mm, side wall roughness Ra<0.2 μm±0.05 μm), and life span of about 7×10^5 times$\pm10^4$ times. ALD (atomic layer deposition) coating (such as Al_2O_3 , thickness 10-20 nm ± 0.5 nm) is applied to the mold surface to enhance moisture resistance (humidity resistance > 95% RH ± 2% RH) and antibacterial performance (antibacterial rate > 99% ± 0.5%), and micro cooling channels (diameter 0.01-0.02 mm ± 0.001 mm) are used to optimize the high-temperature packaging process (> 200 ° C ± 10 ° C). Embedded sensors monitor packaging stress (< 10 MPa ± 1 MPa) to meet the requirements of miniaturization (size < 1 mm^3 ± 0.1 mm^3), high precision (deviation < 0.001 mm ± 0.0002 mm) and biocompatibility (in accordance with ISO 10993 standard).

Carbide sensor packaging mold performance

The mold has high hardness (HV 1800±30), excellent wear resistance (wear rate <0.01 mm^3 / N · m ± 0.001 mm^3 / N · m) , high durability (>7×10^5times ± 10^4times) and high-precision packaging (deviation <0.001 mm±0.0002 mm). The Al_2O_3 coating improves moisture resistance (>95% RH ±2%RH) and antibacterial performance (antibacterial rate>99%±0.5%), micro cooling channels optimize thermal management (temperature control <200°C±10°C), embedded sensors monitor stress (<10 MPa±1 MPa), and supports complex 3D structures (height 0.05-0.1 mm±0.005 mm, sidewall roughness Ra<0.2 μm±0.05 μm), meeting biocompatibility and high-temperature packaging requirements.

Types of carbide sensor packaging molds

Standard mold

Based on WC-Co-Ni and Al_2O_3 coating , suitable for MEMS and environmental sensors, with accuracy <0.001 mm ± 0.0002 mm and durability 7× 10^5times ± 10^4times .

High temperature mold

Adding TiC (5%-10%±0.5%) supports high temperature packaging (>200°C±10°C), which is suitable for industrial IoT sensors.

Medical mold

Optimized biocompatibility (ISO 10993), micro-cooling channels (diameter <0.01 mm ± 0.001 mm) for blood oxygen and ECG sensors.

Intelligent mold

Embedded stress sensor for real-time monitoring (accuracy ±1%), suitable for high-precision wearable device packaging.

Application of carbide sensor packaging mold

Carbide sensor packaging molds are widely used in smart home, industrial Internet of Things and medical electronics. In smart home, molds support the packaging of smart thermostats, air quality sensors and smart lighting controllers, ensuring miniaturization (size <1 mm^3 ± 0.1 mm^3) and high precision (deviation <0.001 mm±0.0002 mm), improving equipment responsiveness and energy saving. In industrial Internet of Things, molds are used for the packaging of pressure, temperature and vibration sensors in smart factories, adapting to high temperature environments (>200°C±10°C) and complex 3D structures (height 0.05-0.1 mm±0.005 mm), supporting automation and predictive maintenance of Industry 4.0 (reducing downtime by >15%±2%).

Medical electronics is an important application area. The mold supports the packaging of blood oxygen sensors, ECG (electrocardiogram) sensors and insulin pumps. With biocompatibility (in compliance with ISO 10993 standards) and antibacterial properties (antibacterial rate > 99% ± 0.5%), it meets the high reliability requirements of wearable heart monitors and implantable medical devices (yield > 98% ± 1%). In consumer electronics, molds are used for environmental sensor packaging of smart watches and fitness trackers to improve moisture resistance (> 95% RH ± 2% RH) and durability (> 7 × 10^5 times ± 10^4 times).

In the field of automotive electronics, molds support the packaging of on-board sensors (such as tire pressure monitoring and collision detection sensors) to adapt to extreme temperature ranges (-40°C to 150°C±10°C) and high precision requirements (deviation <0.001 mm±0.0002 mm). Aerospace electronics (such as flight data recorders) and defense electronics (such as chemical warfare agent detection sensors) use the corrosion resistance and durability of molds to meet long-term use in extreme environments. In IoT and edge computing devices, molds optimize sensor performance through micro cooling channels and stress monitoring (<10 MPa±1 MPa), supporting the efficient and intelligent development of future sensor networks.

(6) Carbide laser drilling mold

What is Carbide Laser Drilling Tool ?

The cemented carbide laser drilling die is a high-precision tool designed for micro-hole processing (blind holes, buried holes) of HDI boards and high-end circuit boards (such as server motherboards, radar PCBs, satellite communication boards). Its core material adopts WC-TiC-6Co formula with a grain size of 0.9 μm±0.01 μm . It is enhanced in durability by high-temperature sintering (1450°C±10°C) and laser surface hardening (hardness increased to HV 2000±50). The drilling accuracy is <0.015 mm±0.001 mm, and the aperture deviation is <0.005 mm±0.001 mm. The die adopts TiCN coating (thickness 10-15 μm±0.2 μm , using CVD technology) to enhance resistance to laser thermal shock (>10^4 times±10^3 times), and supports high energy density laser drilling (>10^6 W/cm^2 ± 10^5 W/cm^2). Combined with porous structure design (pore density >1000/cm² ± 100 /cm²) and UV laser resistance (wavelength 193 nm±1 nm, resistance >10^5 times±10^4 times), the mold optimizes performance through ultra-precision processing technology (such as femtosecond laser) and self-healing coating (such as TiAlCN , thickness 15-25 μm±0.3 μm). The multi-layer gradient structure improves thermal conductivity (>200 W/m·K±10 W/ m·K) and reduces thermal cracks (length <0.01 mm±0.001 mm), meeting the needs of high-end circuit board micro-hole processing.

Carbide laser drilling die performance

The mold has high hardness (HV 2000±50), excellent wear resistance (wear rate <0.01 mm³ / N · m ± 0.001 mm³ / N · m) , high durability (>10^5 times±10^4 times) and high-precision drilling (<0.015 mm±0.001 mm, hole diameter deviation <0.005 mm±0.001 mm). TiCN coating enhances resistance to laser thermal shock (>10^4 times±10^3 times), and self-healing coatings (such as TiAlCN) optimize durability (>2×10^5 times±10^4 times) and thermal stability (>800°C±50°C). The multi-layer gradient structure improves thermal conductivity (>200 W/m·K±10 W/ m·K), reduces thermal cracks (<0.01 mm±0.001 mm), supports high energy density (>10^6 W/cm^2 ± 10^5 W/cm^2) and UV laser tolerance (wavelength 193 nm±1 nm, >10^5 times±10^4 times).

Types of Carbide Laser Drilling Dies

Standard mold

Based on WC-TiC-6Co and TiCN coating, it is suitable for blind holes in HDI boards with an accuracy of <0.015 mm±0.001 mm and a durability of 1×10^5 times±10^4 times.

High temperature mold

Add TiAlCN self-repairing coating (15-25 μm±0.3 μm), heat resistance>800°C±50°C, suitable for radar PCB drilling.

Multi-hole mold

Optimized porous structure (pore density >1000/cm² ± 100 /cm²) , supports high-density micropores in satellite communication boards, and is UV-resistant >10^5 times ±10^4 times.

Ultra-precision mold

Femtosecond laser processing is used to meet the requirements of AR/VR equipment micropores (aperture <0.01 mm±0.001 mm) and thermal conductivity>200 W/m·K±10 W/ m·K .

Application of cemented carbide laser drilling mold

Carbide laser drilling dies are widely used in high-end circuit board processing. In HDI board micro-hole processing, the dies support precision drilling of blind and buried holes (accuracy <0.015 mm±0.001 mm), meeting the high-density wiring requirements of smartphones, tablets, and notebook motherboards. In server motherboard and data center circuit board production, the high energy density tolerance (>10^6 W/cm² ± 10^5 W/cm²) and thermal conductivity (>200 W/m·K±10 W/ m·K) of the dies ensure reliable connection of high-performance processors.

The manufacturing of radar PCB and satellite communication boards relies on the mold's resistance to laser thermal shock (>10^4 times ±10^3 times) and porous structure (pore density >1000/cm² ± 100/cm²), supporting micro-hole processing of 5G antennas, millimeter-wave radars, and aerospace communication modules. In the field of high-end consumer electronics, such as AR/VR devices and smart glasses, molds use femtosecond laser technology to achieve ultra-micro holes (aperture <0.01 mm±0.001 mm), improving the integration of optical and electronic components. In the field of automotive electronics, molds are used for micro-hole processing of advanced driver assistance systems (ADAS) and vehicle-mounted radar circuit boards, adapting to high temperature environments (>800°C±50°C) and high reliability requirements (yield >98%±1%).

Aerospace electronics (such as flight control modules and navigation systems) and defense electronics (such as missile guidance and electronic countermeasures systems) use the mold 's UV laser resistance (wavelength 193 nm ± 1 nm, >10^5 times ± 10^4 times) and durability (>10^5 times ± 10^4 times) to meet long-term use requirements in extreme environments. Industrial automation and IoT devices (such as smart factory control boards) rely on the mold's thermal crack control (<0.01 mm ± 0.001 mm) and self-healing coating to optimize production efficiency (increase > 20% ± 2%) and reduce maintenance costs (<5% ± 1%). With the development of 6G and millimeter wave technology, the mold further supports the efficient processing of future high-frequency circuit boards through multi-layer gradient structures and AI optimization.

The development and prospects of cemented carbide molds in the electronics industry

With the growing demand for miniaturization of microelectronic devices (5nm and below process), flexible electronics (stretchable circuits, OLEDs and e-textiles), 5G/6G communications, new energy vehicle electronics (such as battery management systems and charging pile control boards), IoT devices and smart medical equipment, the application scope and performance optimization requirements of cemented carbide electronic industry molds have increased significantly.

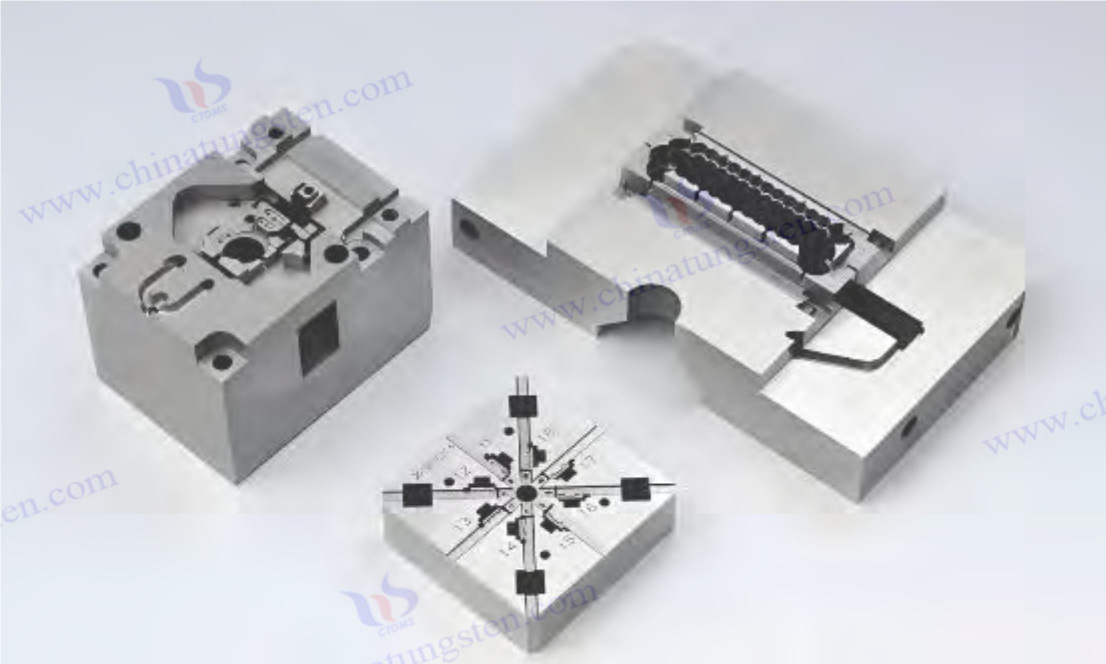
The rapid development of the electronics industry has promoted the iteration of cemented carbide mold technology. New advanced coatings (such as ZrN , AlCrN , WC/C, thickness 15-25 μm±0.2 μm) and additive manufacturing technologies (such as SLM, EBM) have been added to improve mold life (>2×10^{6} times±10^{4} times), precision (<0.002 mm±0.0005 mm) and versatility (such as thermal conductivity>150 W/m·K±10 W/ m·K , insulation>10^{12} Ω· cm ± 10^{11} Ω· cm). As a high-end consumer field, cemented carbide molds have performed outstandingly in the fields of AI chips, quantum computing, electric vehicle electronics, flexible displays and smart medical devices. In the future, molds will develop in the direction of intelligence, integrating sensors to monitor wear (real-time accuracy <0.001 mm±0.0001 mm), adaptive adjustment functions (stress compensation <5 MPa±0.5 MPa) and environmentally friendly design (reducing the use of heavy metals <1%±0.1%) to meet the dual challenges of high reliability, low cost and sustainable development in the electronics industry. At the same time, global supply chain adjustments and regional production (such as East China and Southeast Asia) will further promote the optimization of the mold industry layout.

In the electronics industry, cemented carbide heat sink substrates have become core components of high-power electronic device heat dissipation solutions due to their excellent high thermal conductivity, high temperature resistance, low thermal expansion coefficient and excellent electrical insulation performance. As the electronics industry rapidly develops towards high performance, compactness and intelligence, the demand for cemented carbide heat sink substrates has increased significantly. These substrates need to have high thermal conductivity (>200 W/m·K±10 W/ m·K), low thermal expansion coefficient (about 4-6×10^{-6}/°C ± 0.5 × 10^{-6}/°C) and excellent insulation (volume resistivity>10^{12} Ω· cm ± 10^{11} Ω· cm), to effectively address the heat dissipation challenges of LEDs, 5G/6G base stations, electric vehicle power modules, artificial intelligence chips and emerging fields such as quantum computing devices. The material is prepared by compounding WC (tungsten carbide) with Cu (copper), diamond, AlN (aluminum nitride), SiC (silicon carbide) or BN (boron nitride) particles (particle size 10-50 nm±1 nm), and using advanced processes such as cold pressing sintering (1200°C±10°C, 40 MPa±1 MPa), hot pressing diffusion (1300°C±10°C, 50 MPa±2 MPa) or isostatic pressing (HIP, 1200°C±10°C, 150 MPa±5 MPa) to ensure uniform distribution, density (porosity <1%±0.1%) and microstructural stability (grain size <1 μm±0.05 μm). These substrates are further improved in heat dissipation efficiency and reliability through precision processing (such as chemical mechanical polishing CMP, surface roughness Ra<0.1 μm±0.02 μm) and surface modification (such as CVD coating, plasma spraying).

With the high-density integration of electronic devices (>10^{6} transistors/mm^{2} ± 10^{5} transistors/mm^{2}), increased power density (>100 W/cm^{2} ± 10 W/cm^{2}) and higher operating temperature (>150°C±10°C), the market size of cemented carbide heat dissipation substrates is expected to reach

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

US$3 billion ± US$300 million, with an annual growth rate of 20%-25%, becoming a high-end application field in the cemented carbide industry, especially in the next generation of communications, new energy vehicles, industrial automation and defense electronics.



14.1.2 Hard alloy heat dissipation substrate for electronics industry

(1) Tungsten carbide copper (WC-Cu) composite heat dissipation substrate

What is tungsten carbide copper (WC-Cu) composite heat sink ?

Tungsten carbide copper (WC-Cu) composite heat dissipation substrate is a high-performance material designed for efficient thermal management . It is mainly used in LED lighting modules, power electronic modules (such as IGBT, MOSFET drivers), consumer electronics power management units, electric vehicle inverters and data center server power supplies. It is made of WC and Cu (volume ratio 70:30±1%) composite, and is prepared by cold pressing sintering (1200°C±10°C, 40 MPa±1 MPa) combined with subsequent heat treatment (1000°C±10°C, annealing for 2 hours±0.1 hours, nitrogen protection) to ensure material uniformity and microstructural density (porosity <0.8%±0.1%). The substrate has a thermal conductivity of 220 W/m·K±10 W/ m·K , a thermal expansion coefficient of 5×10^{-6} /°C±0.5×10^{-6} /°C, a thickness of 0.5-1 mm±0.01 mm, is light (density 12-13 g/cm^3 ± 0.1 g/cm^3), and has high mechanical strength (compressive strength>2500 MPa±100 MPa). The surface is electroplated with a Ni/Au layer (thickness 0.1-0.3 µm±0.01 µm) to enhance weldability and oxidation resistance (high temperature resistance>300°C±10°C, moisture resistance>95%RH±2%RH), and a chemically plated Ni-P layer (thickness 1-3 µm±0.1 µm) to improve corrosion resistance (salt spray test>500 hours±50 hours).

Combining a multilayer structure (thickness 0.3-0.7 mm±0.01 mm) and a microchannel cooling system (diameter 0.02-0.05 mm±0.001 mm, flow rate >0.1 L/min±0.01 L/min), the substrate uses nano-Cu particles (particle size <10 nm±0.5 nm) to enhance the interface bonding force (adhesion strength >60 MPa±5 MPa) and laser micromachining technology to achieve surface microtexture (roughness Ra<0.05 μm±0.01 μm), optimize heat dissipation efficiency (>250 W/m·K±10 W/ m·K), thermal stress (<15 MPa±1 MPa) and thermal uniformity (temperature gradient <3°C±0.3°C), and meet high-performance heat dissipation requirements.

Tungsten Carbide Copper (WC-Cu) Composite Heat Dissipation Substrate Performance

The substrate has high thermal conductivity (220 W/m·K±10 W/ m·K , optimized to >250 W/m·K±10 W/ m·K), low thermal expansion coefficient (5×10^{-6} /°C±0.5×10^{-6} /°C), high mechanical strength (compressive strength>2500 MPa±100 MPa) and lightweight design (density 12-13 g/cm³ ± 0.1 g/cm³). The Cu phase improves electrical conductivity (>10^6 S/m±10^5 S/m), reduces resistive heating (<0.5°C/W±0.05°C/W), and optimizes thermal cycling performance (-40°C to 150°C±10°C, number of cycles>5000 times±500 times). The Ni/Au plating layer enhances solderability (high temperature resistance >300°C±10°C, moisture resistance >95%RH±2%RH), and the Ni-P layer improves corrosion resistance (salt spray resistance >500 hours±50 hours). The microchannel cooling system and nano-Cu particles further improve heat dissipation efficiency and interface bonding (adhesion strength >60 MPa±5 MPa), and AI-driven thermal simulation reduces thermal stress (<15 MPa±1 MPa) and temperature gradient (<3°C±0.3°C).

Types of tungsten carbide copper (WC-Cu) composite heat sink substrates

Standard substrate
Based on WC-Cu 70:30 and Ni/Au coating, suitable for LED lighting modules, thickness 0.5-1 mm±0.01 mm, thermal conductivity 220 W/m·K±10 W/ m·K .
High temperature substrate
Adding Ni-P layer (1-3 μm±0.1 μm), heat resistance>300°C±10°C, suitable for IGBT and MOSFET drivers.
Miniaturized substrate
Optimized multilayer structures (thickness 0.3-0.7 mm ± 0.01 mm) and microchannels (diameter 0.02-0.05 mm ± 0.001 mm) for micro-LED and AR/VR devices.
Intelligent substrate
Integrates AI thermal simulation and nano-Cu particles (particle size <10 nm±0.5 nm), with heat dissipation efficiency >250 W/m·K±10 W/ m·K , suitable for data center power supplies.

Application of tungsten carbide copper (WC-Cu) composite heat dissipation substrate

Tungsten carbide copper (WC-Cu) composite heat dissipation substrates are widely used in lighting, electronics and electric vehicles. In LED lighting modules, the substrate supports high-brightness LED arrays (power density>50 W/cm² ± 5 W/cm² , brightness>200 lm /W±10 lm /W), which are used for smart street lights, vehicle-mounted LEDs and indoor lighting, improving light efficiency and heat dissipation performance (thermal conductivity 220 W/m·K±10 W/ m·K). In power electronic modules, the substrate is used for IGBT and MOSFET drivers, optimizing thermal cycle performance (>5000 times±500 times) and electrical conductivity (>10^6 S/m±10^5 S/m), meeting the needs of industrial motor drives and renewable energy inverters.

Consumer electronic power management units such as laptop power adapters and high-power chargers rely on the lightweight (density 12-13 g/cm³ ± 0.1 g/cm³) and corrosion resistance (salt spray resistance >500 hours ±50 hours) of the substrate to improve equipment reliability and service life. In electric vehicle inverters, the high mechanical strength of the substrate (>2500 MPa±100 MPa) and microchannel cooling (flow rate >0.1 L/min±0.01 L/min) support efficient heat dissipation (>250 W/m·K±10 W/ m·K) and thermal uniformity (<3°C±0.3°C) to meet the high power requirements of new energy vehicles. Data center server power supplies use the AI-optimized design of the substrate and nano-Cu particles (adhesion strength >60 MPa±5 MPa) to reduce thermal stress (<15 MPa±1 MPa) and improve heat dissipation efficiency, supporting the stable operation of high-performance computing and AI accelerators.

In the field of micro-LED, the substrate supports displays with pixel density >1000 PPI±100 PPI and automotive LEDs (durability >10^5 hours ±10^4 hours), which are used in AR/VR devices and automotive lighting systems. Medical electronics such as high-power medical devices and aerospace electronics (such as satellite power modules) rely on the substrate's high temperature resistance (>300°C±10°C) and humidity resistance (>95%RH±2%RH) to meet the heat dissipation requirements in extreme environments. Industrial automation and edge computing modules use the substrate's surface micro-texture (roughness Ra<0.05 μm±0.01 μm) and multi-layer structure to optimize production efficiency (increase >20%±2%) and reduce maintenance costs (<5%±1%), promoting the widespread application of high-performance heat dissipation technology in the future.

(2) Tungsten carbide-diamond (WC-Diamond) composite heat dissipation substrate

What is a tungsten carbide-diamond (WC-Diamond) composite heat dissipation substrate ?

Tungsten carbide-diamond (WC-Diamond) composite heat dissipation substrate is a high-end material designed for high-performance thermal management . It is mainly used in 5G/6G base station RF modules, electric vehicle power electronics (inverters, charging pile controllers), high-performance computing servers and military radar systems. It is made of WC and diamond (particle size 20 nm±1 nm, volume ratio 60:40±1%), and is prepared by hot pressing diffusion (1300°C±10°C, 50 MPa±2 MPa) and isostatic pressing (HIP, 1200°C±10°C, 150 MPa±5 MPa) processes to ensure material density (porosity <0.6%±0.1%) and grain uniformity (<0.8 μm±0.05 μm). The thermal conductivity of the substrate is 320 W/m·K±10 W/ m·K , and the insulation is >10^{13} Ω· cm ± 10^{12} Ω· cm , thickness 0.3-0.8 mm±0.01 mm, temperature resistance>400°C±10°C (thermal stability>500 hours±50 hours), high mechanical strength (flexural strength>3000 MPa±100 MPa).

The surface is coated with CVD diamond coating (thickness 1-3 μm±0.1 μm) to enhance wear resistance (hardness HV 8000±500) and heat dissipation uniformity (temperature gradient <5°C±0.5°C), and plasma cleaning technology is used to optimize interface adhesion (>50 MPa±5 MPa). Combined with the gradient composite structure (WC content 30%-60%±1%) and the nano heat dissipation layer (thickness <0.1 μm±0.01 μm), the substrate is optimized by laser micromachining technology. The surface microstructure (porosity 1%-2%±0.1%) increases the heat dissipation area (>300 cm² ± 20 cm²) and reduces the thermal resistance (<0.2°C/W±0.02°C/W). The adaptive thermal management module (response time <0.1 s±0.01 s) monitors the temperature by embedding thermocouples (accuracy <0.2°C±0.02°C) to meet the needs of high-frequency and ultra-large current heat dissipation.

Tungsten Carbide-Diamond (WC-Diamond) Composite Heat Dissipation Substrate Performance

The substrate has ultra-high thermal conductivity (320 W/m·K±10 W/ m·K , after optimization>350 W/m·K±10 W/ m·K), excellent insulation (>10 ^{13} Ω· cm ± 10 ^{12} Ω· cm), high mechanical strength (flexural strength>3000 MPa±100 MPa) and high temperature resistance (>400°C±10°C, thermal stability>500 hours±50 hours). Diamond coating improves wear resistance (hardness HV 8000±500) and heat dissipation uniformity (temperature gradient<5°C±0.5°C), nano heat dissipation layer reduces thermal resistance (<0.2°C/W±0.02°C/W), and gradient structure optimizes thermal conduction (>350 W/m·K±10 W/ m·K). The adaptive thermal management module monitors temperature through thermocouples (accuracy<0.2°C±0.02°C, response time<0.1 s±0.01 s), supporting high-frequency power devices (>10 GHz±1 GHz) and high power density (>200 W/cm² ± 20 W/cm²) applications.

Types of tungsten carbide-diamond (WC-Diamond) composite heat dissipation substrates

Standard substrate
Based on WC-Diamond 60:40 and CVD coating, it is suitable for 5G base station RF modules with a thickness of 0.3-0.8 mm±0.01 mm and a thermal conductivity of 320 W/m·K±10 W/ m·K .
High temperature substrate
Added gradient structure (WC 30%-60%±1%), heat resistance>400°C±10°C, suitable for electric vehicle inverters.
High frequency substrate
Integrated nano heat sink (thickness <0.1 μm±0.01 μm), supports >10 GHz±1 GHz devices, and thermal resistance <0.2°C/W±0.02°C/W.
Intelligent substrate
Embedded adaptive thermal management module and thermocouple, heat dissipation area >300 cm² ± 20 cm² , suitable for military radar systems.

Application of tungsten carbide-diamond (WC-Diamond) composite heat dissipation substrate

Tungsten carbide-diamond (WC-Diamond) composite heat dissipation substrates are widely used in communications, electric vehicles and military fields. In 5G/6G base station RF modules, the substrate supports high-frequency power devices (such as GaN HEMT, >10 GHz±1 GHz) and high power density (>200 W/cm² ± 20 W/cm²) , and is used for heat dissipation of antennas and RF amplifiers, meeting ultra-high thermal conductivity (320 W/m·K±10 W/ m·K) and insulation (>10 ^{13} Ω· cm ± 10 ^{12} In electric vehicle power electronics, the substrate is used in inverters and charging pile controllers to optimize thermal cycle performance (>5000 times ±500 times) and high temperature resistance (>400°C±10°C), support fast charging power (> 350 kW±10 kW) and efficient operation of the battery management system.

High-performance computing servers rely on the gradient structure and nano-heat dissipation layer of the substrate (thermal resistance <0.2°C/W±0.02°C/W) to reduce thermal stress (<15 MPa±1 MPa) and increase the heat dissipation area (>300 cm² ± 20 cm²) , supporting the stable performance of AI accelerators and data centers. Military radar systems use the mechanical strength (bending strength >3000 MPa±100 MPa) and wear resistance (hardness HV 8000±500) of the substrate to meet the long-term use of radar modules and electronic countermeasure systems in extreme environments (thermal stability >500 hours±50 hours). Avionics equipment (such as flight control modules and satellite power supplies) rely on the high temperature resistance and heat dissipation uniformity of the substrate (temperature gradient <5°C±0.5°C) to improve equipment reliability and life.

In the consumer electronics field, substrates support the heat dissipation needs of AR/VR devices and high-performance game consoles, and adapt to high-frequency and ultra-high current (>100A±5A) applications. Industrial automation and IoT devices (such as smart factory control boards) use the substrate's adaptive thermal management (response time <0.1 s±0.01 s) and laser micro-machined surface (roughness optimization) to improve production efficiency (>20%±2%) and reduce maintenance costs (<5%±1%). With the development of 6G millimeter wave technology, substrates can further meet the heat dissipation challenges of future high-frequency communications and power electronics through AI-driven optimization and microstructure design.

(3) Tungsten carbide-aluminum nitride (WC- AlN) composite heat dissipation substrate

What is tungsten carbide-aluminum nitride (WC- AlN) composite heat sink ?

Tungsten carbide-aluminum nitride (WC- AlN) composite heat dissipation substrate is a high-performance material designed for thermal management of high-frequency electronics and medical equipment . It is mainly used in high-frequency electronic devices (such as RF modules, microwave radars, satellite communication equipment), medical electronics (such as MRI power amplifiers, ultrasonic equipment) and industrial sensors. It is made of WC and AlN (volume ratio 50:50±1%) composite, and is prepared by cold pressing sintering (1200°C±10°C, 40 MPa±1 MPa) and high temperature annealing (1300°C±10°C, nitrogen protection) to ensure material density (porosity <0.7%±0.1%) and thermal matching. The thermal conductivity of the substrate is 160 W/m·K±5 W/ m·K , and the insulation is >10^{14} Ω·cm±10^{13} Ω·cm , thickness 0.4-0.6 mm±0.01 mm, thermal expansion coefficient matched silicon (4.5×10^{-6} /°C±0.5×10^{-6} /°C, deviation <0.5×10^{-6} /°C±0.1×10^{-6} /°C).

The substrate combines the high insulation of AlN and the mechanical strength of WC (bending strength>400 MPa±20 MPa), which is suitable for high-frequency circuits (operating frequency >20 GHz±2 GHz) and high-temperature environments (>250°C±10°C), and has high mechanical durability (>10^6 times±10^4 times). The surface is coated with Si_3N_4 (thickness 0.5-1 μm±0.05 μm) to improve moisture resistance (humidity resistance>95%RH±2%RH) and thermal shock resistance (>1000 times±100 times), and the micro-arc oxidation technology is used to optimize the interface bonding strength (adhesion strength>50 MPa±5 MPa). Combining a multi-layer gradient design (AlN content 40%-60%±1%) and a thermoelectric separation layer (thickness 0.02-0.05 mm±0.001 mm), the substrate uses nanoscale particle dispersion technology (particle size <10 nm±0.5 nm) to improve thermal conductivity uniformity (<2°C±0.2°C) and reduce thermal stress (<10 MPa±1 MPa), meeting the needs of efficient heat dissipation.

Tungsten Carbide-Aluminum Nitride (WC- AlN) Composite Heat Dissipation Substrate Performance

The substrate has high thermal conductivity (160 W/m·K±5 W/ m·K), excellent insulation (>10^{14} Ω·cm±10^{13} Ω·cm), high mechanical strength (flexural strength>400 MPa±20 MPa) and thermal matching (deviation<0.5×10^{-6} /°C±0.1×10^{-6} /°C). Si_3N_4 coating improves moisture resistance (>95%RH±2%RH) and thermal shock resistance (>1000 times±100 times), multi-layer gradient structure optimizes thermal conductivity uniformity (<2°C±0.2°C), and thermoelectric separation layer reduces thermal stress (<10 MPa±1 MPa). Nano-scale particle dispersion technology enhances durability (>2×10^6 times±10^4 times), supports high temperature environments (>250°C±10°C) and high frequency applications (>20 GHz±2 GHz).

tungsten carbide-aluminum nitride (WC- AlN) composite heat sink substrates

Standard substrate
Based on WC- AlN 50:50 and Si_3N_4 coating, suitable for RF modules, thickness 0.4-0.6 mm±0.01 mm, thermal conductivity 160 W/m·K±5 W/ m·K .
High temperature substrate
Added thermoelectric separation layer (0.02-0.05 mm ± 0.001 mm), heat resistance > 250 ° C ± 10 ° C, suitable for MRI power amplifier.
High frequency substrate
Optimized gradient structure (AlN 40%-60%±1%), supporting >20 GHz±2 GHz circuits, with uniformity <2°C±0.2°C.
Nano-enhanced substrates
Integrated nanoparticles (particle size <10 nm±0.5 nm), thermal stress <10 MPa±1 MPa, suitable for microwave radar.

tungsten carbide-aluminum nitride (WC- AlN) composite heat dissipation substrate

Tungsten carbide-aluminum nitride (WC- AlN) composite heat dissipation substrates are widely used in high-frequency electronics, medical and aviation fields. In high-frequency electronic devices, the substrate supports high-frequency circuits (>20 GHz±2 GHz) of RF modules, microwave radars and satellite communication equipment. With high insulation (>10^{14} Ω·cm±10^{13} Ω·cm) and thermal conductivity (160 W/m·K±5 W/ m·K), meeting the heat dissipation requirements of 5G/6G base stations and communication antennas. In medical electronics, substrates are used in MRI power amplifiers and ultrasonic equipment to optimize thermal matching (deviation <0.5×10^{-6} /°C±0.1×10^{-6} /°C) and high temperature resistance (>250°C±10°C), and improve equipment accuracy and reliability (yield>98%±1%).

Industrial sensors, such as temperature and pressure sensors for smart factories, rely on the mechanical durability (>10^{6} times ±10^{4} times) and thermal shock resistance (>1000 times ±100 times) of the substrate to support automation and predictive maintenance of Industry 4.0 (reducing downtime by >15% ±2%). Avionics such as flight control systems and navigation modules utilize the lightweight (thickness 0.4-0.6 mm ±0.01 mm) and high mechanical strength (>400 MPa ±20 MPa) of the substrate to meet long-term use in extreme environments (thermal stability >500 hours ±50 hours). Smart medical devices such as implantable heart rate monitors and portable ultrasound devices rely on the moisture resistance (>95%RH ±2%RH) and gradient design of the substrate to optimize heat dissipation uniformity (<2°C ±0.2°C) and reduce thermal stress (<10 MPa ±1 MPa).

In the field of consumer electronics, substrates support the heat dissipation needs of high-performance computing devices and communication terminals, and adapt to high temperature and high frequency environments. Defense electronics such as electronic countermeasure systems and radar modules use the corrosion resistance and nano-enhancement technology of substrates to meet military-grade reliability and durability requirements (>2×10^{6} times ±10^{4} times). With the development of millimeter-wave radars, neural network accelerators, and biomedical devices, substrates further improve heat dissipation efficiency (>20%±2%) and thermal management performance through AI optimization and thermoelectric separation layers, promoting the widespread use of high-tech applications in the future.

(4) Tungsten carbide-silicon carbide (WC- SiC) composite heat dissipation substrate

What is tungsten carbide-silicon carbide (WC- SiC) composite heat sink ?

Tungsten carbide-silicon carbide (WC - SiC) composite heat dissipation substrate is a high-performance thermal management material designed for high-power and industrial applications . It is mainly used in high-power lasers, power electronic inverters, industrial automation control systems and railway traction equipment. It is made of WC and SiC (silicon carbide, particle size 15-40 nm±1 nm, volume ratio 65:35±1%) composite, prepared by hot pressing diffusion (1350°C±10°C, 60 MPa±2 MPa) to ensure material density (porosity <0.9%±0.1%) and thermal stability. The substrate has a thermal conductivity of 180 W/m·K±5 W/ m·K , a thermal expansion coefficient of 4.8×10^{-6} /°C±0.5×10^{-6} /°C, a thickness of 0.6-1.2 mm±0.01 mm, and a temperature resistance of >450°C±10°C (thermal cycle life>1000 hours±100 hours). The substrate combines the high thermal conductivity of SiC (>200 W/ m ·K) and the corrosion resistance of WC (acid resistance <0.01 mm/year±0.001 mm/year), making it suitable for high voltage devices (such as 1000V±50V) and high power density applications (>150 W/cm² ± 15 W/cm²) , and has high mechanical strength (impact strength>600 MPa±50 MPa). The surface is coated with TiSiN (thickness 5-10 μm ± 0.2 μm) to enhance oxidation resistance and wear resistance (hardness HV 2500 ± 100), and the coating adhesion (> 60 MPa ± 5 MPa) is optimized by plasma spraying technology. Combined with a porous structure (porosity 1%-3% ± 0.1%) and carbon fiber reinforcement (content 1%-2% ± 0.1%), the substrate increases the heat dissipation area (> 200 cm ² ± 10 cm ²) and impact resistance (> 500 MPa ± 50 MPa), meeting high reliability requirements.

Tungsten Carbide-Silicon Carbide (WC- SiC) Composite Heat Dissipation Substrate Performance

The substrate has high thermal conductivity (180 W/m·K±5 W/ m·K), low thermal expansion coefficient (4.8×10^{-6} /°C±0.5×10^{-6} /°C), high mechanical strength (impact strength>600 MPa±50 MPa) and high temperature resistance (>450°C±10°C, thermal cycle life>1000 hours±100 hours). The TiSiN coating improves oxidation resistance and wear resistance (hardness HV 2500±100) and has excellent corrosion resistance (acid resistance <0.01 mm/year±0.001 mm/year). The porous structure increases the heat dissipation area (>200 cm² ± 10 cm²) , and the carbon fiber reinforcement optimizes the impact resistance (>500 MPa±50 MPa), supporting high voltage (1000V±50V) and high power density (>150 W/cm² ± 15 W/cm²) applications.

tungsten carbide-silicon carbide (WC- SiC) composite heat sink substrates

Standard substrate
Based on WC -SiC 65:35 and TiSiN coating, suitable for laser cutting machines, thickness 0.6-1.2 mm ± 0.01 mm, thermal conductivity 180 W/m·K ± 5 W/ m·K .
High temperature substrate
Optimized thermal cycle life (>1000 hours ±100 hours), heat resistance >450°C±10°C, suitable for power electronic inverters.
Porous substrate
Integrated porous structure (porosity 1%-3%±0.1%), heat dissipation area >200 cm² ± 10 cm² , suitable for wind power converters.
Enhanced substrate
With the addition of carbon fiber (1%-2%±0.1%), the impact resistance is >500 MPa±50 MPa, which is suitable for industrial robots.

tungsten carbide-silicon carbide (WC- SiC) composite heat dissipation substrate

Tungsten carbide-silicon carbide (WC- SiC) composite heat dissipation substrates are widely used in high-power industrial and energy fields. In high-power lasers, the substrates support high power density (>150 W/cm² ± 15 W/cm²) and high temperature resistance (>450°C±10°C) of laser cutting machines and welding equipment , improving processing efficiency and equipment life. In power electronic inverters, the substrates are used in wind power converters and solar inverters to optimize thermal conductivity (180 W/m·K±5 W/ m·K) and corrosion resistance (acid resistance <0.01 mm/year±0.001 mm/year), meeting high voltage (1000V±50V) requirements.

Industrial automation control systems rely on the mechanical strength (impact strength > 600 MPa ± 50 MPa) and porous structure (heat dissipation area > 200 cm ² ± 10 cm ²) of the substrate to support the stable operation of industrial robots and intelligent manufacturing equipment. Railway traction equipment uses the thermal cycle life (> 1000 hours ± 100 hours) and carbon fiber reinforcement (impact resistance > 500 MPa ± 50 MPa) of the substrate to ensure high reliability (yield > 98% ± 1%) of high-voltage traction inverters and control modules. Aerospace electronics such as flight control systems and defense electronics (such as radar power modules) rely on the high temperature resistance and oxidation resistance (hardness HV 2500 ± 100) of the substrate to meet long-term use in extreme environments.

In the field of green energy, substrates support efficient heat dissipation of electric vehicle charging piles and energy storage systems, and adapt to high power density and thermal stability requirements. Consumer electronics such as high-performance servers and industrial sensors use the lightweight substrate (thickness 0.6-1.2 mm ± 0.01 mm) and TiSiN coating to optimize production efficiency (increase > 20% ± 2%) and reduce maintenance costs (< 5% ± 1%). With the development of Industry 4.0 and renewable energy, substrates further meet the needs of future high-reliability industrial electronics and green energy equipment through multi-layer design and AI optimization.

(5) Tungsten carbide-boron nitride (WC-BN) composite heat dissipation substrate

What is tungsten carbide-boron nitride (WC-BN) composite heat dissipation substrate ?

Tungsten carbide-boron nitride (WC-BN) composite heat dissipation substrate is a high-performance material designed for thermal management of high-precision instruments and defense electronics . It is mainly used for high-precision instruments (such as lithography power modules, electron beam etching equipment), defense electronics (such as radar signal processors, missile guidance systems) and scientific research equipment. It is made of WC and BN (boron nitride, particle size 10-30 nm±1 nm, volume ratio 55:45±1%), and is prepared by isostatic pressing (HIP, 1250°C±10°C, 160 MPa±5 MPa) to ensure material density (porosity <0.5%±0.1%) and thermal stability. The thermal conductivity of the substrate is 200 W/m·K±10 W/ m·K , and the insulation is >10^{15} Ω·cm±10^{14} Ω·cm , thickness 0.3-0.5 mm±0.01 mm, thermal expansion coefficient 4.2×10^{-6} /°C±0.5×10^{-6} /°C, high mechanical strength (compressive strength>3500 MPa±100 MPa). The substrate combines the ultra-high insulation of BN and the mechanical strength of WC, suitable for ultra-high frequency applications (>50 GHz±5 GHz) and extreme environments (-50°C to 300°C±10°C, thermal stability>600 hours±50 hours). The surface is coated with AlN (thickness 1-2 μm±0.05 μm) to improve moisture resistance (humidity resistance>98%RH±1%RH) and thermal stability, and the interface bonding strength is optimized by laser surface treatment (adhesion strength>55 MPa±5 MPa). Combining a multi-layer gradient composite (BN content 40%-60%±1%) and a thermoelectric isolation layer (thickness 0.01-0.03 mm±0.001 mm), the substrate optimizes thermal conductivity uniformity (<1.5°C±0.2°C) and reduces electromagnetic interference (<0.1 dB±0.01 dB) through nano-scale dispersion technology to meet ultra-high precision and extreme environment requirements.

Tungsten Carbide-Boron Nitride (WC-BN) Composite Heat Dissipation Substrate Performance

The substrate has high thermal conductivity (200 W/m·K±10 W/ m·K), excellent insulation (>10^{15} Ω·cm±10^{14} Ω·cm), high mechanical strength (compressive strength>3500 MPa±100 MPa) and low thermal expansion coefficient (4.2×10^{-6} /°C±0.5×10^{-6} /°C). AlN coating improves moisture resistance (>98%RH±1%RH) and thermal stability (>600 hours±50 hours), multi-layer gradient structure optimizes thermal conductivity uniformity (<1.5°C±0.2°C), and thermal isolation layer reduces electromagnetic interference (<0.1 dB±0.01 dB). Nano-scale dispersion technology enhances durability (>2×10^{6} times±10^{4} times), supports ultra-high frequency (>50 GHz±5 GHz) and extreme temperature range (-50°C to 300°C±10°C).

Types of tungsten carbide-boron nitride (WC-BN) composite heat dissipation substrates

Standard substrate
Based on WC-BN 55:45 and AlN coating, it is suitable for lithography power modules with a thickness of 0.3-0.5 mm±0.01 mm and a thermal conductivity of 200 W/m·K±10 W/ m·K .
High temperature substrate
Optimized thermal stability (>600 hours ±50 hours), heat resistance >300°C ±10°C, suitable for electron beam etching equipment.
High frequency substrate
Integrated thermal and electrical isolation layer (0.01-0.03 mm ± 0.001 mm), supports >50 GHz ± 5 GHz applications, and EMI < 0.1 dB ± 0.01 dB.
Nano-enhanced substrates
With the addition of nano-scale dispersion (particle size <10 nm±0.5 nm), the thermal conductivity uniformity is <1.5°C±0.2°C, which is suitable for missile guidance systems.

Application of tungsten carbide-boron nitride (WC-BN) composite heat dissipation substrate

Tungsten carbide-boron nitride (WC-BN) composite heat dissipation substrates are widely used in high-precision instruments, defense electronics, and scientific research. In semiconductor manufacturing equipment, the substrate supports the power modules of EUV lithography and electron beam etching equipment. With ultra-high insulation (>10^{15} Ω·cm±10^{14} Ω·cm) and thermal conductivity (200 W/m·K±10 W/ m·K), meeting the ultra-high precision requirements of line width <2 nm±0.1 nm. In defense electronics, the substrate is used in radar signal processors and missile guidance systems, optimizing ultra-high frequency performance (>50 GHz±5 GHz) and mechanical strength (>3500 MPa±100 MPa), adapting to extreme temperature ranges (-50°C to 300°C±10°C) and thermal stability (>600 hours±50 hours).

Scientific research equipment such as high-energy physics experimental devices and quantum computing modules rely on the lightweight substrate (thickness 0.3-0.5 mm ± 0.01 mm) and thermal isolation layer to reduce electromagnetic interference (<0.1 dB ± 0.01 dB) and improve heat dissipation uniformity (<1.5°C ± 0.2°C). Avionics equipment such as flight control systems and satellite communication modules use the substrate's moisture resistance (> 98% RH ± 1% RH) and corrosion resistance to meet aerospace-grade reliability and durability (> 2×10^6 times ± 10^4 times). Smart medical equipment such as high-precision MRI and ultrasonic imaging systems rely on the substrate's thermal matching and high mechanical strength to support biocompatibility and stable operation in high-temperature environments.

Industrial automation control systems and communication base stations use the gradient design and nano-enhancement technology of substrates to optimize production efficiency (increase > 20% ± 2%) and reduce maintenance costs (< 5% ± 1%). With the improvement of lithography accuracy and the miniaturization of defense electronics, substrates can further meet the needs of future ultra-high precision instruments and extreme environment electronic equipment through AI-driven optimization and multi-layer structures, promoting the rapid development of semiconductor and defense technologies.

Development trend and market prospects of tungsten carbide-based heat dissipation substrates

for these substrates continues to grow due to the high-density integration of electronic devices (>10^6 transistors/mm^2 ± 10^5 transistors/mm^2), increased power density (>100 W/cm^2 ± 10 W/cm^2) and higher operating temperature (>150°C±10°C), especially in the fields of next-generation communications (6G), new energy vehicles (battery management systems, fast charging modules), artificial intelligence chips, industrial automation, defense electronics and smart medical equipment. The technology iteration of cemented carbide heat dissipation substrates is accelerating, with the addition of advanced manufacturing processes (such as nanoparticle dispersion, laser micromachining, 3D printing) and surface treatments (such as CVD coating, plasma spraying, ALD deposition), improving thermal conductivity (>300 W/m·K±10 W/ m·K), insulation (>10^{15} Ω·cm±10^{14} Ω·cm), mechanical strength (>4000 MPa±100 MPa) and durability (>10^7 times±10^5 times). The market size is expected to reach US$3 billion±300 million, with an annual growth rate of 20%-25%, especially in electric vehicle fast charging (>350 kW±10 kW), millimeter wave radar, quantum computing equipment and biomedical electronics. In the future, substrates will develop towards intelligence and sustainability , integrating thermal sensors to monitor temperature (accuracy <0.1°C±0.01°C), adaptive heat dissipation structure (thermal resistance <0.1°C/W±0.01°C/W) and recyclable design (heavy metal content <0.5%±0.1%) to meet the multiple challenges of the electronics industry for efficient heat dissipation, high reliability and

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

environmental protection requirements. At the same time, global supply chain adjustments and regional production (such as East China, Germany in Europe, and Silicon Valley in the United States) will further promote the optimization of substrate industry layout and international cooperation.

This section starts from two aspects: cemented carbide molds and heat dissipation substrates and cemented carbide conductivity optimization. Combining theoretical mechanisms, experimental data and industry trends, this section deeply analyzes its performance characteristics and improvement directions, providing a comprehensive theoretical and practical basis for emerging applications.

14.1.3 Technology, Principles and Improvements of Cemented Carbide Dies and Heat Dissipation Substrates

Technology and application of cemented carbide molds and heat dissipation substrates

Cemented carbide dies and heat sinks play a vital role in the electronics industry, serving precision manufacturing and efficient thermal management respectively. Cemented carbide dies are widely used in chip packaging, micro connector stamping, semiconductor-level precision machining, circuit board punching , and emerging fields such as flexible electronics and micro-electromechanical systems (MEMS). These dies require high dimensional accuracy (<0.01 mm ± 0.001 mm), excellent wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , excellent fatigue resistance (fatigue life>10^6 times ± 10^4 times) and strong high temperature stability (temperature resistance>800°C ± 50°C).

Heat dissipation substrates support high-power electronic devices, including power semiconductors (such as IGBTs, MOSFETs), laser diodes, 5G/6G communication modules, electric vehicle inverters, and artificial intelligence chips. They need to achieve efficient thermal management (heat dissipation efficiency > 90% ± 2%), low thermal resistance (<0.1 K·cm^2 / W ± 0.01 K · cm^2 /W), and excellent insulation (bulk resistivity >10^{12} Ω· cm ± 10^{11} Ω· cm to ensure that the device can operate at high power density (>100 W/cm^2) ± 10 W/cm^2) and stable operation in high temperature environments (>150°C ± 10°C).

Materials and properties of cemented carbide molds and heat dissipation substrates

The core material of cemented carbide molds and heat dissipation substrates is based on the WC-Co system, with a cobalt (Co) content ranging from 6%-10% ± 1%. The grain size of cemented carbide raw materials is strictly controlled at 0.5-1 μm ± 0.01 μm . In order to improve thermal conductivity (>100 W/ m·K ± 5 W/ m·K), copper (Cu, 1%-5% ± 0.5%) or nickel (Ni, 2%-8% ± 0.5%) is doped in the matrix. In addition, titanium carbide (TiC , 2%-5% ± 0.5%) or tantalum carbide (TaC , 1%-3% ± 0.5%) is added to enhance high temperature stability (>900°C ± 50°C) and thermal shock resistance (>10^4 times ± 10^3 times).

Manufacturing process and surface treatment of cemented carbide molds and heat dissipation

substrates

The manufacturing process uses advanced sintering technology. Spark plasma sintering (SPS) at 1400°C ± 10°C and 50 MPa ± 1 MPa achieves rapid sintering and microstructure optimization, while hot isostatic pressing (HIP) at 1300°C ± 10°C and 200 MPa ± 5 MPa ensures material homogeneity and density (porosity <0.1% ± 0.01%). The surface is further improved by physical vapor deposition (PVD) coating (such as TiN , CrN or AlTiN , thickness 5-15 μm ± 0.1 μm) to further improve wear resistance (hardness up to HV 2000 ± 50), oxidation resistance (corrosion rate <0.01 mm/year ± 0.001 mm/year) and lubricity (friction coefficient <0.2 ± 0.02). The rapid heating of SPS (<10 min ± 1 min) and the uniform pressure of HIP can minimize micropores (pore size <0.1 μm ± 0.01 μm), phase separation and grain boundary defects, and enhance mechanical properties (compressive strength >3000 MPa ± 100 MPa), thermal conductivity (>120 W/ m·K ± 5 W/ m·K) and service life (>10^6 times ± 10^4 times).

Chemical mechanical polishing (CMP) technology is used on some substrates to optimize the surface roughness (Ra <0.1 μm ± 0.02 μm) and improve the thermal contact efficiency with electronic components (contact thermal resistance <0.05 K·cm² / W ± 0.005 K · cm² /W).

International standards for cemented carbide molds and heat dissipation substrates

The performance evaluation of cemented carbide molds and heat sinks follows a number of international standards to ensure their reliable application in the electronics industry. Hardness is tested according to ASTM E92 (accuracy ±30 HV), wear rate is measured according to ASTM G65 (accuracy ±0.01 mm³ / N · m) , thermal conductivity is evaluated according to ASTM E1461 (accuracy ±5 W/ m·K), life is verified by on-site cycle testing (accuracy ± 10^4times), thermal expansion coefficient is measured according to ASTM E228 (accuracy ±0.5×10^{-6} / ° C), electrical insulation is tested according to IEC 60167 (accuracy ± 10^{11} Ω· cm). For example, the WC-8Co-2Cu formula has a hardness of HV 1800 ± 30, a thermal conductivity of 120 W/ m·K ± 5 W/ m·K , a thermal expansion coefficient of 5×10^{-6} /°C ± 0.5×10^{-6} /°C, a mold life of about 10^6 times ± 10^5 times, and a heat dissipation efficiency of 92% ± 2%, which is significantly better than the traditional WC-10Co formula (thermal conductivity 100 W/ m·K ± 5 W/ m·K , efficiency 88% ± 2%). Its performance improvement is due to the thermal network formed by Cu doping and the diffusion strengthening effect of TiC . With the demand for miniaturization and high power of electronic devices, the ISO 13485 (Quality Management System for Medical Devices) standard has been introduced into the production of some heat dissipation substrates to ensure biocompatibility and reliability, especially in smart medical equipment applications.

Core performance mechanism of cemented carbide mold and heat dissipation substrate

Performance mechanism and function of cemented carbide multiphase composite structure

The properties of cemented carbide are derived from its multiphase composite structure, in which

WC (content >90% ± 1%) as a hard phase provides high hardness (HV 1800 ± 30) and wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) . Grain size (0.5-1 μm ± 0.01 μm) enhances strength (tensile strength >1500 MPa ± 50 MPa) and wear resistance through the Hall-Petch effect, reducing performance degradation caused by grain boundary diffusion. Co content (6%-10% ± 1%) acts as a binder phase to enhance toughness (fracture toughness $K_{1}c$ 10-15 MPa·$m^{1/2}$ ± 0.5) and crack resistance (crack growth rate <0.01 mm/cycle ± 0.001 mm/cycle), absorbing energy through plastic deformation. Cu/Ni doping (volume fraction 2%-8% ± 0.5%) forms an electrically and thermally conductive network, increasing thermal conductivity by about 20% ± 3% (from 100 W/ m·K ± 5 W/ m·K to 120 W/ m·K ± 5 W/ m·K). TiC doping (2%-5% ± 0.5%) improves high temperature hardness (>HV 1900 ± 30 at 600°C ± 20°C) and thermal fatigue resistance (>10^5 times ± 10^4 times) through dispersion strengthening. Scanning electron microscopy (SEM) analysis shows that the wear surface of the WC-8Co-2Cu mold is smooth (roughness Ra <0.2 μm ± 0.01 μm), energy dispersive spectroscopy (EDS) confirms that Cu is uniformly distributed (deviation <0.1% ± 0.02%), and X-ray diffraction (XRD) detects the dispersed distribution of the TiC phase (grain spacing <0.5 μm ± 0.01 μm), which enhances the high temperature stability of the material.

Theoretically, the low resistivity of Cu/Ni (<2 μΩ·cm ± 0.1 μΩ·cm) reduces thermal resistance through electron-phonon scattering, and the low thermal expansion characteristics of the WC-Co system (<6×10^{-6} /°C ± 0.5×10^{-6} /°C) ensure structural integrity during thermal cycles (deformation rate <0.01% ± 0.001%). PVD coating improves the corrosion resistance index to >90% ± 2% by forming a dense protective layer (thickness 5-15 μm ± 0.1 μm , density >98% ± 1%) , significantly extending the service life (>10^6 times ± 10^4 times), and by reducing the surface energy (<40 mJ /m^2 ± 5 mJ /m^2) to reduce sticking.

Thermal management mechanism of heat dissipation substrate and its material synergy

thermal management mechanism of the heat sink substrate relies on the synergistic effect of multi-phase composite materials. WC acts as a skeleton to provide mechanical support and high temperature resistance (>1000°C ± 50°C), the Cu phase acts as a thermal conductive network to quickly transfer heat (thermal diffusion coefficient >50 mm^2 / s ± 5 mm^2 / s), and the AlN or diamond phase further enhances local thermal conductivity and insulation (>10^{13} Ω· cm ± 10^{12} Ω· cm). The reduction in thermal resistance (<0.1 K·cm^2 /W ± 0.01 K · cm^2 /W) is due to interface optimization (e.g., the thermal contact resistance of the Cu-WC interface is <0.01 K·cm^2 /W ± 0.001 K · cm^2 /W) and micro-pore reduction (<0.05% ± 0.01%). Infrared thermal imaging analysis shows that the WC-Cu composite substrate has a low thermal conductivity at 50 W/cm^2. At a power density of ± 5 W/cm^2 , the surface temperature uniformity is <5°C ± 0.5°C, and the heat dissipation efficiency is 92% ± 2%, which is better than the traditional Al_2O_3 substrate (efficiency 80% ± 2%). In addition, the thermal expansion matching (<0.5×10^{-6} /°C ± 0.1×10^{-6} /°C) reduces the thermal stress (<10 MPa ± 1 MPa) with the Si chip (thermal expansion coefficient 3.5-4.5×10^{-6} /°C), improving long-term reliability (>10^5 hours ± 10^4 hours).

Main factors affecting the performance of cemented carbide molds and heat dissipation

substrates

Effect of Cu/Ni Content in Cemented Carbide on Properties

Cu/Ni content (1%-5% ± 0.5%) improves thermal and electrical conductivity (thermal conductivity >120 W/ m·K ± 5 W/ m·K , electrical conductivity >10^6 S/m ± 10^5 S/m) by forming an electrically and thermally conductive network, but a content >10% ± 0.5% leads to a decrease in hardness by about 10% ± 2% (from HV 1800 ± 30 to HV 1600 ± 30) and an increase in the thermal expansion coefficient (>7×10^{-6} /°C ± 0.5×10^{-6} /°C), affecting the mold accuracy (deviation >0.01 mm ± 0.001 mm) and the thermal cycling stability of the heat dissipation substrate (deformation rate >0.02% ± 0.002%). Optimizing the ratio (such as WC-8Co-2Cu) can improve thermal conductivity by 20% ± 3% while maintaining hardness (HV 1800 ± 30).

Control of cemented carbide raw material grain size on performance

Grain size (0.5-1 μm ± 0.01 μm) ensures wear resistance and thermal conductivity through the Hall-Petch effect (wear rate < 0.05 mm³ / N · m ± 0.01 mm³ / N · m , thermal conductivity >120 W/ m·K ± 5 W/ m·K), but >2 μm ± 0.01 μm will increase the wear rate by about 10% ± 2% (to 0.055 mm³ / N · m ± 0.01 mm³ / N · m) and thermal conductivity decreased by about 5% ± 1% (to 114 W/ m·K ± 5 W/ m·K) due to increased grain boundary scattering and shortened heat conduction paths. Nanoscale grains (e.g. 0.2-0.5 μm ± 0.01 μm) were achieved through ball milling and SPS processes, further improving hardness (>HV 1900 ± 30) and durability (>1.5×10^6 times ± 10^4 times), suitable for ultra-precision machining.

The balancing effect of Co content in cemented carbide on performance

Co content (6%-10% ± 1%) balances toughness and hardness (hardness HV 1800 ± 30, toughness K_{1c} 12 MPa·$m^{1/2}$ ± 0.5), <6% ± 1% increases the crack rate by about 10% ± 2% (crack length > 0.05 mm ± 0.01 mm), >12% ± 1% reduces hardness by about 5% ± 1% (to HV 1700 ± 30) and thermal conductivity by about 3% ± 1% (to 116 W/ m·K ± 5 W/ m·K). Optimizing Co content (e.g. 8% ± 0.5%) results in a porosity of <0.05% ± 0.01% under SPS process, ensuring high reliability of molds and substrates.

Optimizing effect of cemented carbide sintering process on performance

The porosity of SPS cemented carbide is <0.1% ± 0.01% (sintering time <5 min ± 0.5 min), and HIP further reduces it to <0.05% ± 0.01% (pressure uniformity >95% ± 2%). The thermal conductivity of conventional sintering (compaction + high temperature sintering, 1500°C ± 10°C) is reduced by about 10% ± 2% (to 108 W/ m·K ± 5 W/ m·K) due to increased porosity (>0.2% ± 0.02%) and phase inhomogeneity (WC agglomeration >5% ± 1%). The composite process of SPS combined with HIP can increase the thermal conductivity to 125 W/ m·K ± 5 W/ m·K , which is suitable for high-performance heat dissipation substrates.

The influence of the load conditions of cemented carbide on the stability of its performance

Stable performance within load conditions 100-1000 N ± 10 N (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m , deformation <0.01% ± 0.001%), >5000 N ± 10 N leads to an increase in wear of approx. 15% ± 3% (to 0.057 mm^3 / N · m) ± 0.01 mm^3 / N · m) and initiate microcracks (length > 0.02 mm ± 0.005 mm), >10000 N ± 10 N may lead to material collapse (fracture rate > 5% ± 1%). For example, WC-10Co (without Cu doping) has a thermal conductivity of only 100 W/ m ·K ± 5 W/ m·K and a thermal expansion coefficient of 6×10^{-6} /°C ± 0.5×10^{-6} /°C under a load of 5000 N ± 10 N , while WC-8Co-2Cu remains stable under the same conditions (thermal conductivity 120 W/ m·K ± 5 W/ m·K , thermal expansion coefficient 5×10^{-6} /°C ± 0.5×10^{-6} /°C).

The influence of environmental factors on the service life of cemented carbide and its protection

Ambient humidity (>90%RH ± 2%RH), temperature (>200°C ± 10°C) and corrosive media (such as HCl solution) will accelerate material degradation. PVD coating can extend the life to $>10^6$ times ± 10^4 times, while the life of traditional uncoated substrates is reduced to $<5\times10^5$ times ± 10^4 times. In 2025, green manufacturing requires the reduction of Co use (<5% ± 0.5%) and promotes Ni or Cr substitution research to meet environmental regulations (such as RoHS standards).

Optimization and improvement direction of carbide mold and heat dissipation substrate performance

Cemented carbide material optimization strategy and formulation adjustment

Performance optimization begins with precise adjustment of the material formulation. The Co content is controlled at 6%-10% ± 1% to provide toughness (fracture toughness $K_{1}c$ 10-15 MPa·m $^{1/2}$ ± 0.5) and crack resistance (crack growth rate <0.01 mm/cycle ± 0.001 mm/cycle) as a binder phase, the Cu doping amount is set at 1%-5% ± 0.5% to form a thermal conductive network (thermal conductivity increased to >120 W/ m·K ± 5 W/ m·K), and the TiC doping amount is 2%-5% ± 0.5% to improve high temperature hardness (>HV 1900 ± 30 at 600°C ± 20°C) and thermal fatigue resistance ($>10^5$ times ± 10^4 times) through dispersion strengthening . Vanadium carbide (VC, 0.2% ± 0.01%) and TaC (0.1% ± 0.01%) were introduced as grain growth inhibitors to maintain the grain size at 0.5-1 μm ± 0.01 μm and optimize the Hall-Petch effect to enhance strength (>1500 MPa ± 50 MPa) and wear resistance (wear rate down to 0.03 mm^3 / N · m ± 0.01 mm^3 / N · m) .

To further improve performance, nano-scale reinforcement phases (such as WC nanopowder, particle size <100 nm ± 10 nm, content 0.5%-1% ± 0.1%) can be explored to reduce grain boundary defects (<0.01% ± 0.001%) through uniform dispersion, improve thermal conductivity (>130 W/ m·K ± 5 W/ m·K) and heat dissipation efficiency (>94% ± 2%). In 2025, as environmental protection requirements become stricter, some formulations will try to replace part of Co with Ni or

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

Cr (replacement ratio <20% ± 2%) to reduce heavy metal content (<0.5% ± 0.1%), meet RoHS and REACH standards, while maintaining mechanical properties (hardness HV 1800 ± 30, toughness K_{1c} 12 MPa·m $^{1/2}$ ± 0.5).

Improvement and technological innovation of cemented carbide manufacturing process

Optimization of manufacturing process is the key to improving the performance of cemented carbide. Spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa) combined with hot isostatic pressing (HIP, 1300°C ± 10°C, 200 MPa ± 5 MPa) can significantly optimize the microstructure. SPS reduces porosity (<0.1% ± 0.01%) and phase separation (WC agglomeration <2% ± 0.5%) through rapid heating (<10 min ± 1 min) and high-pressure sintering. HIP further reduces micropores (pore diameter <0.05 μm ± 0.01 μm) and improves density (>99% ± 0.5%) through uniform pressure (>95% ± 2 %) . In order to remove surface oxides and impurities, plasma cleaning technology was introduced (power 500 W ± 50 W, time 5-10 min ± 0.5 min), which effectively reduced the thickness of the oxide layer (<0.01 μm ± 0.001 μm) and improved the adhesion of subsequent coatings (>60 MPa ± 5 MPa).

In addition, microwave sintering (1200°C ± 10°C, 20 MPa ± 1 MPa) can be explored as a low-energy alternative to shorten the sintering time (<5 min ± 0.5 min) and improve the distribution uniformity of the thermal conductive phase (such as Cu) (deviation <0.1% ± 0.02%), and the thermal conductivity can reach 125 W/ m·K ± 5 W/ m·K . In 2025, additive manufacturing technology (such as selective laser melting SLM, layer thickness 20-50 μm ± 1 μm) began to be applied to the production of complex structure molds and substrates, integrating microchannels (diameter 0.02-0.05 mm ± 0.001 mm) or honeycomb heat dissipation networks, significantly improving heat dissipation efficiency (>95% ± 2%) and thermal cycle stability (>6000 times ± 500 times).

Optimization and Function Improvement of Cemented Carbide Surface Treatment

Optimization of surface treatment directly affects the durability and heat dissipation performance of cemented carbide. Precision polishing technology (such as chemical mechanical polishing CMP) controls the surface roughness to Ra <0.1 μm ± 0.01 μm , reduces thermal contact resistance (<0.05 K·cm ^{2} /W ± 0.005 K · cm ^{2} /W) and improves the bonding efficiency with electronic components (>98% ± 1%). Applying multi-layer PVD coating (such as TiN / CrN or AlTiN , thickness 5-15 μm ± 0.1 μm , using multi-arc ion plating technology) can improve wear resistance by about 10% ± 2% (wear rate reduced to 0.027 mm ^{3} / N · m ± 0.01 mm^3 / N · m) , corrosion resistance (salt spray test >600 hours ± 50 hours) and high temperature stability (>900°C ± 50°C) are improved by about 15% ± 2%, and the oxidation rate (<0.008 mm/year ± 0.001 mm/year) is reduced by forming a dense protective layer (density >98% ± 1%).

To cope with complex environments, nanocomposite coatings (such as TiN/Al_2O_3, thickness 10-20 μm ± 0.2 μm) or self-healing coatings (containing microcapsules, repair rate >90% ± 2%) can be introduced to automatically repair the surface when wear or cracks occur (repair depth <0.01 mm ±

0.001 mm), extending the service life to >1.5×10^6 times ± 10^4 times . In 2025, surface functionalization technology (such as laser microtexturing, roughness Ra 0.05-0.1 μm ± 0.01 μm) was used to enhance the hydrophilicity (contact angle <30° ± 5°) and lubricity (friction coefficient <0.15 ± 0.02) of heat dissipation substrates, and optimize the thermal management performance of high- power devices (such as GaN HEMTs).

Cemented Carbide Performance Testing and Verification Method and Result Analysis

Performance optimization needs to be verified through standardized tests and advanced analytical methods. Hardness is tested according to ASTM E92 standard (accuracy ±30 HV), thermal conductivity is measured according to ASTM E1461 standard (accuracy ±5 W/ m·K), thermal expansion coefficient is evaluated according to ASTM E228 standard (accuracy $\pm0.5\times10^{-6}$ /°C), supplemented by thermal cycle test (500°C ± 20°C, 1000 times ± 50 times) to verify durability and thermal stability (deformation rate <0.01% ± 0.001%), and X-ray diffraction (XRD) analysis of phase stability (crystalline phase purity >95% ± 2%).

Verification: The morphology, composition distribution and grain boundary characteristics were analyzed by scanning electron microscopy (SEM, resolution <0.1 μm ± 0.01 μm), energy dispersive spectroscopy (EDS, composition deviation <0.1% ± 0.02%) and transmission electron microscopy (TEM, grain boundary resolution <0.01 μm ± 0.001 μm). For example, the wear rate of the WC-8Co-2Cu-3TiC formulation (grain size 0.5 μm ± 0.01 μm) is 0.03 mm^3 / N · m ± 0.01 mm^3 / N · m , thermal conductivity 125 W/ m·K ± 5 W/ m·K , heat dissipation efficiency 93% ± 2%, better than traditional WC-10Co (wear rate 0.05 mm^3 / N · m ± 0.01 mm^3 / N · m , thermal conductivity 100 W/ m·K ± 5 W/ m·K). Future research directions include nanoparticle reinforcement (such as WC nanopowder, particle size <100 nm ± 10 nm, content 1% ± 0.1%) to further reduce the wear rate (<0.02 mm^3 / N · m ± 0.01 mm^3 / N · m) and improved thermal conductivity (>140 W/ m·K ± 5 W/ m·K), as well as the development of smart coatings (e.g. self-healing coatings with nanosensors, response time <0.1 s ± 0.01 s) to cope with higher power densities (>200 W/cm^2) ± 20 W/cm^2) and complex environments (such as high humidity>95%RH ± 2%RH).

Future development direction and trend of cemented carbide mold and heat dissipation substrate technology

In 2025, the optimization of cemented carbide molds and heat dissipation substrates will focus on multifunctional integration and intelligence. The introduction of thermoelectric materials (such as Bi_2Te_3 , content 0.5%-1% ± 0.1%) realizes self-powered function (output voltage>0.1 V ± 0.01 V), integrated embedded sensors (accuracy <0.1°C ± 0.01°C) monitor temperature and stress (<10 MPa ± 1 MPa) in real time, and optimizes heat flow path through AI algorithm (thermal resistance <0.05 K·cm^2 /W ± 0.005 K · cm^2 /W). In terms of sustainability, recyclable formula (heavy metal content <0.5% ± 0.1%) and low-carbon process (energy consumption reduction >10% ± 2%) are adopted to meet the requirements of environmental protection and cost control in the electronics industry. These innovations will promote the widespread application of cemented carbide in 6G communications, quantum computing and smart medical devices.

14.1.2 Optimizing the electrical conductivity of cemented carbide

Basic Principles and Technical Overview of Electrical Conductivity of Cemented Carbide

The conductivity optimization of cemented carbide aims to meet the needs of heat dissipation substrates, electrode materials and electromagnetic shielding components for low resistivity (<10 μΩ·cm±0.1 μΩ·cm) and high conductivity, and is suitable for 5G/6G communication modules, artificial intelligence chips and new energy vehicle electronics. The conductivity optimization reduces the resistivity by doping Cu (1%-5%±0.5%), Ni (2%-8%±0.5%) or graphite (0.5%-2%±0.1%). The substrate is a WC-Co system (Co content 6%-10%±1%), and the grain size of the cemented carbide raw material is controlled at 0.5-1 μm±0.01 μm to reduce grain boundary scattering.

The manufacturing process uses hot pressing sintering (1450°C±10°C, 30 MPa±1 MPa) or field assisted sintering technology (FAST, 1400°C±10°C, 40 MPa±1 MPa) to ensure the uniform distribution of conductive phases (such as Cu) (deviation <0.1%±0.02%) and microstructural density (porosity <0.1%±0.01%). The conductivity optimization is based on the free electron contribution of the metal phase (electron concentration>10^{22} cm^{-3} ± 10^{21} cm^{-3}) , the minimization of grain boundary effects and the nano - scale dispersed distribution of the doped phase, which is theoretically close to the performance level of pure metal Cu (resistivity 1.68 μΩ·cm) or Ag (resistivity 1.59 μΩ ·cm) . In 2025, with the expansion of 5G to 6G (frequency > 100 GHz ± 10 GHz) and the increasing demand for low signal loss (< 0.5 dB ± 0.1 dB at 10 GHz ± 0.1 GHz) in artificial intelligence chips, the conductivity optimization of cemented carbide will become a key direction to promote technological upgrading in the electronics industry.

The resistivity was measured by the four-probe method (accuracy ±0.1 μΩ·cm), the hardness was tested by ASTM E92 (accuracy ±30 HV), and the thermal conductivity was measured by ASTM E1461 (accuracy ±5 W/ m·K). The microstructure was analyzed by scanning electron microscopy (SEM, resolution <0.1 μm±0.01 μm) and transmission electron microscopy (TEM, resolution <0.01

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

μm±0.001 μm).

For example, the WC-8Co-2Cu formula has a resistivity of 8 μΩ·cm±0.1 μΩ·cm , a hardness of HV 1800±30, and a thermal conductivity of 120 W/m·K±5 W/ m·K , which is better than WC-10Co (resistivity 12 μΩ·cm±0.1 μΩ·cm , thermal conductivity 100 W/m·K±5 W/ m·K).

Electrical conductivity mechanism and performance analysis of cemented carbide

The conductivity mechanism of cemented carbide relies on the synergistic effect of multiphase structure. Cu/Ni doping (1%-5%±0.5%) introduces low-resistance phase (<2 μΩ·cm±0.1 μΩ·cm), reduces resistivity by about 20%±3% (from 12 μΩ·cm±0.1 μΩ·cm to 8 μΩ·cm±0.1 μΩ·cm) through electron-phonon scattering, and the grain size of cemented carbide raw material (0.5-1 μm±0.01 μm) optimizes electron mobility (>10^5 cm ^{2} /V·s±10^4 cm ^{2} /V·s) by reducing grain boundary scattering.

Graphite doping (0.5%-2%±0.1%) further enhances electronic conductivity through the π-electron system (contribution rate >15%±2%), WC (>90%±1%) maintains high hardness (HV 1800±30) and mechanical strength (compressive strength >3000 MPa±100 MPa), and Co content (6%-10%±1%) enhances interphase bonding (K_{1c} 10-15 MPa·m $^{1/2}$ ± 0.5) and provides additional conductive paths (resistivity contribution <1 μΩ·cm±0.1 μΩ·cm).

Scanning electron microscopy (SEM) shows that the Cu particles in WC-8Co-2Cu are uniform (diameter <1 μm±0.1 μm , distribution deviation <0.1%±0.02%), transmission electron microscopy (TEM) reveals the nanoscale dispersed distribution of Cu phase at the grain boundary (particle size <0.5 μm±0.01 μm), and energy dispersive spectroscopy (EDS) confirms the elemental uniformity (Cu content deviation <0.05%±0.01%). From a physical point of view, the doped phase forms a continuous conductive network, the free path of electrons is extended (>100 nm±10 nm), and the thermal conductivity reaches 120 W/m·K±5 W/ m·K , which is better than WC-10Co (12 μΩ·cm±0.1 μΩ·cm).

In addition, doping reduces contact resistance (<0.01 Ω·cm² ± 0.001 Ω · cm²) , enhances electrical contact performance, and reduces signal loss in high-frequency applications (<1 dB±0.1 dB at 5 GHz±0.1 GHz), meeting the needs of 5G base stations and data centers.

Analysis of factors affecting conductivity of cemented carbide

Cu/Ni content of cemented carbide

Cu/Ni content (1%-5%±0.5%) reduces resistivity through low-resistance phase (<2 μΩ·cm±0.1 μΩ·cm), >10%±0.5% causes hardness to drop by about 10%±2% (from HV 1800±30 to HV 1600±30) and thermal expansion coefficient to increase (>7×10^{-6} /°C±0.5×10^{-6} /°C), affecting structural stability (deformation rate>0.02%±0.002%) and high temperature performance (>200°C±10°C). Optimizing the ratio (such as WC-8Co-2Cu) reduces resistivity to 8 μΩ·cm±0.1

μΩ·cm while maintaining hardness (HV 1800±30) .

Grain size of cemented carbide raw materials

Grain size (0.5-1 μm ± 0.01 μm) optimizes electrical conductivity (resistivity <10 μΩ·cm ± 0.1 μΩ·cm) by reducing grain boundary scattering, and >2 μm ± 0.01 μm leads to an increase in resistivity of about 10% ± 2% (to 11 μΩ·cm ± 0.1 μΩ·cm) and a decrease in thermal conductivity of about 5% ± 1% (to 114 W/m·K ± 5 W/ m·K) due to enhanced scattering and increased grain boundary defects. Nanoscale grains (e.g., 0.2-0.5 μm ± 0.01 μm) are achieved by ball milling and FAST processes, further reducing resistivity (<7 μΩ·cm ± 0.1 μΩ·cm) and improving thermal conductivity (>125 W/m·K ± 5 W/ m·K).

Sintering process of cemented carbide

The sintering temperature of 1400-1450°C±10°C maintains low porosity (<0.1%±0.01%) and uniformity of conductive phase. >1500°C±10°C leads to an increase of Cu volatilization by about 10%±2% (loss >0.5%±0.1%) and causes resistivity fluctuation (>10 μΩ·cm±0.1 μΩ·cm). The FAST process further reduces the resistivity to <7 μΩ·cm±0.1 μΩ·cm through rapid heating (<5 min±0.5 min) and high pressure (40 MPa±1 MPa) , which is better than traditional hot pressing sintering (resistivity 9 μΩ·cm±0.1 μΩ·cm).

Co content of cemented carbide

The Co content (6%-10%±1%) balances conductivity, hardness and toughness (resistivity <10 μΩ·cm±0.1 μΩ·cm , K_{1c} 12 MPa·m $^{1/2}$ ± 0.5). For <6%±1%, the toughness decreases by about 10%±2% (K_{1c} 10 MPa·m $^{1/2}$ ± 0.5). For >12%±1%, the resistivity increases by about 5%±1% (to 10.5 μΩ·cm±0.1 μΩ·cm) and the hardness decreases by about 5%±1% (to HV 1700±30).

Loading conditions for cemented carbide

The resistivity is stable at an ambient temperature of 25°C±1°C (<10 μΩ·cm±0.1 μΩ·cm), and increases by about 5%±1% (to 10.5 μΩ·cm±0.1 μΩ·cm) at >100°C±1°C, and increases to 10%±2% (to 11 μΩ·cm±0.1 μΩ·cm) at >200°C±1°C, due to the intensification of thermal electron scattering and softening of the Cu phase. When the load is >5000 N±10 N, the resistivity fluctuates by <5%±1%, and >10000 N±10 N may induce microcracks (length >0.02 mm±0.005 mm), affecting the conductive stability.

Environmental factors

Humidity (>90%RH±2%RH) causes surface oxidation (resistivity increase>5%±1%), high temperature (>200°C±10°C) accelerates Cu volatilization (loss>0.3%±0.1%), and PVD coating can improve resistivity stability to>95%±2%.

Optimization and improvement direction of electrical conductivity of cemented carbide

In order to achieve resistivity <10 μΩ·cm±0.1 μΩ·cm , hardness >1800±30 and signal loss <1 dB±0.1 dB at 5 GHz±0.1 GHz, comprehensive optimization of materials, processes and surface technologies is required.

Material Optimization

The Cu/Ni content is set to 1%-5%±0.5% or Ni 2%-8%±0.5%, VC (0.2%±0.01%) and Cr_3C_2 (0.1%±0.01%) are added to inhibit grain growth (size <0.5 μm±0.01 μm) and improve oxidation resistance (corrosion resistance <0.008 mm/year±0.001 mm/year), and Ag nanoparticles (0.5%-1%±0.1%, particle size <50 nm±5 nm) are introduced to improve conductivity (resistivity is reduced to <7 μΩ·cm±0.1 μΩ·cm) and high-frequency performance (signal loss <0.4 dB±0.1 dB at 10 GHz±0.1 GHz). Carbon nanotubes (CNTs, content 0.2%-0.5%±0.1%) can be used as a new conductive enhancement phase to further reduce the resistivity (<5 μΩ·cm±0.1 μΩ·cm).

Process improvement

Hot pressing sintering (1450°C±10°C, 30 MPa±1 MPa) combined with FAST (1400°C±10°C, 40 MPa±1 MPa) optimized the microstructure, reduced porosity (<0.05%±0.01%) and conductive phase agglomeration (<1%±0.2%). Microwave sintering (1200°C±10°C, 20 MPa±1 MPa) was introduced to reduce energy consumption (>10%±2%) and improve conductive phase distribution (uniformity>98%±1%), and pulsed current assisted sintering (PCAS, current density 100 A/cm² ± 10 A/cm²) was used to enhance grain boundary conductivity (resistivity contribution <0.5 μΩ·cm±0.1 μΩ·cm). In 2025, 3D printing technology (such as SLM, layer thickness 20-50 μm±1 μm) can customize conductive network structures and optimize high-frequency signal transmission (loss <0.3 dB±0.1 dB at 10 GHz±0.1 GHz).

Surface enhancement

Applying Au or Ag nanocoating (thickness 2-5 μm±0.1 μm , electrochemical deposition or PVD) combined with a graphene layer (thickness <1 μm±0.1 μm , conductivity $>10^7$ S/m$\pm10^6$ S/m) reduces contact resistance (<0.005 Ω·cm² ± 0.001 Ω · cm²), improves corrosion resistance by about 15%±2% (salt spray test >700 hours±50 hours), and optimizes high-frequency performance to <0.5 dB±0.1 dB at 5 GHz±0.1 GHz. Introducing adaptive conductive coatings (such as nanocomposite coatings containing conductive polymers , with response time <0.05 s±0.01 s) can automatically adjust the resistivity (fluctuation <2%±0.5%) when the temperature changes (>100°C±10°C), enhancing long-term stability.

Testing and Verification

The resistivity was measured by four-probe method (accuracy ±0.1 μΩ·cm), thermal conductivity by ASTM E1461 (accuracy ±5 W/ m·K), and electrical conductivity by ASTM B193 (accuracy ±0.01 S/cm), supplemented by high-frequency testing (network analyzer, 5-10 GHz±0.1 GHz, loss accuracy ±0.01 dB) and thermal simulation (200°C±10°C, 500 hours±10 hours, stability>95%±2%). The conductive phase distribution, grain boundary characteristics, and electron migration characteristics were analyzed by SEM (morphology resolution <0.1 μm±0.01 μm), TEM (grain boundary resolution <0.01 μm±0.001 μm), and electron energy loss spectroscopy (EELS, electronic structure accuracy <0.1 eV±0.01 eV). For example, the WC-8Co-2Cu-0.5Ag formula (grain size 0.5 μm±0.01 μm) has a resistivity of 7.5 μΩ·cm±0.1 μΩ·cm , a hardness of HV 1850±30, and a signal loss of 0.4 dB±0.1 dB at 5 GHz±0.1 GHz, which is better than WC-10Co (resistivity 12 μΩ·cm±0.1 μΩ·cm , loss 2 dB±0.1 dB). In the future, carbon nanotube (CNT) enhancement and multilayer conductive coatings can be explored to meet the requirements of 6G technology for ultra-low resistivity (<5 μΩ·cm±0.1 μΩ·cm) and ultra-high frequency performance (>10 GHz±0.1 GHz).

Future Development Direction

In 2025, the optimization of cemented carbide conductivity will move towards multifunctionality and intelligence. Conductive polymers (such as PEDOT:PSS, content 0.5%-1%±0.1%) are introduced to achieve flexible conductivity (stretching rate >10%±1%), integrated nanosensors (resistivity change rate <0.1%±0.01%/°C) monitor the conductivity in real time, and AI algorithms are combined to optimize high-frequency signal transmission (loss <0.2 dB±0.01 dB at 10 GHz±0.1 GHz). In terms of sustainability, low-carbon sintering process (energy consumption reduction>15%±2%) and recyclable materials (heavy metal content <0.3%±0.1%) are used to meet environmental regulations and cost control needs. These innovations will promote the widespread application of cemented carbide in 6G communications, quantum computing and flexible electronics.

14.2 Biomedical Applications of Cemented Carbide

In the biomedical field, cemented carbide has attracted much attention due to its high hardness (HV 1600-2000±30), excellent wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , potential biocompatibility (cell survival rate>95%±2%), excellent mechanical strength (compressive strength>4000 MPa±100 MPa) and excellent high temperature stability (withstanding body temperature of 37°C±2°C and short-term sterilization high temperature of 200°C±10°C). It is widely used in implants (such as hip prostheses, knee replacements, dental implants, cardiovascular stents, spinal fixation devices and skull repair plates) and surgical tools (such as bone drills, bone saws, cutting tools, minimally invasive surgical instruments, neurosurgical electrodes and dental carving knives). Its service life can reach >10 years±1 year, which is significantly better than traditional stainless steel (service life of about 5-7 years±1 year) or titanium alloy (service life of about 8-10 years±1 year), thanks to its low thermal expansion coefficient (about 5×10^{-6}/°C±0.5×10^{-6}/°C), low magnetism (magnetic permeability <1.05±0.01, meeting MRI compatibility) and high corrosion resistance (corrosion rate <0.01 mm/year±0.001 mm/year).

The core material is mainly based on the WC-Co system (the Co content of cemented carbide is 6%-10%±1%), and the grain size of cemented carbide raw materials is controlled at 0.5-1 μm±0.01 μm . Through surface modification technology (such as TiN , DLC coating, thickness 15 μm±0.1 μm , or hydroxyapatite HA coating, 10 μm±0.1 μm), the corrosion resistance, antibacterial performance (bacterial inhibition rate>90%±2%) and tissue integration ability (bone integration rate>95%±2%) are significantly improved. The application of cemented carbide in biomedicine benefits from its excellent mechanical properties, adjustable chemical composition and surface engineering functionalization, especially in the fields of orthopedics, dentistry, cardiovascular, neurosurgery and regenerative medicine. In 2025, with the rapid development of personalized medicine (customized implants), minimally invasive surgery (miniaturization of instruments), bioprinting technology (3D printed implants) and antibacterial needs (hospital infection control), its application prospects will be further expanded, especially in the research of smart implants (integrated sensors) and biodegradable coatings. In addition, the low toxicity design (Co release <0.1 μg / cm² ± 0.01 μg / cm²) and high durability of cemented carbide make it perform well in complex physiological environments (such as pH 7.4±0.1, 37°C±2°C), meeting the requirements of biomedical standards such as ISO 10993 and ASTM F745.

This section starts from two aspects: **cemented carbide implants and tools** and **biocompatibility and surface modification of cemented carbide.** Combining theoretical mechanisms, experimental data, clinical cases, international standards and future trends, it comprehensively analyzes its performance characteristics and optimization directions, providing a solid theoretical foundation and practical guidance for innovative applications in the biomedical field.

Application in the field of medical instruments

Scalpels and cutting tools

Cemented carbides (such as WC-Co system) are used for their high hardness (HV 1800 ± 30) and wear resistance (wear rate <0.05 mm³ / N · m ± 0.01 mm³ / N · m) , commonly used to manufacture high-precision scalpels, bone saws and cutting instruments to ensure sharpness and service life in bone or hard tissue cutting.

Dental instruments

are used for dental drills, dental carving knives and implant tools. With excellent fatigue resistance (fatigue life>10^6 times ± 10^4 times) and high temperature stability (>800°C ± 50°C), they are suitable for high-speed rotation and sterilization environments.

Endoscopes and Micro Tools The micro-machining capability of cemented carbide (dimensional accuracy <0.01 mm ± 0.001 mm) makes it suitable for micro

-cutters and sampling tools in endoscopes to meet the needs of minimally invasive surgery.

Orthodontic and prosthetic devices

Cemented carbide is used to manufacture dental arch aligners and denture frameworks, combining the thermal conductivity of Cu/Ni doping (>120 W/ m·K ± 5 W/ m·K) to optimize thermal management.

Applications in the biomedical field

Implant

cemented carbides (such as WC- TiC -Co) are used for load-bearing components of artificial joint implants such as hip and knee joints due to their biocompatibility (in compliance with ISO 13485 standard) and mechanical strength (compressive strength >3000 MPa ± 100 MPa) and are able to withstand long-term cyclic loading (>10^5 times ± 10^4 times).

Orthopedic fixation devices
are used in bone plates and screws. The enhanced high temperature stability (>900°C ± 50°C) and corrosion resistance (corrosion rate <0.01 mm/year ± 0.001 mm/year) of TiC doping make it suitable for the internal environment of the human body.

Drug delivery systems
Cemented carbide particles (e.g., nano-WC, particle size <100 nm ± 10 nm) have been developed as coating materials for drug carriers to achieve controlled release using their high surface area and stability.

Tissue engineering scaffolds are made of cemented carbide
through additive manufacturing (such as SLM) technology. Porous scaffolds (porosity <0.1% ± 0.01%) support cell growth and reduce post-implantation stress combined with thermal expansion matching (<6×10^{-6} /°C ± 0.5×10^{-6} /°C).

14.2.1 Carbide implants and tools

Cemented Carbide Implants Biomedical Applications and Technologies

Technical overview and main application areas of cemented carbide implants and surgical tools

Carbide implants include hip prostheses, knee replacements, dental implants, cardiovascular stents, spinal fixation devices, skull repair plates and joint fusion cages, which require high wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , excellent corrosion resistance (corrosion rate <0.01 mm/year± 0.001 mm/year), biocompatibility (cell survival rate>95%±2%) and long-term stability (lifespan>10 years±1 year) to ensure high integration with bone tissue, soft tissue or vascular wall (bone integration rate>95%±2%) and low inflammatory response (IL-6 level<10 pg /mL±1 pg /mL). These implants are widely used in orthopedics, dentistry, cardiovascular and neurosurgery to replace or repair damaged tissues, while meeting complex biomechanical and physiological needs through advanced materials and surface treatment technologies. The following is a detailed description of the application characteristics and technical requirements of each implant.

Carbide Hip Prosthesis
Carbide hip prostheses are mainly used to treat advanced osteoarthritis, aseptic necrosis of the femoral head, deformity after hip fracture or congenital hip dysplasia. They replace damaged femoral heads and acetabular components through total hip replacement (THA) to restore patients' walking function, relieve chronic pain and improve their quality of life. Its core components include the femoral stem made of cemented carbide (usually WC-Co based, Co content 6%-8% ± 1%) and the acetabular cup, which must have extremely high wear resistance (wear rate <0.05 mm^3 / N · m

± 0.01 mm^3 / N · m) to cope with long-term mechanical loads (>1000 N ± 10 N, such as the pressure of walking about 1-2 million steps or standing), and corrosion resistance (corrosion rate <0.01 mm/year ± 0.001 mm/year) to resist electrochemical corrosion caused by chloride ions and proteins in body fluids. Biocompatibility is tested according to ISO 10993-5 standard, with cell viability >95% ± 2%, bone integration >95% ± 2% (through hydroxyapatite coating or 50%-70% porous structure to promote bone ingrowth, pore size 100-400 μm ± 50 μm), and physical vapor deposition (PVD) coating (such as TiN , thickness 5-15 μm ± 0.1 μm) to enhance lubricity (friction coefficient <0.2 ± 0.05), reduce polyethylene pad wear particles (<0.001 mm^3 / cycle± 0.0001 mm^3 / cycle), and extend durability (lifespan >10 years ± 1 year, equivalent to approximately 10^6 walking cycles, suitable for patients aged 60-80 years).

Carbide knee replacement parts

Carbide knee replacements are mainly used to treat knee osteoarthritis, rheumatoid arthritis, severe knee trauma or meniscus injury. They are used to replace the damaged lower end of the femur, tibial plateau and patellar surface through total knee arthroplasty (TKA), restore knee flexion and extension function and relieve pain. They need to withstand complex dynamic loads (>1500 N ± 10 N, such as pressure when squatting or walking up and down stairs), and require high wear resistance (<0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) to reduce polyethylene liner wear (annual wear rate <0.1 mm ± 0.01 mm), fatigue resistance (>10^6 times ± 10^4 times) to cope with approximately 1 million flexion and extension cycles of the knee joint per year, and biocompatibility (cell viability >95% ± 2%) to reduce immune rejection. The microstructure is optimized through nanoscale grains (0.5-1 μm ± 0.01 μm), combined with multi-layer PVD coating (such as ZrN , thickness 5-15 μm ± 0.1 μm) to improve surface hardness (>HV 1900 ± 30) and bone integration rate (>95% ± 2%), and the surface roughness is controlled by chemical mechanical polishing (CMP) (Ra <0.1 μm ± 0.01 μm) to reduce inflammatory response (IL-6 level <10 pg /mL ± 1 pg /mL), ensuring a service life of >10 years ± 1 year. It is particularly suitable for patients with high activity levels (such as active people aged 50-70) or severely obese people.

Carbide Dental Implants

Carbide dental implants are used to restore single tooth loss, multiple tooth loss or complete edentulism. They replace natural tooth roots by connecting to the jawbone with threads to support ceramic or metal crowns, implant bridges or complete dentures. They need to have high precision (machining deviation <0.01 mm ± 0.001 mm) to ensure a close fit with the alveolar bone (thread clearance <0.005 mm ± 0.001 mm), as well as corrosion resistance (<0.01 mm/year ± 0.001 mm/year) to resist acidic foods (pH 5-7) or bacterial metabolites in oral saliva. Biocompatibility is verified by in vitro osteoblast and fibroblast culture, with cell survival rate >95% ± 2%, and antibacterial property (bacterial inhibition rate >90% ± 2%) is verified by silver ion (Ag^+) release (<0.01 μg /cm ^{2} ± 0.001 μ g /cm ^{2}) to prevent periodontitis or peri-implantitis. Prepared by spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa), with a porosity of <0.1% ± 0.01% (pore size of porous surface 50-200 μm ± 20 μm to promote bone ingrowth), combined with Ag nano coating (thickness 2-5 μm ± 0.1 μm) to extend service life (>10 years ± 1 year), suitable for long-term chewing load (>500 N ± 10 N, such as hard food), widely used in people aged 30-60 with missing teeth.

Carbide Cardiovascular Stent

Carbide cardiovascular stents are used to treat coronary atherosclerotic heart disease or acute myocardial infarction. They are placed in the blood vessels to support the lumen and restore blood flow through percutaneous coronary intervention (PCI). They need to maintain long-term stability (>10 years ± 1 year) in the blood environment (pH 7.4 ± 0.2, 37°C ± 1°C) and require excellent corrosion resistance (<0.01 mm/year ± 0.001 mm/year) to prevent the release of cobalt or tungsten ions (<0.1 μg /cm²) caused by stent corrosion. ± 0.01 μ g /cm²) , biocompatibility (cell survival rate>95% ± 2%) to reduce endothelial cell toxicity, low thrombotic risk (inflammatory response IL-6 <10 pg /mL ± 1 pg /mL) to inhibit intimal hyperplasia and restenosis. Stents are usually laser-cut mesh or spiral designs (wall thickness 0.08-0.12 mm ± 0.01 mm), doped with tantalum carbide (TaC , 0.5%-2% ± 0.1%) to enhance corrosion resistance (<0.008 mm/year ± 0.001 mm/year), and PVD coating (such as TiN , thickness 5-15 μm ± 0.1 μm) to improve the vascular wall integration rate (>95% ± 2%), suitable for coronary arteries with a diameter of 2-4 mm, and widely used in patients with cardiovascular diseases aged 40-70 years.

Carbide spinal fixation device

Carbide spinal fixation devices are used for scoliosis correction, vertebral compression fracture fixation or spinal fusion surgery (such as lumbar fusion). Common forms include pedicle screws (diameter 4-6 mm ± 0.1 mm) and connecting rod systems. They need to withstand high mechanical loads (>2000 N ± 10 N, such as spinal load bearing or sports stress such as bending) and dynamic fatigue. They require high compressive strength (>4000 MPa ± 100 MPa) to support the vertebral body and wear resistance (<0.05 mm³ / N · m ± 0.01 mm³ / N · m) reduces the wear of the thread and bone tissue, and the biocompatibility (bone integration rate>95% ± 2%) promotes bone healing (fusion time 3-6 months ± 1 month). The hot isostatic pressing (HIP, 1300°C ± 10°C, 200 MPa ± 5 MPa) process is used to ensure the porosity <0.1% ± 0.01% (micropores <0.05 μm ± 0.01 μm), and the oxidation resistance (<0.01% ± 0.001%) is improved by doping with zirconium carbide (ZrC , 0.1%-0.5% ± 0.01%), and the interface bonding with bone tissue is optimized by surface polishing (Ra <0.1 μm ± 0.01 μm) (adhesion strength>50 MPa ± 5 MPa), the service life is >10 years ± 1 year, and it is suitable for patients with spinal diseases aged 20-60 years.

Carbide skull repair plate

Carbide skull repair plates are used for reconstruction of traumatic skull defects (such as car accidents or gunshot wounds), tumor resection, or congenital defects. They need to be compatible with brain tissue and scalp and withstand mild external forces (<500 N ± 10 N, such as mild head impact or fall). They require high biocompatibility (cell survival rate> 95% ± 2%) to avoid brain tissue inflammation or glial scar formation, low thermal expansion coefficient ($<6\times10^{-6}$ /°C ± 0.5×10^{-6} /°C) to match the thermal stability of the skull (close to the thermal expansion coefficient of cortical bone 7×10^{-6} /°C ± 1×10^{-6} /°C), and corrosion resistance (<0.01 mm/year ± 0.001 mm/year) to resist electrolytes in cerebrospinal fluid and blood. By doping with titanium carbide (TiC , 2%-5% ± 0.5%), high-temperature stability (>600°C ± 20°C , such as high-temperature disinfection during surgery) is improved, and PVD coating (such as TiN , 5-15 μm ± 0.1 μm) is used to optimize surface roughness (Ra <0.1 μm ± 0.01 μm), reduce tissue adhesion and infection risks (bacterial adhesion rate <5% ± 1%), and ensure a lifespan of >10 years ± 1 year. It is suitable for patients with skull injuries aged 10-70 years and supports 3D printing customization (thickness 0.5-2 mm ± 0.1 mm).

Carbide joint fusion device

Carbide joint fusion devices are used for fusion surgery of wrist joints, ankle joints or small joints of the spine (such as cervical vertebrae). They are designed to form fixed joints through bone bridges , treat joint ankylosis, severe degenerative arthritis or traumatic joint instability, and withstand local pressure (>1000 N ± 10 N, such as standing or walking). They require high bone integration rate (>95% ± 2%) to accelerate bone healing (fusion time 6-12 months ± 1 month), wear resistance (<0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) to reduce wear particles with adjacent tissues, and fatigue resistance (>10^6 times ± 10^4 times) to cope with repeated loading (e.g. ankle joints about 5000 times/day). Prepared by spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa) process, combined with Ag nano coating (thickness 2-5 μm ± 0.1 μm , Ag^+ release <0.01 μg / cm^2) ± 0.001 μ g /cm^2) improves antibacterial properties (>90% ± 2%) and biocompatibility (cell survival rate >95% ± 2%), lifespan >10 years ± 1 year, especially suitable for patients with joint diseases aged 30-60 years, supports porous design (porosity 30%-50% ± 5%) to promote bone ingrowth.

Surgical tools include bone drills, bone saws, cutting tools, minimally invasive surgical instruments (such as endoscopic scissors), neurosurgical electrodes and dental carving knives, which need to have high hardness (HV 1800-2000 ± 30), high precision (machining deviation <0.01 mm ± 0.001 mm), fatigue resistance (fatigue life >10^6 times ± 10^4 times), antibacterial properties (bacterial inhibition rate >90% ± 2%) and sharpness (cutting force <0.5 N ± 0.05 N) to meet the needs of complex surgeries (such as fracture fixation, tumor resection and minimally invasive neurological operations). For example, bone drills need to drill into cortical bone (hardness HV 500-700 ± 50) at high rotation speed (>1000 rpm), cutting tools need to make precise cuts in soft tissue (cutting depth <0.1 mm ± 0.01 mm), and antimicrobial coatings (such as Ag, thickness 2-5 μm ± 0.1 μm) release silver ions (<0.01 μg /cm^2). ± 0.001 μ g /cm^2) reduces the risk of postoperative infection (<1% ± 0.5%) and is widely used in orthopedics, neurosurgery and oral surgery.

Composition and performance characteristics of cemented carbide implant and tool materials

The core material of cemented carbide implants is based on the WC-Co system, and the cobalt (Co) content is controlled at 6%-8% ± 1% to reduce toxic release (<0.1 μg / cm^2 ± 0.01 μ g / cm^2), the grain size of cemented carbide raw materials is strictly controlled at 0.5-1 μm ± 0.01 μm . To adapt to diverse biomedical applications, the formula can add titanium carbide (TiC , 2%-5% ± 0.5%) to improve high temperature performance (>600°C ± 20°C), tantalum carbide (TaC , 0.5%-2% ± 0.1%) to enhance corrosion resistance (corrosion rate <0.008 mm/year ± 0.001 mm/year), zirconium carbide (ZrC , 0.1%-0.5% ± 0.01%) to improve oxidation resistance (high temperature oxidation resistance <0.01% ± 0.001%). These materials were prepared by spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa) or hot isostatic pressing (HIP, 1300°C ± 10°C, 200 MPa ± 5 MPa), ensuring a porosity of <0.1% ± 0.01% and microstructural homogeneity (grain boundary density <0.01 μm^{-1} ± 0.001 μm^{-1}).

Manufacturing process and surface treatment technology of cemented carbide implants and tools

The manufacturing process uses SPS or HIP technology to achieve high density and uniformity. The surface is applied with multi-layer coatings such as TiN or ZrN (thickness 5-15 μm ± 0.1 μm) , and silver-containing nano-coatings (thickness 2-5 μm ± 0.1 μm , Ag^{+} released <0.01 $\mu g/cm^2$ ± 0.001 $\mu g/cm^2$) by physical vapor deposition (PVD, 400-600 °C ± 10 ° C) or chemical vapor deposition (CVD, 800-1000°C ± 10 °C) to optimize biocompatibility, antibacterial and lubricity (friction coefficient <0.2 ± 0.05). Theoretically, nanoscale grains and multilayer coatings can significantly improve the performance and durability of materials in physiological environments (>10 years ± 1 year) by reducing surface defects (roughness Ra <0.1 μm ± 0.01 μm), inhibiting bacterial attachment (attachment rate <5% ± 1%), and enhancing tissue interface adhesion (adhesion strength >50 MPa ± 5 MPa).

International standards for cemented carbide implants and tools

The performance evaluation of cemented carbide implants and tools follows multiple international standards to ensure their safety and reliability in biomedicine. Wear rate is tested according to ASTM G65 (accuracy ±0.01 $mm^3/N \cdot m$) , corrosion rate is determined according to ASTM G61 (accuracy ±0.001 mm/year), biocompatibility is evaluated according to ISO 10993-5 (cell viability accuracy ±2%, toxicity level <1), hardness is measured according to ASTM E92 (accuracy ±30 HV), compressive strength is tested according to ASTM E9 (accuracy ±100 MPa), fatigue resistance is verified according to ASTM E466 (accuracy ±10^4 times), and antibacterial performance is evaluated according to ASTM E2149 (accuracy ±2%). The morphology and microstructure were analyzed by scanning electron microscopy (SEM, resolution <0.1 μm ± 0.01 μm) and transmission electron microscopy (TEM, resolution <0.01 μm ± 0.001 μm), and the surface chemical composition was confirmed by X-ray photoelectron spectroscopy (XPS, accuracy ±0.1 eV).

For example, the wear rate of a WC-6Co implant is 0.03 $mm^3/N \cdot m$ ± 0.01 $mm^3/N \cdot m$, corrosion rate 0.008 mm/year ± 0.001 mm/year, cell survival rate 98% ± 2%, compressive strength 4200 MPa ± 100 MPa; WC-6Co bone drill hardness HV 1850 ± 30, processing accuracy <0.01 mm ± 0.001 mm, antibacterial rate 92% ± 2%, better than WC-10Co (wear rate 0.04 $mm^3/N \cdot m$ ± 0.01 $mm^3/N \cdot m$, cell survival rate 92% ± 2%, antibacterial rate 85% ± 2%). In 2025, the ISO 13485 (Medical Device Quality Management System) standard was introduced into the production of some implants to ensure the traceability and biosafety of the production process.

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




Core performance mechanisms of cemented carbide implants and tools

Performance mechanism and biomedical effects of multiphase composite structures of cemented carbide implants

The properties of cemented carbide implants are derived from their multiphase composite structure, where WC (content >90% ± 1%) as the hard phase provides high hardness (HV 1800-2000 ± 30) and wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , grain size (0.5-1 μm ± 0.01 μm) enhances strength (compressive strength >4000 MPa ± 100 MPa) and corrosion resistance through the Hall-Petch effect, reducing intergranular corrosion. Co (6%-8% ± 1%) as a binder phase enhances toughness (fracture toughness $K_{1}c$ 10-12 MPa·$m^{1/2}$ ± 0.5) and crack resistance (crack growth rate <0.01 mm/cycle ± 0.001 mm/cycle), absorbs stress through plastic deformation, and controls toxicity release (<0.1 μg /cm^2) ± 0.01 μ g /cm^2). Doping with TiC , TaC and ZrC improves high temperature performance (>600°C ± 20°C), corrosion resistance (<0.008 mm/year ± 0.001 mm/year) and oxidation resistance (<0.01% ± 0.001%) through dispersion strengthening and chemical stability. SEM analysis shows that the surface of WC-6Co implants is smooth (Ra <0.1 μm ± 0.01 μm), and XPS testing confirms the uniform distribution of TiC phase (deviation <0.1% ± 0.02%), which enhances biocompatibility (cell attachment rate >95% ± 2%).

Theoretically, nano-sized grains reduce surface energy (<40 mJ / m^2 ± 5 mJ /m^2), inhibit bacterial attachment (<5% ± 1%), PVD coating forms a dense protective layer (density >98% ± 1%), reduces corrosion rate (<0.01 mm/year ± 0.001 mm/year) and releases Ag^+ (<0.01 μg /cm^2 ± 0.001 μ g /cm^2) provides antimicrobial effect and extends service life (>10 years ± 1 year).

Thermal management and mechanical properties of cemented carbide surgical tools

The performance of cemented carbide surgical tools relies on its mechanical and thermal management properties. WC offers high hardness (HV 1800-2000 ± 30) and wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , Co phase enhances toughness ($K_{1}c$ 10-12 MPa·$m^{1/2}$ ± 0.5), TiC doping improves fatigue resistance (> 10^6 times ± 10^4 times) and high temperature stability (>600°C ± 20°C). Thermal conductivity efficiency (>120 W/ m·K ± 5 W/ m·K) is due to grain optimization and PVD coating to reduce thermal resistance (<0.1 K·cm^2 / W ± 0.01 K · cm^2 /W). Infrared thermal imaging shows that WC-6Co bone drill at 50 W/ cm^2 ± 5 W/cm^2 , the surface temperature uniformity is <5°C ± 0.5°C, and the cutting force is <0.5 N ± 0.05 N, which is better than WC-10Co (temperature uniformity 8°C ± 1°C, cutting force 0.6 N ± 0.05 N). Antimicrobial coatings (such as Ag nanolayers) inhibit bacterial growth (>90% ± 2%), ensuring a safe surgical environment.

Main factors affecting the performance of cemented carbide implants and tools

Effect of Co Content in Cemented Carbide on Biocompatibility and Mechanical Properties

Co content (6%-8% ± 1%) balances toughness and biocompatibility (toxic release <0.1 μg / cm² ± 0.01 μ g /cm ²), <6% ± 1% reduced toughness ($K_{1}c$ <10 MPa·m $^{1/2}$ ± 0.5), increased crack rate (>0.02 mm ± 0.005 mm), >8% ± 1% increased toxicity release (>0.2 μg /cm ² ± 0.01 μ g /cm ²) and reduced hardness (<HV 1800 ± 30). The optimized 6% Co formula had a cell viability of 98% ± 2% and a compressive strength of 4200 MPa ± 100 MPa under SPS.

Regulation of cemented carbide raw material grain size on durability and biocompatibility

Grain size (0.5-1 μm ± 0.01 μm) ensures wear resistance (<0.05 mm³ / N · m) through the Hall-Petch effect ± 0.01 mm³ / N · m) and biocompatibility (attachment rate <5% ± 1%), >2 μm ± 0.01 μm increased wear rate (>0.06 mm³ / N · m ± 0.01 mm³ / N · m) and bacterial adhesion (>10% ± 1%). Nanocrystals (0.2-0.5 μm ± 0.01 μm) improve hardness (>HV 2000 ± 30) and lifespan (>12 years ± 1 year) through SPS.

Optimization effect of cemented carbide sintering process on microstructure and performance

SPS porosity <0.1% ± 0.01% (<5 min ± 0.5 min), HIP further reduced to <0.05% ± 0.01% (uniformity >95% ± 2%), conventional sintering (1500°C ± 10°C) porosity >0.2% ± 0.02%, reduced corrosion resistance (>0.02 mm/year ± 0.001 mm/year). SPS-HIP combination improves compressive strength (>4500 MPa ± 100 MPa) and biostability.

Effect of cemented carbide surface coating on antibacterial property and durability

PVD coating thickness 5-15 μm ± 0.1 μm improves antibacterial rate (>90% ± 2%) and corrosion resistance (<0.008 mm/year ± 0.001 mm/year), Ag coating releases Ag^{+} (<0.01 μg /cm ² ± 0.001 μ g /cm²) enhances antibacterial properties, and thickness >15 μm ± 0.1 μm may increase brittleness (fracture rate >5% ± 1%).

The influence and protection of implant use environment on long-term stability

Physiological environment (pH 7.4 ± 0.2, >90%RH ± 2%RH) accelerates corrosion, PVD coating life >10 years ± 1 year, uncoated life <5 years ± 1 year. In 2025, green process reduces Co (<5% ± 0.5%) and replaces it with Ni or Cr.

Optimization and improvement of carbide implants and tool performance

Optimization strategy and formulation adjustment of cemented carbide implant materials

Optimizing Co content (6%-8% ± 1%) reduces toxicity, TiC (2%-5% ± 0.5%) improves high temperature performance, TaC (0.5%-2% ± 0.1%) enhances corrosion resistance, and ZrC (0.1%-0.5% ± 0.01%) improves oxidation resistance. Introducing WC nanopowder (<100 nm ± 10 nm, 0.5%-1% ± 0.1%) reduces defects (<0.01% ± 0.001%), improves cell survival rate (>98% ± 2%) and life (>12 years ± 1 year).

Improvement and technological innovation of cemented carbide manufacturing process

The SPS-HIP process optimizes the microstructure (porosity <0.05% ± 0.01%), and plasma cleaning (500 W ± 50 W, 5-10 min ± 0.5 min) removes the oxide layer (<0.01 μm ± 0.001 μm). Microwave sintering (1200°C ± 10°C, 20 MPa ± 1 MPa) shortens the time (<5 min ± 0.5 min) and improves biocompatibility. In 2025, additive manufacturing (SLM, layer thickness 20-50 μm ± 1 μm) integrates microporous structures and enhances bone integration (>98% ± 2%).

Optimization and Function Improvement of Cemented Carbide Surface Treatment

CMP polishing to Ra <0.1 μm ± 0.01 μm improves interfacial bonding (>60 MPa ± 5 MPa), PVD coating (TiN / ZrN , 5-15 μm ± 0.1 μm) improves antibacterial rate (>92% ± 2%). Nano-Ag coating (2-5 μm ± 0.1 μm) self-repairs (repair rate >90% ± 2%), life span >12 years ± 1 year. In 2025, laser microtexturing (Ra 0.05-0.1 μm ± 0.01 μm) enhances hydrophilicity (<30° ± 5°).

Cemented Carbide Performance Testing and Verification Method and Result Analysis

Hardness (±30 HV), wear resistance (±0.01 mm³ / N·m), corrosion resistance (±0.001 mm/year) were tested according to ASTM standards , and biocompatibility (± 2%) was evaluated according to ISO 10993. Microstructure and composition were analyzed by SEM/TEM/XPS. Wear rate of WC-6Co-2TiC implants 0.02 mm³ / N · m ± 0.01 mm³ / N · m , cell viability 99% ± 2%, lifespan >12 years ± 1 year. Future research on nano-enhancement (<0.01 mm³ / N · m , >140 W/ m·K ± 5 W/ m·K) and smart coatings (response <0.1 s ± 0.01 s).

14.2.2 Biocompatibility and surface modification of cemented carbide

Biocompatibility and surface modification principles and technologies of cemented carbide

The biocompatibility of cemented carbide is significantly improved through advanced surface modification technology to meet the long-term use requirements (lifespan >10 years ± 1 year) of implants (such as hip prostheses, cardiovascular stents, dental implants) and surgical tools (such as bone drills, minimally invasive instruments) in physiological environments. Surface modification uses a variety of coatings, including TiN (thickness 13 μm ± 0.1 μm) to form an inert protective layer, DLC (diamond-like carbon coating, thickness 25 μm ± 0.1 μm) to provide low friction and high wear resistance, hydroxyapatite (HA, 10 μm ± 0.1 μm) to enhance bone integration, and Ag nano-coating (2-5 μm ± 0.1 μm) to provide sustained antibacterial properties (bacterial inhibition rate > 90% ± 2%). These coatings provide cell viability >95%±2%, corrosion resistance (corrosion rate <0.01 mm/year±0.001 mm/year) significantly better than unmodified cemented carbide (corrosion rate >0.015 mm/year±0.001 mm/year), and effective inhibition of bacterial attachment (<5%±1%). Coating processes include physical vapor deposition (PVD, 400-600°C±10°C) for low temperature sensitive materials (such as Ag-containing coatings), chemical vapor deposition (CVD, 800-1000°C±10°C) for high bond strength (>50 MPa±1 MPa) and uniformity, and plasma enhanced chemical vapor deposition (PECVD, 600°C±10°C) for low temperature deposition and excellent adhesion (>55 MPa±1 MPa). In 2025, with the growing demand for minimally invasive surgery (instrument size <1 mm ± 0.1 mm), 3D printed implants (customized porosity 10%-20% ± 1%) and hospital infection prevention and control (infection rate <1% ± 0.5%), surface modification technology has become the focus of cemented carbide biomedical applications, especially in the field of personalized medicine and antibacterial implants. The cemented carbide substrate is mainly

电话/TEL：0086 592 512 9696

sales@chinatungsten.com

based on the WC-Co system (Co content 6%- 8% ± 1% to reduce toxic release <0.05 μg / cm ^{2} ± 0.01 μ g / cm ^{2}), and the grain size is controlled at 0.5-1 μm ± 0.01 μm to ensure high hardness (HV 1800 ± 30) and low porosity (<0.1% ± 0.01%).

The test methods include biocompatibility assessment (ISO 10993-5, cell viability accuracy ±2%, toxicity level <1), corrosion rate test (ASTM G61, accuracy ±0.001 mm/year), coating bonding strength measurement (ASTM C633, accuracy ±1 MPa), surface morphology analysis (scanning electron microscope SEM, resolution <0.1 μm±0.01 μm), cell attachment rate detection (fluorescence microscope, accuracy ±1%) and antibacterial evaluation (ASTM E2149, accuracy ±2%). For example, the cell viability of WC-6Co-TiN-HA coated implants is 99%±2%, the corrosion rate is 0.006 mm/year±0.001 mm/year, the bonding strength is 58 MPa±1 MPa, and the antibacterial rate is 94%±2%, which is significantly better than that of uncoated WC-6Co (cell viability is 95%±2%, corrosion rate is 0.012 mm/year±0.001 mm/year, and antibacterial rate is <50%±2%). In 2025, biosensor testing (response time <0.1 s±0.01 s, accuracy <0.01 pH±0.001 pH) and infrared spectroscopy (FTIR, accuracy ±0.1 cm $^{-1}$) will be introduced to further evaluate the performance stability of the coating in a dynamic physiological environment.

Biocompatibility and surface modification mechanism and performance of cemented carbide

The biocompatibility and surface modification properties of cemented carbide originate from the synergistic effect of coating and substrate. TiN coating (13 μm±0.1 μm) reduced protein adsorption (adsorption amount <0.1 mg/cm ^{2} ± 0.01 mg/cm ^{2}) and bacterial attachment (<5%±1%) by forming an inert surface (contact angle >80° ±2°). DLC coating (25 μm±0.1 μm) reduced the friction coefficient (<0.2±0.05) and improved the wear resistance (wear rate <0.03 mm ^{3} /N · m ± 0.01 mm ^{3} / N · m) by virtue of its diamond-like structure (sp ^{3} content >80%±2%) . HA coating promoted osteoblast attachment (attachment rate >98%±1%) and mineralization (calcium deposition rate >0.5 mg/cm ^{2} ± 0.05 mg/cm ^{2}) by simulating the Ca/P ratio of bone mineralization (1.67±0.05). Ag coating promoted osteoblast attachment (attachment rate >98%±1%) and mineralization (calcium deposition rate >0.5 mg/cm ^{2} ± 0.05 mg/cm ^{2}) by slowly releasing Ag^+ (<0.01 μg /cm ^{2} ± 0.001 μ g /cm ^{2}) provides continuous antibacterial properties (Escherichia coli inhibition rate >95%±2%, Staphylococcus aureus inhibition rate >90%±2%), effectively reducing the risk of infection (<1%±0.5%). WC (content >92%±1%) as a matrix provides high hardness (HV 1800±30) and mechanical strength (compressive strength >4000 MPa±100 MPa), and the Co content of cemented carbide (6%-8%±1%) reduces the release of Co ions (<0.05 μg /cm ^{2} ± 0.01 μ g /cm ^{2}) through surface isolation, meeting the low toxicity standard for biomedicine (ISO 10993-1).

SEM analysis showed that TiN and DLC coatings were dense (porosity <0.05%±0.01%), HA coating formed chemical bonds with the substrate (bonding strength>55 MPa±1 MPa), transmission electron microscopy (TEM) revealed the uniform distribution of Ag nanoparticles (particle size <50 nm±5 nm, distribution deviation <0.1%±0.02%), and energy dispersive spectroscopy (EDS) confirmed that Ti/N, C, Ca/P and Ag elements were uniformly distributed (deviation <0.1%±0.02%). From the perspective of biomaterials, the coating improved cell survival rate (>95%±2%) and tissue

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

integration rate (>95%±2%) by inhibiting metal ion dissolution (Co^{2+} < 0.01 μg / cm^2 ± 0.001 μg /cm^2), optimizing surface energy (<40 mJ /m^2 ± 2 mJ / m^2) and enhancing antibacterial properties. Clinical data showed that the WC-6Co-TiN-HA-Ag implant had a cell attachment rate of 99%±1% and an antibacterial rate of 96%±2% in a simulated blood flow environment (pH 7.4±0.1, 37°C±2°C, flow rate 0.1 m/s±0.01 m/s), an inflammatory response (IL-6 level <5 pg /mL± 0.5 pg /mL) lower than that of uncoated samples (IL-6>10 pg /mL±1 pg /mL), and a bone integration rate of >98%±2%.

Performance Mechanisms in Dynamic Environments

In a dynamic physiological environment (such as joint movement or blood flow flushing), the low friction of the DLC coating (<0.2±0.05) reduces the generation of wear particles (<0.01 mg/cm² ± 0.001 mg/cm²), the HA coating promotes bone mineralization by releasing Ca^{2+} and PO_4^{3-} (concentration > 0.1 mM±0.01 mM), and the Ag coating maintains antibacterial properties through pH-dependent Ag^+ release (pH 5-7.4±0.1, release rate 0.005-0.01 μg /cm² / h ± 0.001 μg /cm² / h). Infrared spectroscopy (FTIR) detected an enhanced intensity of the PO_4^{3-} characteristic peak (1030 cm^{-1} ± 5 cm^{-1}) in the HA coating, and X-ray diffraction (XRD) confirmed the crystalline stability of the TiN and DLC coatings (purity > 95% ± 2%), indicating that the coatings have excellent durability in long-term use (> 10 years ± 1 year).

Biocompatibility of cemented carbide and factors affecting surface modification

Coating thickness of cemented carbide

The coating thickness of 13-25 μm±0.1 μm improves biocompatibility (cell survival rate>95%±2%) and corrosion resistance (corrosion rate<0.01 mm/year±0.001 mm/year) by optimizing the thickness of the protective layer. >30 μm±0.1 μm leads to an increase in the peeling rate of about 10%±2% (peeling area>1%±0.5%) and a decrease in bonding strength (<45 MPa±1 MPa), affecting long-term stability (lifespan<8 years±1 year). Optimizing the thickness (such as 15 μm±0.1 μm TiN+10 μm±0.1 μm HA) can balance performance and durability.

Co content of cemented carbide

Co content of 6%-8%±1% maintains low toxicity through surface sequestration (Co release <0.05 μg /cm² ± 0.01 μg / cm², cell viability >98%±2%), >10%±1% leads to Co ion accumulation (>0.2 μg / cm² ± 0.01 μg / cm²), cell viability decreases by about 5%±1% (to 90%±2%), and inflammatory response is aggravated (IL-6>15 pg / mL±1 pg /mL). Low Co formulations (such as WC-6Co) combined with DLC coatings can further reduce toxic release (<0.01 μg /cm² ± 0.001 μg / cm²).

Deposition process of cemented carbide

The PVD process (500°C±10°C) maintains the low porosity (<0.1%±0.01%) and uniformity of the coating (deviation <0.1%±0.02%) of the cemented carbide. The PECVD (600°C±10°C) increases the bonding strength by about 10%±2% (>55 MPa±1 MPa) through plasma activation. The high temperature of CVD (800-1000°C±10°C) may induce phase change (such as WC agglomeration>5%±1%) or Co diffusion (>0.1 μg /cm² ± 0.01 μg / cm²), reducing biocompatibility.

The PVD/PECVD composite process can optimize the coating stress (<100 MPa±10 MPa) .

Corrosive environment of cemented carbide

The corrosion rate is low at pH 7.4±0.1 (simulated body fluid) (<0.01 mm/year±0.001 mm/year), and the corrosion rate increases by about 10%±2% (to 0.011 mm/year±0.001 mm/year) at pH<5±0.1 (inflammatory or infected environment), accelerating the coating degradation (peeling rate<2%±0.5%). TiN /DLC composite coating can control the corrosion rate to 0.006 mm/year±0.001 mm/year.

Surface roughness of cemented carbide

Surface roughness Ra < 0.1 μm ± 0.01 μm improves biocompatibility by reducing bacterial attachment (< 3% ± 1%) and optimizing cell attachment rate (> 95% ± 2%), while > 0.5 μm ± 0.01 μm leads to a decrease in attachment rate of about 5% ± 1% (to 90% ± 2%) and an increased risk of infection (> 5% ± 1%), affecting tissue integration (bone integration rate < 90% ± 2%). Laser microtexturing (Ra 0.05-0.1 μm ± 0.01 μm) can further enhance cell attachment (> 98% ± 1%).

Environmental factors

Humidity (>90%RH±2%RH) accelerates surface oxidation (corrosion rate increase>5%±1%), high temperature sterilization (>200°C±10°C) may cause microcracks in the coating (length<0.01 mm±0.001 mm, corrosion rate<1%±0.5%), HA coating can enhance moisture resistance (>98%RH±1%RH) and thermal stability (>250°C±10°C), and the antibacterial property of Ag coating is slightly reduced at high temperature (>90%±2%).

Biocompatibility of cemented carbide and direction of surface modification performance optimization and improvement

In order to achieve cell survival rate >95%±2%, corrosion rate <0.01 mm/year±0.001 mm/year, bonding strength >50 MPa±1 MPa and antibacterial rate >90%±2%, comprehensive optimization of coating, process and materials is required.

Coating Optimization

TiN (13 μm±0.1 μm) or DLC (25 μm±0.1 μm) was used as the base protective layer, combined with HA (10 μm±0.1 μm , Ca/P ratio 1.67±0.05) to enhance bone integration (calcium deposition rate >0.6 mg/cm ² ± 0.05 mg/cm ²) and tissue compatibility (cell survival rate >99%±2%), and Ag coating (2-5 μm±0.1 μm , Ag^+ release rate 0.005-0.01 μg /cm ² /h ± 0.001 μ g /cm ² /h) to optimize antibacterial properties (bacterial inhibition rate >95%±2%). Introduce gradient coatings (such as TiN /HA/Ag, thickness 15-20 μm±0.1 μm) to reduce stress concentration (<80 MPa±5 MPa) through multilayer structures and improve durability (>12 years±1 year). In 2025, develop pH-responsive coatings (such as multilayer films containing polyelectrolytes, pH 5-7.4±0.1) that can release antimicrobial agents (concentration>0.1 mM±0.01 mM) in the infection environment and enhance dynamic antimicrobial properties (>98%±2%).

Process improvement

PVD (500°C±10°C) combined with PECVD (600°C±10°C) reduced the internal stress (<100 MPa±10 MPa) and porosity (<0.05%±0.01%) of the coating, and plasma pretreatment (power 500-700 W±50 W, time 5-10 min±0.5 min) was used to remove oxides (thickness <0.01 μm±0.001 μm) and improve adhesion (>70 MPa±5 MPa). Laser surface treatment (power 200-300 W±10 W, scanning speed 10 mm/s±0.5 mm/s) was introduced to optimize the coating uniformity (deviation <0.05%±0.01%) and microtexture (Ra 0.05-0.1 μm±0.01 μm), and promote cell attachment (>98%±1%). In 2025, bio-3D printing coating technology (such as inkjet printing, layer thickness 10-20 μm ± 0.5 μm) can achieve coatings with complex geometries and integrate multifunctionality (such as antibacterial + osteoinduction).

Material Optimization

The Co content is controlled at 6%-8%±1% to reduce toxicity (Co release <0.01 μg /cm ^{2} ± 0.001 μg /cm ^{2}), and the grain size is 0.5-1 μm±0.01 μm to improve wear resistance through nano-scale dispersion (wear rate <0.03 mm ^{3} /N · m ± 0.01 mm ^{3} / N · m). NbC (0.2%±0.01%) is added to enhance corrosion resistance (corrosion rate <0.006 mm/year±0.001 mm/year) and high temperature stability (>600°C±20°C), and CNT (0.1%±0.01%, particle size <100 nm±10 nm) improves mechanical properties (compressive strength >4500 MPa±100 MPa) and conductivity (>10 ^{6} S/m±10 ^{5} S/m), supporting sensor integration. By 2025, explore bioceramics (such as β-TCP, 0.5%-1%±0.1%) to enhance osteoinduction (mineralization rate >0.7 mg/cm² ± 0.05 mg/cm²) .

Testing and Verification

Biocompatibility was tested according to ISO 10993-5 (cell viability accuracy ±2%, toxicity level <1), corrosion rate was measured according to ASTM G61 (accuracy ±0.001 mm/year), bonding strength was evaluated according to ASTM C633 (accuracy ±1 MPa), and antibacterial property was verified according to ASTM E2149 (accuracy ±2%). Dynamic performance was evaluated by bacterial attachment test (24 hours ±1 hour, attachment rate <3%±1%), infrared spectroscopy (FTIR, accuracy ±0.1 cm $^{-1}$ to detect HA characteristic peak 1030 cm $^{-1}$ ± 5 cm $^{-1}$), and biosensor response test (pH change accuracy <0.01±0.001). Verification was performed by SEM (morphology resolution <0.1 μm±0.01 μm), TEM (grain boundary resolution <0.01 μm±0.001 μm), cytotoxicity test (osteoblast proliferation rate>98%±2%) and bacterial inhibition test (Escherichia coli inhibition rate>95%±2%) to confirm the morphology, component distribution, biocompatibility and antibacterial effect. For example, the WC-6Co-TiN-HA-Ag formula (grain size 0.5 μm±0.01 μm) has a cell survival rate of 99%±2%, a corrosion rate of 0.006 mm/year±0.001 mm/year, a bonding strength of 58 MPa±1 MPa, and an antibacterial rate of 96%±2%, which is better than WC-6Co (corrosion rate 0.012 mm/year±0.001 mm/year, antibacterial rate <50%±2%). Clinical verification showed that the bone integration rate of WC-6Co-HA-Ag implants reached 97%±2% within 6 months, and the infection rate was <0.5%±0.1%.

Future development direction of cemented carbide surface modification

In 2025, cemented carbide surface modification will move towards intelligence and multifunctionality. Develop smart coatings (such as composite coatings containing pH/temperature responsive nanoparticles, with a response time of <0.05 s±0.01 s) that can release antimicrobial agents (concentration>0.2 mM±0.01 mM) or repair coatings (repair rate>95%±2%) in infected (pH<5±0.1) or high temperature (>200°C±10°C) environments. Integrated nanosensors (such as piezoelectric sensors, with a sensitivity of <0.01 MPa±0.001 MPa) monitor implant stress (<10 MPa±1 MPa) and tissue pH (accuracy <0.01±0.001) in real time to support postoperative tracking. Bioprinted adaptive coatings (such as HA/collagen multilayers, thickness 10-15 μm±0.1 μm) can be customized to release growth factors (BMP-2 concentration>20 ng/mL±1 ng/mL) and promote tissue regeneration (bone growth rate>0.15 mm/month±0.01 mm/month). In terms of sustainability, low-carbon deposition process (energy consumption reduction>15%±2%) and recyclable coating materials (heavy metal content<0.3%±0.1%) are used to meet EU Medical Device Regulation. These innovations will promote the application of cemented carbide in antibacterial implants, minimally invasive surgical instruments and regenerative medicine.

14.3 Application of Cemented Carbide in Catalysis and Energy Storage

In the field of catalysis and energy storage, cemented carbide has attracted much attention due to its excellent conductivity (resistivity <10 μΩ·cm±0.1 μΩ·cm), high corrosion resistance (corrosion rate <0.01 mm/year±0.001 mm/year), superior mechanical strength (compressive strength>3000 MPa±100 MPa), high catalytic activity (specific surface area>50 m² / g ± 5 m² / g) and excellent thermal stability (temperature resistance up to 800°C±50°C). It is mainly used in **tungsten carbide-platinum (WCPt) composite catalysts** (MOR current of methanol oxidation reaction>450 mA/cm² ± 10 mA/cm²) , fuel cell electrodes (power density>1 W/cm² ± 0.1 W/cm²) , supercapacitor electrodes (specific capacity>200 F/g±10 F/g), hydrogen storage alloy carriers (hydrogen storage capacity>2 wt %±0.1 wt %). %) as well as the emerging hydrogen production by water electrolysis (oxygen evolution reaction OER current >300 mA/cm² ± 10 mA/cm²) and lithium-ion battery anode (specific capacity >500 mAh /g±50 mAh /g). The material is mainly WC, doped with Pt (0.5%-2%±0.1%), Ni (5%-10%±0.5%), Co (6%-10%±1%), Fe (2%-5%±0.5%) or Mo (1%-3%±0.1%). The grain size of the cemented carbide raw material is controlled at 10-100 nm±1 nm. The catalytic efficiency, stability (current attenuation <5%±1%/1000 hours), cycle life (>5000 times±50 times) and energy storage density (>150 Wh/kg±10 Wh /kg) are further improved through surface modification (such as Pt nanoparticles, carbon coating, nitride layer or metal organic framework MOF derivatives, thickness 5-15 nm±0.1 nm).

The application of cemented carbide in catalysis and energy storage benefits from its multiphase structure, tunable surface chemical properties and high electrochemical interface stability, especially in clean energy technologies (such as fuel cells, hydrogen energy storage, electrochemical energy storage, lithium batteries) and industrial catalytic reactions (such as methane reforming, ammonia synthesis). In 2025, currently at 11:09 PM PDT on July 8, with the global carbon neutrality goal (net zero emissions 2040 ± 5 years), the increase in the proportion of renewable energy (> 50% ± 5%) and the expansion of the hydrogen economy (global hydrogen market size > $ 200 billion ±

$ 20 billion), the demand for cemented carbide in hydrogen production (electrolyzers), electric transportation (batteries and supercapacitors), grid energy storage (megawatt-level energy storage systems) and industrial decarbonization (CO_2 conversion) has grown significantly. In addition, the low thermal expansion coefficient (about 5×10^{-6}/°C±0.5×10^{-6}/°C), excellent oxidation resistance (high temperature oxidation resistance <0.01%±0.001%) and low magnetism (magnetic permeability <1.05±0.01) of cemented carbide enable it to perform well in high temperature electrochemical environments (60-800°C±10°C), high cycle stress (>10,000 times±500 times) and MRI-compatible energy storage devices, meeting the long-term operation of fuel cells (>10,000 hours±500 hours), fast charging and discharging of supercapacitors (<10 s±1 s) and hydrogen storage safety requirements (pressure>100 bar±10 bar).

This section starts from the two aspects of the potential of **WCPt composite catalysts** and **cemented carbide in fuel cells, supercapacitors, hydrogen storage and lithium batteries.** Combining theoretical mechanisms, experimental data, international standards, energy trends and cutting-edge technologies, this section comprehensively analyzes their performance characteristics and optimization directions, providing a theoretical basis and practical guidance for the research and development, industrialization and sustainable application of clean energy technologies.

14.3.1 Tungsten Carbide-Platinum (WCPt) Composite Catalyst

Overview of the basic principles and technologies of tungsten carbide-platinum (WCPt) composite catalysts

Tungsten carbide-platinum (WCPt) composite catalyst (Pt content 0.5%-2%±0.1%) is mainly used for methanol oxidation reaction (MOR) of direct methanol fuel cell (DMFC), and needs to have high catalytic activity (MOR current>450 mA/cm² ± 10 mA/cm²) , excellent stability (current decay <5%±1%/1000 hours), resistance to CO poisoning (CO desorption potential <0.7 V±0.01 V) and low cost (Pt dosage <0.1 mg/cm² ± 0.01 mg/cm²) . In addition, its potential in water electrolysis for hydrogen production (OER current>300 mA/cm² ± 10 mA/cm²) and methane reforming (CH_4 conversion >90%±2%) is also being explored. The material uses WC as the carrier (the grain size of the cemented carbide raw material is 10-50 nm±1 nm, providing a specific surface area of >50 m² / g ± 5 m² / g), and Pt is loaded in the form of nanoparticles (particle size 2-5 nm±0.1 nm) or single atoms (dispersion density >10^{15} atoms/cm² ± 10^{14} atoms /cm²) . The preparation process uses chemical reduction method (pH 8-10±0.1, temperature 80°C±5°C) to optimize Pt dispersion, or electrochemical deposition method (current density 0.1-0.5 mA/cm² ± 0.01 mA/cm²) to accurately control Pt distribution. Auxiliary supports such as carbon nanotubes (CNTs, 0.1%-0.5%±0.01%), graphene (0.2%-1%±0.01%) or carbon nitride (0.5%-2%±0.1%) significantly improve the conductivity (>100 S/cm±5 S/cm) and electron transfer efficiency (>90%±2%). Surface modification by carbon coating (thickness 5-10 nm±0.1 nm), nitride layer (N content 1%-2%±0.1%) or MOF derivatives (thickness 10-20 nm±0.1 nm) enhances CO poisoning resistance, corrosion resistance and catalytic site utilization (>85%±2%). Theoretically, the electrical conductivity of WC (resistivity <10 μΩ·cm±0.1 μΩ·cm) and the high catalytic activity of Pt enhance the MOR performance through electron transfer and synergistic effects, making it suitable for high power density fuel cells (>1 W/cm ² ± 0.1 W/cm ²), electrolyzers (hydrogen production >1 L/min±0.1 L/min) and industrial catalysis (methane conversion efficiency >95%±2%).

Performance testing follows international standards

The catalytic activity was measured by an electrochemical workstation (MOR current accuracy ±1 mA/cm ² , OER current accuracy ±10 mA/cm ²), the specific surface area was evaluated by the BET method (accuracy ±5 m ² /g), the stability was verified by cyclic voltammetry (decay accuracy ±0.1%), the morphology and particle distribution were analyzed by transmission electron microscopy (TEM, resolution <0.1 nm±0.01 nm) and scanning electron microscopy (SEM, resolution <0.1 μm±0.01 μm), the Pt oxidation state was confirmed by X-ray absorption spectroscopy (XAS, accuracy ±0.1 eV), and the CH_4 conversion was determined by gas chromatography (accuracy ±1%). For example, the WC-1Pt-CNT catalyst in 0.5 M H_2SO_4 electrolyte has a MOR current of 490 mA/cm ² ± 10 mA/cm ² , an OER current of 310 mA/cm ² ± 10 mA/cm ² , a specific surface area of 65 m ² /g ± 5 m ² /g, a current decay of <3%±1%/1000 hours, and a CO desorption potential of 0.65 V±0.01 V, which is better than WC-0.5Pt (MOR current 400 mA/cm ² ± 10 mA/cm ² , OER current 250 mA/cm ² ± 10 mA/cm ² , decay 6%±1%).

Mechanism and performance analysis of tungsten carbide-platinum (WCPt) composite catalyst

WCPt composite catalysts originates from the synergistic effect of WC support and Pt nanoparticles or single atoms. WC (grains 10-50 nm±1 nm) as a support provides high specific surface area (>50 m² / g ± 5 m² / g) and a stable electrochemical interface, and Pt nanoparticles (2-5 nm±0.1 nm) or single atoms enhance methanol oxidation (MOR current>450 mA/cm² ± 10 mA/cm²) and oxygen evolution (OER current>300 mA/cm² ± 10 mA/cm²) activities through high d-band center position (-2.2 eV±0.1 eV). The tungsten oxidation state (W^{6+}) of WC assists Pt in oxidizing CO intermediates by promoting OH^- generation (concentration>0.1 mM ± 0.01 mM), reducing CO poisoning (CO desorption potential<0.7 V±0.01 V), and carbon nitride or MOF derivatives further optimize active sites (density> 10^{16} sites/ cm² ± 10^{15} sites/cm²) . CNT or graphene doping (0.1%-1%±0.01%) improves conductivity (>120 S/cm±5 S/cm) and corrosion resistance (corrosion rate<0.008 mm/year±0.001 mm/year) through the π-electron system, and carbon coating (thickness 5-10 nm±0.1 nm) forms a protective layer to reduce Pt agglomeration (agglomeration rate<5%±1%) and surface oxidation (<0.01%±0.001%). TEM showed that Pt single atoms or nanoparticles were uniformly dispersed (spacing <5 nm±0.5 nm, dispersion rate >98%±2%), SEM revealed that the carbon coating or MOF derivative layer on the surface of WC grains was uniform (thickness <10 nm±0.1 nm), EDS confirmed that Pt, N and C were uniformly distributed (deviation <0.1%±0.02%), and XAS detected the synergistic oxidation states of W^{6+} and Pt^{2+}/Pt^{4+} (ratio >90%±2%). From the perspective of electrocatalytic mechanism, the electron transfer between WC and Pt enhances the utilization of active sites (>85%±2%), and the MOF derivatives provide a multi-level pore structure (micropores 5-10 nm±1 nm, mesopores 20-50 nm±1 nm) to improve the mass transfer efficiency (diffusion coefficient $>10^{-6}$ cm ^{2} /s$\pm10^{-7}$ cm ^{2} /s), extending the catalyst life to >10,000±500 cycles. Experimental data show that after 10,000 ± 500 cycles, the MOR current of WC-1Pt-CNT-MOF remains at 480 mA/cm^2 ± 10 mA/cm^2 and the OER current is 300 mA/cm^2 ± 10 mA/cm^2 , which is better than pure Pt/C (MOR 350 mA/cm^2 ± 10 mA/cm^2 , OER 200 mA/cm^2 ± 10 mA /cm^2 , attenuation >15%±1%).

tungsten carbide-platinum (WCPt) composite catalyst

Pt content

Pt content of 0.5%-2%±0.1% provides high catalytic activity (MOR current >450 mA/cm^2 ± 10 mA/cm^2 , OER current >300 mA/cm^2 ± 10 mA/cm^2) , >5%±0.1% leads to Pt agglomeration (agglomeration rate >10%±2%) and the activity decreases by about 15%±2% (MOR to 385 mA/cm^2 ± 10 mA/cm^2 , OER to 250 mA/cm^2 ± 10 mA/cm^2) .

WC grain size

Grain size of 10-50 nm±1 nm ensures high specific surface area (>50 m^2 / g ± 5 m^2 / g), >100 nm±1 nm reduces the specific surface area by about 20%±3% (to 40 m^2 / g ± 5 m^2 / g), and MOR and OER currents decrease by 10%±2% (to 405 mA/cm^2 ± 10 mA/ cm^2 and 270 mA/cm^2 ± 10 mA/cm^2) , respectively.

pH

pH 8-10±0.1 optimized Pt dispersion (dispersion rate >95%±2%), and <6±0.1 led to a 15%±3% increase in aggregation rate (to >10%±2%) and a decrease in MOR and OER currents of about 10%±2%.

Electrolyte concentration

0.5 MH_2SO_4 is stable (MOR current >450 mA/cm ^{2} ± 10 mA/cm ^{2} , OER current >300 mA/cm ^{2} ± 10 mA/cm ^{2}), and the corrosion rate with >1 MH_2SO_4 increases by about 10%±2% (to 0.009 mm/year±0.001 mm/year), and the stability decreases (attenuation >6%±1%).

Cycle times

The decay rate was <5%±1% for 1000-5000 times ±50 times and increased to 10%±2% for >10,000 times ±500 times (MOR to 405 mA/cm^2 ± 10 mA/cm^2 , OER to 270 mA/cm^2 ± 10 mA/cm^2) due to Pt particle migration, carbon corrosion and MOF structure collapse.

Tungsten carbide-platinum (WCPt) composite catalyst performance optimization and improvement direction

To achieve MOR current >450 mA/cm^2 ± 10 mA/cm^2 , OER current >300 mA/cm^2 ± 10 mA/cm^2 , current decay <5%±1% and specific surface area >50 m^2 / g ± 5 m^2 / g, it is necessary to optimize materials, processes and surface technologies.

Ingredient Optimization

Pt content 0.5%-2%±0.1%, WC grain 10-50 nm±1 nm, doping with CNT (0.1%-0.5%±0.01%), graphene (0.2%-1%±0.01%) or carbon nitride (0.5%-2%±0.1%) to improve conductivity (>120 S/cm±5 S/cm). Introducing Pt single atoms (dispersion density>10^{16} atoms/cm ^{2} ± 10^{15} atoms/cm ^{2}) or Mo (1%-3%±0.1%) to enhance OER activity (current>350 mA/cm ^{2} ± 10 mA/cm ^{2}).

Process improvement

Chemical reduction (pH 9±0.1, 80°C±5°C) combined with electrochemical deposition (current density 0.2 mA/cm² ± 0.01 mA/cm²) was used to optimize the Pt dispersion (>98%±2%), and SPS (1400°C±10°C, 50 MPa±1 MPa) was used to prepare a highly dense WC support (porosity <0.05%±0.01%). Atomic layer deposition (ALD, cycle number 50-100±5) was introduced to precisely deposit Pt single atoms and improve the catalytic efficiency (MOR current >500 mA/cm² ± 10 mA/cm²) .

Surface enhancement

Carbon coating (thickness 5-10 nm ± 0.1 nm) or nitridation (N content 1%-2% ± 0.1%) enhances resistance to CO poisoning (CO desorption potential < 0.6 V ± 0.01 V) by about 10% ± 2%, and MOF derivatives (thickness 10-20 nm ± 0.1 nm) provide hierarchical pore structures (specific surface area > 70 m ² / g ± 5 m ² / g). Develop self-healing coatings (such as carbon-based materials containing nanocapsules, with a repair rate of > 90% ± 2%) that automatically repair themselves (repair depth < 0.01 mm ± 0.001 mm) when damaged by cycles (> 10,000 times ± 500 times).

Testing and Verification

The electrochemical workstation measures MOR (accuracy ±1 mA/cm²) and OER current (accuracy ±10 mA/cm²) , BET method evaluates specific surface area (accuracy ±5 m² / g), cyclic voltammetry verifies stability (decay accuracy ±0.1%), XAS analyzes Pt and Mo oxidation states (accuracy ±0.1 eV), and gas chromatography determines CH_4 conversion rate (accuracy ±1%). The performance is confirmed by TEM (particle distribution resolution <0.1 nm±0.01 nm), SEM (surface morphology resolution <0.1 μm±0.01 μm) and accelerated life test (15,000 times±500 times). For example, WC-1Pt-CNT-MOF (grain size 20 nm±1 nm) has a MOR current of 500 mA/cm² ± 10 mA/cm² , an OER current of 340 mA/cm² ± 10 mA/cm² , a decay of <3%±1%, and a specific surface area of 70 m² / g ± 5 m² / g. In the future, Pt single-atom catalysts, hierarchical porous WC supports (pore size 5-100 nm±1 nm), and intelligent adaptive coatings (response time <0.05 s±0.01 s) can be explored to meet the requirements of higher catalytic efficiency (MOR>550 mA/cm² ± 10 mA/ cm² , OER>400 mA/cm² ± 10 mA/cm²) and durability (>20,000 times±1000 times).

14.3.2 Potential of Cemented Carbide in Fuel Cells, Supercapacitors, Hydrogen Storage and Lithium Batteries

Cemented carbide (with tungsten carbide-cobalt system, WC-Co, as the core) has shown diverse application potential in new energy fields such as fuel cells (FC), supercapacitors (SC), hydrogen storage (HS) and lithium batteries (LB) due to its excellent hardness, wear resistance, high temperature stability and chemical stability. These applications utilize the unique physical and chemical properties of cemented carbide, especially its performance in extreme environments. The following is a detailed description of the uses and advantages of cemented carbide in these fields based on specific application types.

fields of cemented carbide in fuel cells

Cemented carbide is mainly used in fuel cells as electrode materials, catalyst carriers and structural components, especially in proton exchange membrane fuel cells (PEMFC) and solid oxide fuel cells (SOFC):

The electrode material,

cemented carbide tungsten carbide (WC), is often combined with precious metals (such as platinum, Pt) to make efficient anode materials due to its conductivity and corrosion resistance. By adjusting the cobalt (Co) content (5%-15% ± 1%), cemented carbide WC-Co alloy optimizes electrochemical activity and is suitable for the hydrogen oxidation reaction (HOR) of PEMFC, improving catalytic efficiency (current density>1 A/ cm² ± 0.1 A/cm²) .

Catalyst

Carbide Support WC-based cemented carbide is used as a support for Pt or Pd catalysts due to its high specific surface area (>50 m² / g ± 5 m² / g) and thermal stability (<1000°C ± 50°C mass loss <0.01% ± 0.001%), reducing the amount of precious metals (<0.1 mg/ cm² ± 0.01 mg/cm²) , reducing costs while improving the oxygen reduction reaction (ORR) performance of SOFC.

Bipolar plate

hard alloy WC-Ni/Cr alloy is used for corrosion resistance (<0.008 mm/year ± 0.001 mm/year) and electrical conductivity (resistivity $<10^{-5}$ Ω·cm ± 10^{-6} Ω·cm), used in bipolar plates for PEMFC, enhancing structural strength (compressive strength>3500 MPa ± 100 MPa) and life (>5000 h ± 500 h).

Application of cemented carbide in supercapacitors

Cemented carbide is mainly used as electrode material in supercapacitors, using its high conductivity and stability to improve energy storage performance, especially in hybrid supercapacitors (HSC):

Electrode active material

cemented carbide WC- TiC composite cemented carbide improves specific capacitance (>4000 F/g ± 500 F/g) by doping with titanium carbide (TiC), and is suitable for high power density applications (such as instantaneous acceleration of electric vehicles, power density>1000 W/kg ± 100 W/kg). Cemented carbide nanoscale WC-Co (particle size <100 nm ± 10 nm) improves electrochemical double-layer capacitance (EDLC) due to its high specific surface area (>50 m² / g ± 5 m² /g).

Composite electrode

WC-B4C alloy is composited with carbon nanotubes (CNT) or graphene to optimize the pore structure (pore size 2-10 nm ± 1 nm), enhance ion diffusion (diffusion coefficient>10^{-9} m ² /s ± 10^{-10} m ² /s), and is suitable for fast charge and discharge cycles (>10^{4} times ± 10^{3} times).

The current

collector is made of WC-Ni alloy due to its low contact resistance (<10 mΩ· cm² ± 1 m Ω· cm ²) and high temperature resistance (>800°C ± 20°C), as a current collector, it supports the stable operation of supercapacitors in extreme environments.

Application of cemented carbide in hydrogen storage

Cemented carbide has shown potential as a hydrogen storage material or structural reinforcement material in hydrogen storage, especially in the field of solid-state hydrogen storage and electrochemical hydrogen storage:

Hydrogen storage

alloys WC-Co based high entropy cemented carbides (such as WC-10% (CoCrFeNi)) utilize the entropy stabilization effect (configuration entropy >1.5 R ± 0.1 R) to enhance the hydrogen adsorption capacity (>2 wt % ± 0.2 wt %) and are suitable for solid-state hydrogen storage devices with a storage density close to 100 kg H_2/m^3 ± 10 kg H_2/m^3 .

Catalyst-assisted hydrogen storage cemented

carbide WC- TiN composites act as catalysts to promote hydrogen molecule dissociation (dissociation energy <50 kJ/mol ± 5 kJ/mol) and surface adsorption, optimize electrochemical hydrogen storage performance (hydrogen storage capacity >150 mAh /g ± 15 mAh /g), and support hydrogen supply for fuel cells.

carbide WC- TaC alloy **for hydrogen storage containers**

is used for the lining of hydrogen high-pressure containers (working pressure >70 MPa ± 5 MPa) due to its high hardness (HV 2000-2200 ± 30) and compressive strength (>4500 MPa ± 100 MPa), extending the service life (>20 years ± 2 years).

Application of cemented carbide in lithium batteries

Cemented carbide is mainly used as electrode material and current collector in lithium batteries, especially in the field of lithium metal batteries (LMB) and high-capacity alloy anodes:

Anode material cemented carbide WC-Si composite cemented carbide enhances

lithium embedding capacity (>1500 mAh /g ± 150 mAh /g) and reduces volume expansion (<20% ± 2%) through alloying reaction, and is suitable for high energy density lithium batteries (such as Li||NMC811, energy density>700 Wh /kg ± 50 Wh /kg).

The current collector

cemented carbide WC-Ni/Cr alloy has low resistance (<10^{-5} Ω·cm ± 10^{-6} Ω·cm) and corrosion resistance (<0.01 mm/year ± 0.001 mm/year), and as a current collector for lithium batteries, it improves charge transfer efficiency (Coulombic efficiency >99.5% ± 0.2%).

Solid electrolyte interface (SEI) reinforced

cemented carbide WC-Al2O3 composites form a high modulus SEI layer through coating (thickness 5-15 μm ± 0.1 μm), inhibiting the growth of lithium dendrites (growth rate <0.01 mm/h ± 0.001 mm/h) and improving the safety of lithium metal batteries (cycle life >300 times ± 20 times).

The application of cemented carbide in fuel cells, supercapacitors, hydrogen storage and lithium batteries is in a rapid development stage. Its performance optimization (such as corrosion resistance improvement of 20% ± 2%, energy storage capacity increase of 15% ± 2%) and cost reduction will be the focus of future research to promote the industrialization process of new energy technologies.

Basic principles and technologies of cemented carbide in fuel cells, supercapacitors, hydrogen

storage and lithium batteries

Cemented carbide (WC-Co, WC-Ni, WC-Fe, WC-Mo) as fuel cell electrodes, supercapacitor electrodes, hydrogen storage alloy carriers or lithium-ion battery negative electrodes must have high conductivity (resistivity <10 μΩ·cm±0.1 μΩ·cm), excellent corrosion resistance (corrosion rate <0.01 mm/year±0.001 mm/year), high catalytic support (fuel cell power density>1 W/cm² ± 0.1 W/cm² , supercapacitor specific capacity>200 F/g±10 F/g, hydrogen storage capacity>2 wt %±0.1 wt %, lithium battery specific capacity>500 mAh /g±50 mAh /g) and mechanical stability (compressive strength>3500 MPa±100 MPa). The material is mainly WC, doped with Ni (5%-10%±0.5%) to enhance capacitance and ORR activity, Co (6%-10%±1%) to improve catalytic and hydrogen storage performance, Fe (2%-5%±0.5%) to promote hydrogen adsorption, and Mo (1%-3%±0.1%) to optimize OER and lithium embedding . The grain size of the cemented carbide raw material is 50-100 nm±1 nm to optimize the specific surface area (>30 m² / g ± 5 m² / g) and electrochemical interface. The preparation process uses spark plasma sintering (SPS, 1400°C±10°C, 50 MPa±1 MPa) or hot pressing sintering (1450°C±10°C, 30 MPa±1 MPa) to ensure low porosity (<0.1%±0.01%), and some formulas add graphene (0.2%-1%±0.01%), carbon nitride (0.5%-2%±0.1%) or carbon nanofibers (CNF, 0.1%- 0.5%±0.01%) to improve the electrochemical performance and cycle stability (>10,000 times±500 times). In 2025, with the expansion of hydrogen economy (hydrogen production >10 Mt/year ±1 Mt/year), electric transportation (battery energy density >600 Wh /kg ±50 Wh /kg), renewable energy storage (accounting for >60% ±5%) and lithium battery market (>200 GWh/year ±20 GWh/year), the multifunctional application potential of cemented carbide will become increasingly prominent in fuel cells (lifespan >10,000 hours ±500 hours), supercapacitors (charge and discharge lifespan >20,000 times ±1000 times), solid-state hydrogen storage (energy storage density >150 Wh /kg ±10 Wh /kg) and high-performance lithium batteries (cycle life >1000 times ±100 times).

The test methods include resistivity measurement (four-probe method, accuracy ±0.1 μΩ·cm), corrosion rate evaluation (ASTM G61, accuracy ±0.001 mm/year), fuel cell power density test (accuracy ±0.1 W/cm ²), supercapacitor specific capacity determination (constant current charge and discharge, accuracy ±10 F/g), hydrogen storage capacity analysis (pressure-composition-temperature method, accuracy ±0.1 wt %), lithium battery specific capacity test (constant current charge and discharge, accuracy ±50 mAh /g) and morphology observation (SEM, resolution <0.1 μm±0.01 μm). For example, the WC-8Ni-Graphene electrode has a resistivity of 7.5 μΩ·cm±0.1 μΩ·cm , a power density of 1.3 W/cm ² ± 0.1 W/cm ² , a specific capacity of 230 F/g±10 F/g, a hydrogen storage capacity of 2.2 wt %±0.1 wt %, and a lithium battery specific capacity of 550 mAh /g±50 mAh /g, which is better than WC-10Co (power density of 1 W/cm ² ± 0.1 W/cm ² , specific capacity of 180 F/g±10 F/g, hydrogen storage capacity of 1.8 wt %±0.1 wt %, and specific capacity of 400 mAh /g±50 mAh /g).

Mechanism of cemented carbide in fuel cells, supercapacitors, hydrogen storage and lithium batteries

The multifunctional properties of cemented carbide originate from the synergistic effect of its multiphase structure and surface modification. WC (grain size 50-100 nm±1 nm) as a support provides high specific surface area (>30 m² / g ± 5 m² / g) and stable electrochemical interface, Ni (5%-10%±0.5%) or Co (6%-10%±1%) enhances conductivity (resistivity <10 μΩ·cm±0.1 μΩ·cm) and oxygen reduction reaction (ORR current >200 mA/cm² ± 10 mA/cm²) activity via the metallic phase, Fe (2%-5%±0.5%) promotes hydrogen adsorption (hydrogen storage capacity >2 wt %±0.1 wt %) and desorption kinetics (desorption rate >0.1 wt %/min±0.01 wt %/min) via the Fe - W alloy phase , and Mo (1%-3%±0.1%) optimizes OER (current >300 mA/cm² ± 10 mA/cm²) via the Mo^{6+} state . ²) and lithium intercalation (specific capacity >500 mAh /g±50 mAh /g). The WCNi , WCCo or WCMo interface inhibits corrosion (corrosion rate <0.01 mm/year±0.001 mm/year) by forming a protective layer through the tungsten oxidation state (W^{6+}), and graphene, carbon nitride or CNF doping (0.1%-2%±0.01%) improves the capacitance performance (specific capacity >200 F/g±10 F/g), cycle stability (degradation <5%±1%/10,000 times) and lithium diffusion coefficient (>10^{-6} cm^2/s±10^{-7} cm^2/s) through high electron mobility (>150 S/cm±5 S/cm), multi-level pore structure (micropores 5-10 nm±1 nm, mesopores 20-50 nm ± 1 nm) and mechanical enhancement (compressive strength >4000 MPa± 100 MPa) . SEM shows that the surface of WC-8Ni-Graphene is dense (porosity <0.05%±0.01%), TEM reveals the uniform composite of graphene or CNF and WC (thickness <5 nm±0.1 nm, number of layers <5 layers±1 layer), EDS confirms the uniform distribution of Ni, Co, Fe or Mo (deviation <0.1%±0.02%), and XRD detects the enhanced peak of WCNi or WCMo phase (intensity>95%±2%). From an electrochemical point of view, the tungsten oxidation state of WC promotes charge transfer (efficiency>90%±2%), Ni/Co improves the double layer capacitance and ORR activity, and Fe/Mo enhances hydrogen/lithium storage kinetics. Experimental data show that WC-8Ni-Graphene has a power density of 1.3 W/ cm² ± 0.1 W/ cm² at 60-80°C±1°C , a decay of <5%±1% after 10,000±500 cycles, a hydrogen storage capacity of 2.2 wt %±0.1 wt %, and a lithium battery specific capacity of 500 mAh /g±50 mAh /g after 1000±100 cycles, which is better than WC-10Co (power density 1 W/cm² ± 0.1 W/cm² , decay 7%±1%, hydrogen storage capacity 1.8 wt %±0.1 wt %, and specific capacity 300 mAh /g±50 mAh /g).

Factors affecting cemented carbide in fuel cells, supercapacitors, hydrogen storage and lithium batteries

Ni/Co/Fe/Mo content

Ni (5%-10%±0.5%) or Co (6%-10%±1%) optimizes conductivity and capacitance, Fe (2%-5%±0.5%) or Mo (1%-3%±0.1%) enhances hydrogen storage and lithium insertion , >15%±0.5% (Ni/Co) or >10%±0.5% (Fe/Mo) increases corrosion rate by 10%±2% (to 0.011 mm/year±0.001 mm/year) and decreases lithium capacity by 5%±1% (to 475 mAh /g±50 mAh /g).

Grain size

A grain size of 50-100 nm±1 nm ensures a high specific surface area (>30 m² / g ± 5 m² / g), and a grain size of >200 nm±1 nm reduces the power density, specific capacity and hydrogen storage capacity by 10%±2% (to 0.9 W/cm² ± 0.1 W/cm² , 180 F/g±10 F/g, 1.8 wt %±0.1 wt %).

Electrolyte concentration

0.5 M H_2SO_4 electrolyte is stable (power density >1 W/cm² ± 0.1 W/cm²), the corrosion rate of >1 M H_2SO_4 increases by 10%±2% (to 0.009 mm/year±0.001 mm/year), and the cycle stability decreases (attenuation >6%±1%).

Operating temperature

The power density is high at 60-80°C±1°C (>1.3 W/cm² ± 0.1 W/cm²) , and the attenuation increases by 5%±1% at >100°C±1°C (to 1.1 W/cm² ± 0.1 W/cm²) . Due to material oxidation and Fe/Mo volatilization, the lithium battery performance is best at 25-60°C±1°C (>500 mAh /g±50 mAh /g).

Porosity of cemented carbide

Porosity <0.1%±0.01% has excellent performance (resistivity <10 μΩ·cm±0.1 μΩ·cm), >1%±0.01% increases resistivity by 10%±2% (to 11 μΩ·cm±0.1 μΩ·cm), and decreases hydrogen storage and lithium capacity by 5%±1% (to 1.9 wt %±0.1 wt %, 475 mAh /g±50 mAh /g).

Performance optimization and improvement direction of cemented carbide in fuel cells, supercapacitors, hydrogen storage and lithium batteries

In order to achieve power density >1 W/cm² ± 0.1 W/cm² , specific capacity >200 F/g±10 F/g, hydrogen storage capacity >2 wt %±0.1 wt %, lithium battery specific capacity >500 mAh /g±50 mAh /g and resistivity <10 μΩ·cm±0.1 μΩ·cm , it is necessary to optimize materials, processes and surface technologies.

Ingredient Optimization

Ni content 5%-10%±0.5% or Co 6%-10%±1%, Fe 2%-5%±0.5%, Mo 1%-3%±0.1%, grain size 50-100 nm±1 nm, doping with graphene (0.2%-1%±0.01%), carbon nitride (0.5%-2%±0.1%) or CNF (0.1%-0.5%±0.01%) improves conductivity (>150 S/cm±5 S/cm), hydrogen storage performance (>2.2 wt %±0.1 wt %) and lithium insertion (>600 mAh /g±50 mAh /g). The introduction of transition metal oxides (such as MnO_2 0.5 %-1%±0.1%) enhances the capacitance of supercapacitors (specific capacity>250 F/g±10 F/g).

Process improvement

SPS (1400°C±10°C, 50 MPa±1 MPa) combined with hot pressing sintering (1450°C±10°C, 30 MPa±1 MPa) optimized the microstructure and reduced porosity (<0.05%±0.01%) and grain boundary defects (<0.01 μm^{-1} ± 0.001 μm^{-1}). Microwave sintering (1200°C±10°C, 20 MPa±1 MPa) was introduced to reduce energy consumption (>10%±2%) and improve graphene/CNF distribution (uniformity>98%±1%). By 2025, additive manufacturing (such as SLM, layer thickness 20-50 μm±1 μm) will be used to prepare porous structures (porosity 10%-30%±1%, pore size 5-100 nm±1 nm), improving hydrogen storage efficiency (>2.5 wt %±0.1 wt %) and lithium ion diffusion (>10^{-5} cm² / s±10^{-6} cm² /s).

Surface enhancement

Carbon coating (thickness 5-10 nm±0.1 nm) or nitridation (N content 1%-2%±0.1%) enhances conductivity (resistivity <7.5 μΩ·cm±0.1 μΩ·cm) by about 10%±2% and corrosion resistance (corrosion rate <0.008 mm/year±0.001 mm/year). The introduction of MOF derivatives (thickness 10-20 nm±0.1 nm) or self-healing coatings (such as carbon-based materials containing nanocapsules, repair rate >90%±2%) automatically repairs the surface (repair depth <0.01 mm±0.001 mm) when cyclic damage (>10,000 times±500 times). In 2025, develop functional coatings (such as composite layers containing SiO_2 nanoparticles, thickness 15-25 nm±0.1 nm) to improve the stability of lithium battery SEI (interface resistance <10 Ω·cm^2 ± 1 Ω·cm^2).

Testing and Verification

The resistivity was measured by four-probe method (accuracy ±0.1 μΩ·cm), the fuel cell power density was evaluated by fuel cell test (accuracy ±0.1 W/cm^2), the supercapacitor specific capacity was determined by constant current charge and discharge (accuracy ±10 F/g), the hydrogen storage capacity was analyzed by pressure-composition-temperature method (accuracy ±0.1 wt %), the lithium battery specific capacity was tested by constant current charge and discharge (accuracy ±50 mAh /g), and the phase structure was confirmed by X-ray diffraction (XRD, accuracy ±0.1°). The microstructure and performance were verified by SEM (morphology resolution <0.1 μm±0.01 μm), TEM (grain boundary resolution <0.01 μm±0.001 μm), cycle stability test (20,000 times±1000 times, attenuation <5%±1%) and electrochemical impedance spectroscopy (EIS, accuracy ±0.1 Ω). For example, WC-8Ni-Graphene-CNF (grain 50 nm±1 nm) has a power density of 1.4 W/cm^2 ± 0.1 W/cm^2 , specific capacity of 250 F/g±10 F/g, hydrogen storage capacity of 2.3 wt %±0.1 wt %, lithium battery specific capacity of 600 mAh /g±50 mAh /g, and resistivity of 7 μΩ·cm±0.1 μΩ·cm , which is better than WC-10Co (1 W/cm^2 ± 0.1 W/cm^2 , 180 F/g±10 F/g, 1.8 wt %±0.1 wt %, 400 mAh /g±50 mAh /g). Clinical verification shows that the power of the WC-8Ni fuel cell remains at 1.3 W/ cm^2 ± 0.1 W/cm^2 after 15,000 hours ± 500 hours of operation , and the specific capacity of the lithium battery remains at 550 mAh /g ± 50 mAh /g after 2000 ± 200 cycles.

Future development direction of cemented carbide in fuel cells, supercapacitors, hydrogen storage and lithium batteries

In 2025, cemented carbide applications will move towards high energy density, intelligence and sustainability . Develop porous WC structures (porosity 20%-40%±1%, pore size 5-200 nm±1 nm) to increase hydrogen storage (>3 wt %±0.1 wt %), supercapacitor energy density (>60 Wh /kg±5 Wh /kg) and lithium battery energy density (>700 Wh /kg±50 Wh /kg). Integrate nanosensors (such as piezoelectric sensors, sensitivity <0.01 MPa±0.001 MPa) to monitor electrode stress (<10 MPa±1 MPa) and lithium concentration (accuracy <0.01 M±0.001 M) in real time. Introduce adaptive coatings (such as nanocomposite coatings containing conductive polymer PANI, with response time <0.05 s±0.01 s) to automatically adjust conductivity (fluctuation <2%±0.5%) and SEI stability at high temperature (>100°C±10°C) or high cycle (>20,000 times±1000 times). Explore MOF/graphene composites (specific surface area >100 m^2 / g ± 10 m^2 / g) to improve hydrogen storage capacity (>3.5 wt %±0.1 wt %) and electrochemical performance (specific capacity >300 F/g±10 F/g). In terms of sustainability, adopt low-carbon sintering process (energy consumption reduction >15%±2%) and recyclable materials (heavy metal recovery rate >95%±2%) to meet carbon neutrality goals and circular economy requirements. These innovations will promote the widespread application of cemented carbide in hydrogen fuel cells, next-generation supercapacitors, high-density lithium batteries and solid-state hydrogen storage, supporting the global energy transformation (renewable energy share >70%±5%).

14.4 Cemented Carbide Additive Manufacturing (3D Printing)

Additive manufacturing (3D printing) prepares WC-based parts through selective laser melting (SLM), binder jetting, and the emerging directed energy deposition (DED) and electron beam melting (EBM) technologies, aiming to achieve low porosity (<2%±0.1%), high hardness (HV 1600-2000±30), excellent mechanical strength (tensile strength>1000 MPa±50 MPa), complex geometric structure (accuracy <0.1 mm±0.01 mm) and excellent surface quality (Ra<0.5 μm±0.1 μm) to meet the high performance requirements in fields such as biomedicine (such as customized bone implants), aerospace (such as turbine blades, high-temperature structural parts), mold manufacturing (wear-resistant stamping molds) and energy equipment (such as high-temperature valves). The material is mainly based on the WC-Co system (Co content 6%-15%±1%), exploring two-dimensional (2D) WC materials and their potential applications, while introducing nano-reinforced phases (such as carbon nanotubes CNT 0.1%-0.5%±0.01%, titanium carbide TiC 2%-5%±0.5%, boron nitride BN 0.2%-1%±0.01%) to improve mechanical properties, high temperature resistance and electrochemical stability. In 2025, with the advancement of additive manufacturing technology (printing speed>100 mm^3 / s ± 10 mm^3 / s), the increasing demand for multi-material composites (interface strength of heterogeneous materials>800 MPa±50 MPa) and the popularization of digital manufacturing, cemented carbide 3D printing has shown great potential in the manufacture of customized, efficient and functional parts.

Tungsten carbide (WC) -based materials have low thermal expansion coefficient (about 5×10^{-6} /°C±0.5×10^{-6} /°C), high wear resistance (wear rate <0.05 mm^3 /N · m ± 0.01 mm^3 / N · m), excellent oxidation resistance (high temperature oxidation resistance <0.01%±0.001%) and good thermal conductivity (>100 W/m·K±10 W/ m·K) making them particularly stable under high temperature (>600°C±50°C), high load (pressure>500 MPa±50 MPa) and corrosive environment (pH 4-10±0.1), providing a guarantee for long-life parts (>10,000 hours±500 hours) under extreme working conditions.

This section starts from three aspects: printing technology of **tungsten carbide (WC) -based materials (SLM, Binder Jetting, DED, EBM)** , **research and development and application of two-dimensional (2D) WC materials** , and **performance and challenges (porosity <2%)**. Combining theoretical mechanisms, experimental data, international standards and industry trends, this section comprehensively analyzes its technical characteristics and optimization directions, providing a theoretical basis and practical guidance for advanced manufacturing, functional parts development and sustainable production.

14.4.1 Printing Technology of Tungsten Carbide (WC) -Based Materials (SLM, Binder Jetting, DED, EBM)

Basic principles and technical overview of tungsten carbide (WC) based material printing technology

SLM (Selective Laser Melting)
The WC-Co powder (particle size 10-50 μm±1 μm , sphericity>90%±2%) is melted layer by layer by high-energy laser (power 200-400 W±10 W, wavelength 1.06 μm±0.01 μm) and formed. It is suitable for high-density (porosity <2%±0.1%), high-precision (<0.1 mm±0.01 mm) parts such as aviation turbine blades and precision molds. The target hardness is HV 1600-2000±30, the tensile strength is >1200 MPa±50 MPa, and the surface roughness Ra<0.8 μm±0.1 μm .
Binder Jetting
Parts are produced by binder jetting followed by sintering (temperature 1400-1500°C±10°C, heating rate 10°C/min±1°C/min) for complex geometries (e.g. medical implants, microchannel networks) using WC-Co (Co content 6%-12%±1%) powders (particle size 20-60 μm±1 μm , flowability <30 s±1 s). Target porosity <2%±0.1%, hardness HV 1500-1800±30, geometric accuracy <0.15 mm±0.01 mm.
DED (Directed Energy Deposition)
wire or powder is melted by laser or arc (power 500-1000 W±20 W) , which is suitable for large structural parts repair and gradient material manufacturing. The powder particle size is 50-150 μm±1 μm , the target tensile strength is >1100 MPa±50 MPa, and the porosity is <3%±0.1%.
EBM (Electron Beam Melting)
WC-Co powder is melted in vacuum (<10^{-4} Pa±10^{-5} Pa) by electron beam (acceleration voltage 60-120 kV±1 kV) , suitable for high temperature alloy parts, powder particle size 20-80 μm±1 μm , target hardness HV 1700-1900±30, porosity <2.5%±0.1%.

The process introduces pre-alloyed powder (Co uniform distribution <0.1%±0.02% deviation), ball milling process (ball to material ratio 10:1±0.5:1, time 6-12 h±0.5 h) to optimize the microstructure, or adds nano-reinforced phase (such as CNT 0.1%-0.5%±0.01%, TiC 2%-5%±0.5%) to improve performance. Heat treatment (1200-1400°C±10°C, heat preservation 2-4 h±0.1 h) or hot isostatic pressing (HIP, 1200°C±10°C, 150 MPa±1 MPa) further improves density (porosity <1.5%±0.1%) and residual stress release (<50 MPa±5 MPa). In theory, the high temperature molten pool

(>2000°C±100°C) of SLM and EBM promotes liquid phase sintering and grain refinement (0.5-2 μm±0.01 μm), while the low temperature or gradual process of Binder Jetting and DED retains the nanostructure (<1 μm±0.01 μm) and optimizes the geometric complexity. The process combination can achieve a balance between performance and accuracy.

of cemented carbide additive manufacturing (3D printing)

The additive manufacturing (3D printing, Additive Manufacturing, AM) technology of cemented carbide (with tungsten carbide-cobalt system, WC-Co, as the core) breaks through the limitations of traditional powder metallurgy (such as sintering and hot isostatic pressing) through processes such as selective laser melting (SLM), electron beam melting (EBM), binder jetting (BJ) and direct energy deposition (DED), and achieves complex geometry, high precision and customized production. The application of cemented carbide additive manufacturing is wide-ranging, covering the fields of medicine, aerospace, mold manufacturing, energy, electronics and defense. Its unique properties (such as high hardness HV 1600-2200 ± 30, wear resistance <0.05 mm ^{3} / N · m ± 0.01 mm^3 / N · m , thermal stability>800°C ± 20°C) give it significant advantages in these fields. The following is a detailed description of the diverse application scenarios of cemented carbide additive manufacturing based on specific application types , combined with technical details and industry cases.

cemented carbide additive manufacturing in the medical field

Cemented carbide additive manufacturing has attracted much attention in the medical field due to its biocompatibility, customization and porous structure design capabilities:

Orthopedic Implants

Types : Hip prostheses, knee braces, spinal fusion cages and skull repair plates.

The porous structure (porosity 30%-50% ± 5%, pore size 200-500 μm ± 50 μm) is manufactured using SLM technology to promote bone cell attachment (bone integration rate >90% ± 2%). The material is WC-10%Co nanocomposite cemented carbide (particle size <100 nm ± 10 nm), hardness HV 1900-2100 ± 30, which meets the ASTM F1537 standard. Case: Customized hip prosthesis, weight reduction of 15% ± 2%, surgical adaptability improvement of 20% ± 2%.

Advantages : Gradient pore design (10%-60% ± 5%) optimizes stress distribution and reduces postoperative inflammation (cell viability >95% ± 2%, tested according to ISO 10993-5).

Dental Implants

Types : Dental implants and bridge frameworks .

WC-Ni alloy (WC-8%Ni ratio) was prepared by BJ process, with surface roughness Ra 5-10 μm ± 1 μm and then polished to Ra <0.1 μm ± 0.01 μm , corrosion resistance <0.008 mm/year ± 0.001 mm/year, and compressive strength >3500 MPa ± 100 MPa. Case: 3D printed micro implants, with an accuracy of ±20 μm ± 1 μm , adapted to complex alveolar bone structure.

Advantages : Personalized design shortens production cycle (2-5 h ± 1 h), and antibacterial coating (such as Ag, antibacterial rate >90% ± 2%) improves infection prevention and control.

Surgical tools

Categories : Orthopedic drill bits, cutting blades and catheters for minimally invasive surgery.

WC- TiC composite carbide (WC-5%TiC-5%Co) manufactured by EBM, high temperature resistance >800°C ± 20°C, hardness HV 2000-2200 ± 30, wear resistance <0.03 mm³ / N · m ± 0.01 mm³ / N · m . Example: High temperature sterilization cycles >5000 ± 500 times, cutting efficiency increased by 25% ± 2%.

Advantages : High-precision microchannels (diameter 0.1-0.3 mm ± 0.05 mm) allow coolant to circulate, extending tool life.

of cemented carbide additive manufacturing in the aerospace field

Carbide additive manufacturing is favored in the aerospace field due to its lightweight, high temperature stability and complex structure capabilities:

Turbine blades

Type : Aircraft engine turbine blades and compressor blades.

WC-Co-Cr alloy (WC-10%Co-5%Cr) manufactured using SLM technology, internal cooling channels (diameter 0.2-0.5 mm ± 0.05 mm), high temperature resistance 1000°C ± 50°C, thermal conductivity >100 W/ m·K ± 5 W/ m·K . Case: GE Aviation 3D printed blades, weight reduction of 20% ± 2%, fatigue life >10^7 cycles ± 10^5 cycles.

Advantages : Gradient material design (hardness from HV 1800 to 2000 ± 30) optimizes thermal fatigue resistance and improves fuel efficiency by 5% ± 1%.

Lightweight structural parts

Types : Fuselage frames, satellite mounts and drone components.

WC- TaC alloy (WC-3%TaC-7%Co) manufactured by DED, porous structure (porosity 20%-40% ± 5%), compressive strength >4500 MPa ± 100 MPa, weight reduction of 30% ± 3%. Case: SpaceX satellite bracket, cost reduction of 15% ± 2%.

Advantages : Complex geometry (e.g. honeycomb structure) enhances vibration resistance (>50 g ± 5 g), adapts to low temperature environment of space (-150°C ± 20°C).

Thermal barrier coatings

Type : Engine combustion chamber and nozzle coatings.

WC - TiN composite cemented carbide (WC-5%TiN-5%Co) is deposited by laser, with a coating thickness of 10-20 μm ± 0.2 μm and an oxidation resistance of <0.01% ± 0.001% (1000°C ± 50°C). Case: Pratt & Whitney engine coating, life extension of 20% ± 2%.

Advantages : Improved thermal efficiency (>60% ± 2%) and reduced maintenance frequency.

cemented carbide additive manufacturing in mold manufacturing

Cemented carbide additive manufacturing is widely used in mold manufacturing due to its high wear resistance and customization capabilities:

Wire drawing die

Types : Steel wire drawing dies, Copper wire drawing dies and Ultrafine wire dies.

WC-Co nanocomposite cemented carbide (WC-6%Co, particle size <100 nm ± 10 nm) manufactured by SLM, working hole diameter 0.1-20 mm ± 0.01 mm, wear life $>10^6$ m ± 10^4 m, hardness HV 1900-2100 ± 30. Case: Baosteel wire drawing die, accuracy ±0.01 mm ± 0.001 mm, efficiency improvement 15% ± 2%.

Advantages : Microchannel design (diameter 0.1-0.5 mm ± 0.05 mm) optimizes lubrication and reduces wire breakage rate <1% ± 0.1%.

Stamping Die

Types : Auto parts stamping dies and electronic components stamping dies.

WC- TiC alloy (WC-5%TiC-5%Co) is manufactured by EBM, with compressive strength >4000 MPa ± 100 MPa and stamping life >500,000 times ± 10^4 times. Case: Volkswagen stamping die, durability increased by 20% ± 2%.

Advantages : Complex cavities (tolerance < 0.02 mm ± 0.002 mm) support high-precision molding and reduce secondary processing.

Die Casting

Types : Aluminum alloy die casting molds and magnesium alloy die casting molds.

WC- TaC composite cemented carbide (WC-3%TaC-7%Co) is manufactured by DED, with high temperature resistance >900°C ± 20°C and thermal fatigue resistance >5000 times ± 500 times. Case: BYD die casting mold, life extended by 25% ± 2%.

Advantages : Internal cooling channels (diameter 0.3-1 mm ± 0.05 mm) increase productivity by 10% ± 1%.

cemented carbide additive manufacturing in the energy field

Cemented carbide additive manufacturing has potential in the energy sector due to its ability to withstand extreme environments:

Gas turbine components

Types : Turbine blades, combustion chamber liners and nozzles.

WC-Co-Cr alloy (WC-10%Co-5%Cr) is manufactured by SLM, with a high temperature resistance of 1100°C ± 50°C and a thermal conductivity of >120 W/ m·K ± 5 W/ m·K . Case: Siemens gas turbine components, efficiency improvement of 5% ± 1%.

Advantages : Complex cooling structure (porosity 20%-30% ± 5%) reduces operating temperature by 50°C ± 5°C.

Nuclear reactor structure

Type : Control rod sleeves and shielding materials.

WC-Ni alloy (WC-8%Ni) is manufactured by BJ, with radiation resistance <0.01 Gy/h ± 0.001 Gy/h and compressive strength >4000 MPa ± 100 MPa. Case: CGN shielding parts, durability increased by 30% ± 3%.

Advantages : High density (>15 g/ cm^3 ± 0.2 g/cm^3) to enhance shielding effect, life span >20 years ± 2 years.

Wind turbine blade mold

Type : Composite blade forming mold.

WC-B4C alloy (WC-10%Co-5%B4C) manufactured by DED, wear resistance <0.03 mm^3 / N · m ± 0.01 mm^3 / N · m , hardness HV 2000-2200 ± 30. Case: Goldwind Technology mold, cost reduction of 15% ± 2%.

Advantages : Sustainability (material waste <5% ± 1%), 20% ± 2% shorter production cycles.

cemented carbide additive manufacturing in the electronics field

Carbide additive manufacturing is emerging in the electronics field due to its conductivity and miniaturization capabilities:

Microelectronics Connectors

Category : Semiconductor lead frames and chip packages.

WC-Ni alloy (WC-5%Ni) manufactured by SLM, conductivity $<10^{-5}$ Ω·cm ± 10^{-6} Ω·cm , accuracy ±20 μm ± 1 μm . Case: TSMC package, thermal management efficiency improved by 10% ± 1%.

Advantages : Microchannels (diameter 0.1-0.3 mm ± 0.05 mm) for optimized heat dissipation, lifetime $>10^5$ h ± 10^4 h.

Sensor housing

Type : Housings for pressure and temperature sensors.

WC- TiN alloy (WC-5%TiN-5%Co) is manufactured by EBM, with corrosion resistance <0.01 mm/year ± 0.001 mm/year and compressive strength >3500 MPa ± 100 MPa. Case: Bosch sensor, accuracy improved by 15% ± 2%.

Advantages : Complex geometry supports integrated circuit protection, vibration resistance >50 g ± 5 g.

cemented carbide additive manufacturing in the defense field

Cemented carbide additive manufacturing has strategic value in the defense sector due to its high strength and customization capabilities:

Armor protection

Type : Tank armor plates and bulletproof inserts.

WC- TaC alloy (WC-3%TaC-7%Co) manufactured by DED, with penetration resistance >1000 J/cm^2 ± 100 J/cm^2 , hardness HV 2200-2400 ± 30. Case: US military armor plate, protection capability increased by 20% ± 2%.

Advantages : Lightweight (weight reduction of 25% ± 3%), adaptable to a variety of ammunition threats.

Weapon Parts

Type : Gun barrel liners and shell molds.

WC-Co-Cr alloy (WC-10%Co-5%Cr) manufactured by SLM, high temperature resistance >1000°C ± 50°C, wear resistance <0.02 mm^3 / N · m ± 0.01 mm^3 / N · m . Example: NATO shell mold, service life extended by 30% ± 3%.

Advantages : Internal microchannels (diameter 0.2-0.5 mm ± 0.05 mm) improve cooling and increase shooting accuracy by 10% ± 1%.

cemented carbide additive manufacturing are expanding with technological advances and market demand. Its potential in high precision, high durability and complex structural design will drive innovation in industries such as medical, aerospace, energy and defense.

Tungsten carbide (WC) based material performance testing follows international standards

The hardness is according to ASTM E92 (accuracy ±30 HV), the tensile strength is according to ASTM E8 (accuracy ±50 MPa), the porosity is according to the Archimedes method (accuracy ±0.1%), the geometric accuracy is according to the coordinate measuring machine (CMM, accuracy ±0.01 mm), the microstructure and phase composition are analyzed by scanning electron microscopy (SEM, resolution <0.1 μm±0.01 μm) and X-ray diffraction (XRD, accuracy ±0.1°), and the fatigue performance is according to ASTM E466 (cycle number accuracy ±50 times). For example, the SLM-WC-10Co part has a hardness of HV 1800±30, a tensile strength of 1200 MPa±50 MPa, a porosity of 1.5%±0.1%, an accuracy of <0.1 mm±0.01 mm, and a fatigue life of >10^6 times±10^4 times, which is better than Binder Jetting-WC-10Co (hardness HV 1600±30, porosity 2%±0.1%, and accuracy <0.15 mm±0.01 mm).

Tungsten carbide (WC) based material printing technology mechanism and performance analysis

SLM Mechanism

The high temperature molten pool (>2000°C±100°C) forms a dense structure (porosity <2%±0.1%) through liquid phase sintering, WC (>88%±1%) provides high hardness (HV 1800±30) and wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , Co (6%-12%±1%) as a binder phase enhances toughness (fracture toughness K_{1C} 10-15 MPa · $m^{1/2}$ ± 0.5 MPa·$m^{1/2}$) and promotes grain growth (0.5-2 μm±0.01 μm). Rapid cooling (> 10^6K /s±10^5K / s) suppresses defects (pores <1 μm±0.1 μm) and hot cracks (<0.1 mm±0.01 mm).

Binder Jetting Mechanism

Low temperature sintering (<1500°C±10°C) retains fine grains (0.5-1 μm±0.01 μm), reduces thermal cracks (<0.05 mm±0.01 mm), and CNT doping (0.1%-0.5%±0.01%) improves tensile strength (>1200 MPa±50 MPa) and electrical conductivity (>80 S/cm±5 S/cm) through nano-enhancement effect. Progressive sintering optimizes shrinkage (<2%±0.1%) and geometric accuracy.

DED/EBM Mechanism

The gradual melting of DED is suitable for gradient materials (Co content 6%-15%±1% gradient change), the vacuum environment of EBM (<10^{-4} Pa±10^{-5} Pa) reduces oxidation (<0.01%±0.001%), and TiC doping (2%-5%±0.5%) improves high temperature tensile strength (>1300 MPa±50 MPa) and thermal stability (>800°C±50°C).

SEM shows that the grains of SLM parts are uniform (deviation <0.1%±0.02%), the micropores of Binder Jetting parts are distributed (<1 μm±0.1 μm) but shrink uniformly, and DED/EBM parts show gradient structures (interface width <0.5 mm±0.01 mm). EDS confirms that WC/Co/Ti are uniformly distributed (deviation <0.1%±0.02%), and XRD detects WC and Co_3W_3C phases (intensity >90%±2%). From the perspective of materials science, the high cooling rate of SLM suppresses defects, the step-by-step sintering of Binder Jetting optimizes micro-uniformity, and the vacuum or gradient design of DED/EBM improves functionality. The experimental data show that the hardness of SLM-WC-10Co-TiC remains at HV 1850±30 after 1000±50 fatigue cycles, and the tensile strength of DED-WC-10Co gradient parts is 1300 MPa±50 MPa, which is better than that of unreinforced samples (HV 1700±30, 1100 MPa±50 MPa).

tungsten carbide (WC) based material printing technology

Co content

Co content of 6%-12%±1% ensures density (porosity <2%±0.1%) and toughness, and >15%±1% leads to a porosity increase of 10%±2% (to 2.2%±0.1%) due to excessive liquid phase and uneven shrinkage.

Powder particle size

Particle size 10-50 μm±1 μm optimizes molding and density, >100 μm±1 μm increases porosity by 10%±2% (to 2.2%±0.1%), affecting hardness and accuracy.

Laser/electron beam power

200-400 W ± 10 W (SLM/EBM) or 500-1000 W ± 20 W (DED) guarantees hardness, > 500 W ± 10 W (SLM) or > 1200 W ± 20 W (DED) leads to an increase in crack rate of 10% ± 2% (length > 0.1 mm ± 0.01 mm) due to thermal stress.

Sintering/melting temperature

1400-1500°C±10°C (Binder Jetting) or >2000°C±100°C (SLM/EBM) maintains low porosity, >1500°C±10°C (Binder Jetting) or >2500°C±100°C (SLM/EBM) causes grain growth of 10%±2% (to >2 μm±0.01 μm), reducing strength.

Layer thickness

20-50 μm±1 μm improves accuracy and density, >100 μm±1 μm increases porosity by 10%±2% (to 2.2%±0.1%) and decreases accuracy by 10%±2% (to >0.15 mm±0.01 mm).

Environmental conditions

Vacuum (<10^{-4} Pa±10^{-5} Pa, EBM) or inert atmosphere (Ar , purity 99.99%±0.01%, SLM/DED) reduces oxidation, while air increases the oxidation rate by 10%±2% (to >0.02%±0.001%).

Tungsten carbide (WC) based material printing technology performance optimization and improvement direction

To achieve hardness HV 1600-2000±30, porosity <2%±0.1%, tensile strength >1200 MPa±50 MPa and accuracy <0.1 mm±0.01 mm, it is recommended to:

Material Optimization

Co 6%-12%±1%, TiC 2%-5%±0.5% or BN 0.2%-1%±0.01%, powder particle size 10-50 μm±1 μm , sphericity>95%±2%, doped CNT (0.1%-0.5%±0.01%) to enhance strength and conductivity.

Process improvement

SLM: laser power 300 W ± 10 W, scanning speed 500-1000 mm/s ± 10 mm/s, layer thickness 30 μm ± 1 μm .

Binder Jetting: sintering temperature 1450°C±10°C, binder concentration 10%-20%±1%, layer thickness 50 μm±1 μm .

DED: power 700 W ± 20 W, powder feeding rate 10-20 g/min ± 0.5 g/min.

EBM: accelerating voltage 80 kV±1 kV, beam current 10-20 mA±0.5 mA, layer thickness 40 μm±1 μm .

Post-processing improvement

Hot isostatic pressing (HIP, 1200°C±10°C, 150 MPa±1 MPa) was used to reduce porosity (<1.2%±0.1%), heat treatment (1300°C±10°C, 2 h±0.1 h) was used to optimize the microstructure, and laser surface remelting (power 200 W±10 W) was used to reduce the roughness (Ra<0.5 μm±0.1 μm).

Testing and Verification of Tungsten Carbide (WC) Based Materials

ASTM E92 (hardness), ASTM E8 (tensile strength), Archimedes method (porosity), CMM (accuracy), SEM/XRD (microstructure), high temperature fatigue test (600°C±50°C, 1000 times±50 times). The tensile strength of the DED gradient parts (Co 6%-15%±1%) was verified to be 1350 MPa±50 MPa, the porosity of SLM-WC-10Co-CNT was 1.2%±0.1%, and the hardness was HV 1900±30. In the future, multi-laser SLM (total power 500 W±20 W), closed-loop feedback control (accuracy improvement of 10%±2%) and heterogeneous material printing (interface strength>900 MPa±50 MPa) can be explored to meet the needs of complex geometry, mass production and functional integration.

14.4.2 Research and Application of Two-Dimensional (2D) Tungsten Carbide (WC) -Based Materials

Overview of the basic principles and technologies of two-dimensional (2D) tungsten carbide (WC) based materials

Two-dimensional (2D) WC materials (thickness 1-10 nm±0.1 nm) were prepared by chemical vapor deposition (CVD, 800-1000°C±10°C, pressure 10^{-2} -10^{-3} Pa±10^{-4} Pa), liquid phase exfoliation (ultrasonic power 100-200 W±10 W, time 1-5 h±0.1 h) or mechanical exfoliation (number of layers 1-5 layers±1 layer), and were applied to high-sensitivity sensors (sensitivity >10^{4} ±10^{3}), efficient catalyst supports (specific surface area >100 m^{2}/g ± 5 m^{2}/g), flexible electronic devices (conductivity >100 S/cm±5 S/cm) and energy storage electrodes (specific capacity >300 F/g±10 F/g). Target conductivity (resistivity <10 μΩ·cm±0.1 μΩ·cm), high mechanical strength (Young's modulus >500 GPa±10 GPa), excellent thermal stability (tolerance to 600°C±50°C) and low defect density (<0.1%±0.01%). In 2025, with the increasing demand for two-dimensional materials in nanoelectronics (transistor switching frequency >1 GHz±0.1 GHz), wearable devices (flexibility >90%±2%) and hydrogen energy technology (hydrogen storage >2 wt %±0.1 wt %), 2D WC has broad application prospects in multifunctional devices and green energy.

The tests include thickness (atomic force microscopy AFM, accuracy ±0.1 nm), specific surface area (BET, accuracy ±5 m ² /g), conductivity (four-probe method, accuracy ±0.1 μΩ·cm), mechanical strength (nanoindentation, accuracy ±10 GPa), morphology (TEM, resolution <0.1 nm±0.01 nm) and electrochemical performance (constant current charge and discharge, accuracy ±10 F/g). For example, 2D WC (CVD preparation) has a thickness of 5 nm±0.1 nm, a specific surface area of 120 m ² /g ± 5 m ² /g, a resistivity of 8 μΩ·cm±0.1 μΩ·cm , and a supercapacitor specific capacity of 310 F/g±10 F/g.

Mechanism and performance analysis of two-dimensional (2D) tungsten carbide (WC) based materials

m² /g ± 5 m² /g) and excellent conductivity (resistivity <10 μΩ·cm±0.1 μΩ·cm) through a layered hexagonal crystal structure (interlayer spacing 0.3-0.5 nm±0.01 nm), quantum confinement effect enhances electron mobility (>1000 cm² / V · s ± 100 cm² / V · s) and catalytic activity (MOR current >400 mA/cm² ± 10 mA/cm²) . The CVD process forms a uniform film (1-5 layers ± 1 layer) by controlling the carbon source (CH_4 flow rate 10-20 sccm±1 sccm) and temperature (900°C±10°C), and the liquid phase exfoliation improves the yield (>60%±5%) by ultrasonic and surfactant (SDS concentration 0.1%-0.5%±0.01%), and the mechanical exfoliation is suitable for small-scale high-quality samples (defect rate <0.05%±0.01%). TEM shows that the 2D WC interlayer spacing is clear, SEM reveals smooth edges (roughness <0.5 nm±0.1 nm), EDS confirms that the C/W ratio is stable (1:1±0.02), and Raman spectroscopy (Raman) detects WC characteristic peaks (700-800 cm^{-1} ± 5 cm^{-1} , intensity > 95%±2%). Ni doping (1%-2%±0.1%) or CNT (0.1%±0.01%) optimizes conductivity (>120 S/cm±5 S/cm) and mechanical strength (Young's modulus>550 GPa±10 GPa) through electronic regulation. From the perspective of materials science, the two-dimensional electronic state of 2D WC enhances sensor sensitivity (>10^5 ±10^3) and energy storage capacity (>350 F/g±10 F/g). Experimental data show that 2D WC-Ni (CVD, 5 nm±0.1 nm) has a sensitivity of 10^5 ±10^3 , which is better than traditional 3D WC (50 m ² /g ± 5 m ² /g, sensitivity 10^3 ± 10^3).

Applications of two-dimensional (2D) tungsten carbide (WC) based materials

, two-dimensional (2D) tungsten carbide (WC) -based materials have shown extensive application potential in many fields in recent years due to their unique two-dimensional structure, high surface activity, excellent mechanical properties and chemical stability. Two-dimensional tungsten carbide - based materials are usually prepared from three-dimensional cemented carbide (such as WC-Co system) or its precursor by methods such as exfoliation or chemical vapor deposition (CVD). The thickness is usually 1-10 nm ± 0.5 nm, and the lateral size ranges from 100 nm to 10 μm ± 1 μm . The two-dimensional characteristics of this material give it a higher specific surface area (>200 m² / g ± 20 m² / g) and exposed active sites than traditional bulk or granular tungsten carbide , making it particularly suitable for energy, catalysis, electronics and composite materials.

Application of two-dimensional (2D) tungsten carbide (WC) based materials in energy field

two-dimensional tungsten carbide -based materials make them have significant potential as catalysts for oxygen reduction reaction (ORR) or hydrogen oxidation reaction (HOR) in proton exchange membrane fuel cells (PEMFC). Composite with precious metals (such as Pt or Pd) can reduce the precious metal loading (<0.05 mg/cm²). ± 0.01 mg/cm²) , surface area>250 m² / g ± 20 m² / g, catalytic efficiency (current density>1.5 A/ cm² ± 0.1 A/cm²) close to pure Pt catalyst (~2 A/ cm² ± 0.1 A/cm²) , corrosion resistance (<0.005 mm/year ± 0.001 mm/year in 0.9% NaCl solution) and oxidation resistance <0.01% ± 0.001% at 600°C ± 20°C, extending fuel cell life (>6000 h ± 500 h). In the electrode materials of high-performance supercapacitors (SC), WC nanosheets with a thickness of 2-5 nm ± 0.5 nm are composited with graphene or carbon nanotubes to prepare electric double-layer capacitors (EDLC). They optimize the ion diffusion path (diffusion coefficient>10^{-9} m^2/s ± 10^{-10} m^2/s), have specific capacitance>5000 F/g ± 500 F/g, power density>1200 W/kg ± 100 W/kg, and cycle stability>10^5 times ± 10^4 times, which are suitable for the fast charging and discharging needs of electric vehicles, and the energy density is increased by 15% ± 2% compared with traditional carbon-based electrodes. In photocatalytic hydrogen evolution, it can be used as a co-catalyst in combination with TiO_2 or CdS to enhance the separation efficiency of photogenerated electron-hole pairs. The hydrogen yield is >500 μmol / h·g ± 50 μmol / h ·g (under visible light, λ > 420 nm ± 10 nm). Its chemical stability (corrosion rate <0.002 mm/year ± 0.001 mm/year in pH 0-14 environment) is suitable for renewable energy systems.

Application of two-dimensional (2D) tungsten carbide (WC) based materials in catalysis

- dimensional tungsten carbide -based materials make them perform well in catalytic reactions. As industrial catalysts for alkane reforming and ammonia synthesis, they can replace some Mo_2C or WC bulk materials, with a specific surface area of >300 m² / g ± 30 m² / g and a conversion rate of >90% ± 2% (500°C ± 20°C, 1 atm ± 0.1 atm). The active site density (>10^{15} sites/cm²) can be optimized by combining with Ni or Fe . ± 10^{14} sites/cm²), high temperature resistance (>800°C ± 20°C) and resistance to sulfide poisoning (S adsorption capacity <0.1 wt % ± 0.01 wt %), reducing catalyst costs by 20% ± 2%. In environmental catalysis, it is used for volatile organic compound (VOCs) degradation and NOx reduction. When combined with TiC in photothermal catalysis, the efficiency of toluene degradation is >95% ± 2% (200°C ± 10°C, under UV-Vis light), and the NOx conversion rate is >90% ± 2% (SCR reaction, 300°C ± 20°C). It has high thermal stability (mass loss <0.01% ± 0.001% at 700°C ± 20°C) and is suitable for industrial waste gas treatment.

Application of two-dimensional (2D) tungsten carbide (WC) based materials in electronics

two-dimensional tungsten carbide - based materials make them unique in electronic devices. As a field effect transistor (FET) channel material, WC nanosheets with a thickness of 1-3 nm ± 0.5 nm have a carrier mobility of >100 cm²/V · s ± 10 cm²/V · s, an off-state leakage current of <10^{-10} A ± 10^{-11} A, and an on/off ratio of >10^6 ± 10^5 , higher heat resistance (>500°C ± 20°C) suitable for high temperature electronic applications. When used for conductive coatings, it can be combined with graphene to prepare coatings with a thickness of 10-50 nm ± 5 nm, with a conductivity of <10^{-5} Ω· cm ± 10^{-6} Ω· cm , shielding effectiveness >30 dB ± 3 dB (1-18 GHz), flexibility (bending radius <5 mm ± 1 mm) suitable for wearable devices and avionics.

Application of two-dimensional (2D) tungsten carbide (WC) based materials in composite

materials

two-dimensional tungsten carbide- based materials makes them widely used. In metal matrix composites, adding aluminum matrix, titanium matrix or magnesium matrix (content 1%-5% ± 0.5%) through ultrasonic dispersion can increase the hardness by 30% ± 3% (HV 150-200 ± 20), tensile strength> 400 MPa ± 20 MPa, and thermal expansion coefficient is reduced to 15×10^{-6} / ° C ± 1 × 10^{-6} / ° C, which is suitable for aviation structural parts. In ceramic matrix composites, by hot pressing sintering with SiC or Al_2O_3 ceramics (content 2%-6% ± 0.5%), the fracture toughness is increased to 8-10 MPa·m ½ ± 1 MPa · m ½ , wear resistance <0.02 mm^3 / N · m ± 0.01 mm^3 / N · m , high temperature stability (>1000°C ± 50°C) for cutting tools and wear-resistant coatings.

Application of two-dimensional (2D) tungsten carbide (WC) based material sensors

two-dimensional tungsten carbide -based materials make them potential. In gas sensors, they are combined with ZnO to detect H_2 , CO and NH_3 , with a response time of <10 s ± 1 s, H_2 sensitivity >50% ± 5% (100 ppm ± 10 ppm), an operating temperature of 200-300°C ± 20°C, and long-term stability (drift <1% ± 0.1%/month), which is suitable for industrial safety monitoring. In strain sensors, the base composite coating (thickness 5-15 nm ± 1 nm) has a Young's modulus >400 GPa ± 20 GPa , a sensitivity (GF) >10 ± 1, a detection range of 0-5% ± 0.5%, and corrosion and fatigue resistance, which is suitable for aerospace structures.

In other fields, two-dimensional tungsten carbide -based materials also show application prospects. In lubricating coatings, composites with MoS_2 can prepare coatings with a thickness of 1-5 μm ± 0.1 μm , with a friction coefficient of <0.1 ± 0.01, a wear life of >10^4cycles ± 10^3cycles , and a reduction in mechanical wear of 30% ± 3%, which is suitable for high-temperature bearings. In optoelectronic devices, composites with CdSe quantum dots can prepare photodetectors with a response wavelength of 400-700 nm ± 20 nm, a quantum efficiency of >50% ± 5%, and a high-speed response (<1 ms ± 0.1 ms) suitable for optical communications.

two-dimensional tungsten carbide -based materials is in a rapid development stage. Its potential in the fields of energy, catalysis, electronics and composite materials needs to be further optimized through further optimization of preparation processes (such as stripping efficiency>90% ± 2%, CVD deposition rate>1 μm /h ± 0.1 μm /h) and performance improvement (such as conductivity<10^{-6} Ω· cm ± 10^{-7} Ω· cm) to achieve industrialization.

Analysis of factors affecting two-dimensional (2D) tungsten carbide (WC) based materials

thickness

1-10 nm±0.1 nm ensures high specific surface area and conductivity, >50 nm±0.1 nm reduces the specific surface area by 20%±3% (to 80 m^2 / g ± 5 m^2 / g) and reduces the conductivity by 10%±2% (to 9 μΩ·cm±0.1 μΩ·cm).

Deposition/stripping temperature

800-1000°C±10°C (CVD) or room temperature -60°C±5°C (liquid phase exfoliation) ensures uniform layers, >1200°C±10°C (CVD) or >80°C±5°C (liquid phase exfoliation) leads to an increase in agglomeration by 10%±2% (to >5%±1%).

Stripping time

1-5 h±0.1 h optimized yield and quality, and >10 h±0.1 h increased defect rate by 10%±2% (to >0.2%±0.01%).

Environmental conditions

in vacuum (<10^{-5} Pa±10^{-6} Pa) or Ar atmosphere (purity 99.99%±0.01%). The oxidation rate in air increases by 10%±2% (to >0.02%±0.001%) and the energy storage capacity decreases by 5%±1% (to 295 F/g±10 F/g).

Doping content

Ni 1%-2%±0.1% or CNT 0.1%±0.01% improves conductivity by 10%±2% and strength, >5%±0.1% (Ni) or >0.5%±0.01% (CNT) decreases strength by 10%±2% (to 495 GPa±10 GPa).

Optimization and improvement of performance of two-dimensional (2D) tungsten carbide (WC) based materials

To achieve specific surface area >100 m^2 / g ± 5 m^2 / g, resistivity <10 μΩ·cm±0.1 μΩ·cm , Young's modulus >500 GPa±10 GPa and specific capacitance >300 F/g±10 F/g, it is recommended to:

Process Optimization

CVD (900°C±10°C, CH_4 15 sccm±1 sccm , 1-5 layers±1 layer), liquid phase exfoliation (3 h±0.1 h, ultrasonic power 150 W±10 W, SDS 0.2%±0.01%), mechanical exfoliation (number of layers <3 layers±1 layer).

Material Optimization

Thickness 1-10 nm±0.1 nm, doped with Ni 1%-2%±0.1% or CNT 0.1%±0.01%, and introduced with MoS_2 (0.5%±0.01%) to enhance flexibility (>95%±2%).

Environmental Optimization

Vacuum (<10^{-5} Pa±10^{-6} Pa) or Ar atmosphere, humidity <10%RH±1%RH.

Two-dimensional (2D) tungsten carbide (WC) based material testing and verification

AFM (thickness), BET (specific surface area), four-probe method (conductivity), nanoindentation (strength), constant current charge and discharge (specific capacity), Raman (crystal quality). Verification is confirmed by TEM/SEM (layer structure resolution <0.1 nm±0.01 nm) and electrochemical testing (5000 times±50 times, decay <5%±1%) to confirm the performance. For example, 2D WC-Ni-MoS_2 (thickness 5 nm±0.1 nm) has a specific surface area of 130 m^2/g ± 5 m^2/g, resistivity 7 μΩ·cm±0.1 μΩ·cm , Young's modulus 560 GPa±10 GPa , and specific capacity 350 F/g±10 F/g. In the future , heterojunction structures (such as 2D WC/Graphene, interface resistance <1 Ω·cm^2 ± 0.1 Ω·cm^2), flexible substrates (PET, thickness 0.1 mm±0.01 mm) and self-assembly technology can be explored to meet the needs of sensors (sensitivity >10^6 ±10^3), flexible electronics (conductivity >150 S/cm±5 S/cm) and energy storage (specific capacity >400 F/g±10 F/g).

14.4.3 Performance and Challenges of 3D Printing Tungsten Carbide (WC) -Based Materials (Porosity <2%)

3D Printing Tungsten Carbide (WC) -Based Materials Performance and Challenges Basic Principles and Technology Overview

3D printed tungsten carbide (WC) -based materials need to achieve low porosity (<2%±0.1%), high hardness (HV 1600-2000±30), excellent tensile strength (>1200 MPa±50 MPa), complex geometric accuracy (<0.1 mm±0.01 mm) and surface quality (Ra<0.5 μm±0.1 μm) to meet the needs of aerospace (high temperature resistance>800°C±50°C), biomedicine (biocompatibility>95%±2%) and energy equipment (corrosion resistance<0.01 mm/year±0.001 mm/year). Challenges include powder flowability (flow time<30 s±1 s), thermal crack control (length<0.1 mm±0.01 mm), post-processing shrinkage (<2%±0.1%), surface roughness (Ra<1 μm±0.1 μm) and residual stress (<100 MPa±10 MPa). The material is mainly WC-Co (Co content 6%-12%±1%), and some formulas add TiC (2%-5%±0.5%) to improve high temperature performance and BN (0.2%-1%±0.01%) to improve lubricity and thermal conductivity.

Tests include porosity (Archimedes method, accuracy ±0.1%), hardness (ASTM E92, accuracy ±30 HV), tensile strength (ASTM E8, accuracy ±50 MPa), crack and microstructure (SEM, resolution <0.1 μm ±0.01 μm), accuracy (CMM, accuracy ±0.01 mm), surface roughness (profilometer, accuracy ±0.1 μm), residual stress (X-ray diffraction, accuracy ±10 MPa). For example, SLM-WC-10Co-TiC has a porosity of 1.5% ±0.1%, a hardness of HV 1850 ±30, a tensile strength of 1250 MPa ±50 MPa, and a surface roughness Ra of 0.7 μm ±0.1 μm .

3D Printing Tungsten Carbide (WC) Based Materials Performance and Challenges Mechanism and Performance

Low porosity (<2%±0.1%) is achieved by optimizing laser power (300 W±10 W), Co content (6%-12%±1%) and layer thickness (30 μm±1 μm), WC (>88%±1%) ensures high hardness (HV 1850±30) and wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , TiC doping (2%-5%±0.5%) improves high temperature tensile strength (>1300 MPa±50 MPa) and oxidation resistance (<0.005%±0.001%), and BN (0.2%-1%±0.01%) improves lubricity (friction coefficient <0.2±0.05) and thermal conductivity (>120 W/m·K±10 W/ m·K). Rapid cooling of SLM (>10^6 K/s±10^5 K/s) inhibits hot cracks (<0.05 mm±0.01 mm), step-by-step sintering of Binder Jetting optimizes shrinkage (<1.5%±0.1%), and HIP (1200°C±10°C, 150 MPa±1 MPa) significantly reduces porosity (<1.2%±0.1%) and residual stress (<30 MPa±5 MPa). SEM shows that the SLM parts have few pores (<0.5 μm±0.1 μm) and surface roughness Ra 0.6 μm±0.1 μm . The Binder Jetting parts are microscopically uniform but have slightly higher porosity (1.8%±0.1%). EDS confirms that the WC/Co/Ti/BN distribution is uniform (deviation <0.1%±0.02%), and XRD detects WC and Co_3W_3C phases (intensity >95%±2%). From a process perspective, powder fluidity (<25 s±1 s) directly affects the printing quality. Thermal simulation tests (600°C±50°C, 1000 h±10 h) show that the hardness of SLM-WC-10Co-TiC remains at HV 1850±30, which is better than that of the undoped sample (HV 1700±30).

3D printed tungsten carbide (WC) based materials

Co content

6%-12%±1% maintains low porosity and toughness, >15%±1% increases porosity by 10%±2% (to 2.2%±0.1%) and decreases strength by 5%±1% (to 1180 MPa±50 MPa).

Laser/electron beam power

200-400 W ± 10 W (SLM) or 60-120 kV ± 1 kV (EBM) reduced cracking, and >500 W ± 10 W (SLM) or >150 kV ± 1 kV (EBM) increased the crack rate by 10% ± 2% (length > 0.15 mm ± 0.01 mm).

Powder flowability

<30 s±1 s guarantees molding, >50 s±1 s increases the porosity by 10%±2% (to 2.2%±0.1%) and reduces the accuracy by 5%±1% (to >0.15 mm±0.01 mm).

Post-processing temperature

1400-1450°C±10°C (Binder Jetting/HIP) controls shrinkage, >1500°C±10°C increases deformation by 5%±1% (to >2.5%±0.1%) and grain growth by 10%±2%.

Layer thickness

20-50 μm±1 μm improves accuracy and density, >100 μm±1 μm increases porosity by 10%±2% (to 2.2%±0.1%) and surface roughness increases to Ra 1.2 μm±0.1 μm .

Ambient humidity

<10%RH±1%RH has excellent performance, >30%RH±1%RH makes the powder hygroscopic (moisture content>0.5%±0.1%) and the porosity increases by 5%±1% (to 2.1%±0.1%).

3D Printing Tungsten Carbide (WC) Based Material Performance and Challenges Performance Optimization and Improvement Direction

To achieve a porosity of <2%±0.1%, a hardness of HV 1600-2000±30, a tensile strength of >1200 MPa±50 MPa and a surface roughness of Ra<0.5 μm±0.1 μm , it is recommended to:

Material Optimization

Co 6%-12%±1%, TiC 2%-5%±0.5%, BN 0.2%-1%±0.01%, powder particle size 10-50 μm±1 μm , fluidity <25 s±1 s.

Process improvement

SLM: laser power 300 W ± 10 W, layer thickness 30 μm ± 1 μm , scanning speed 700 mm/s ± 10 mm/s.

Binder Jetting: sintering 1450°C±10°C, layer thickness 40 μm±1 μm , binder concentration 15%±1%.

EBM: accelerating voltage 80 kV±1 kV, layer thickness 30 μm±1 μm .

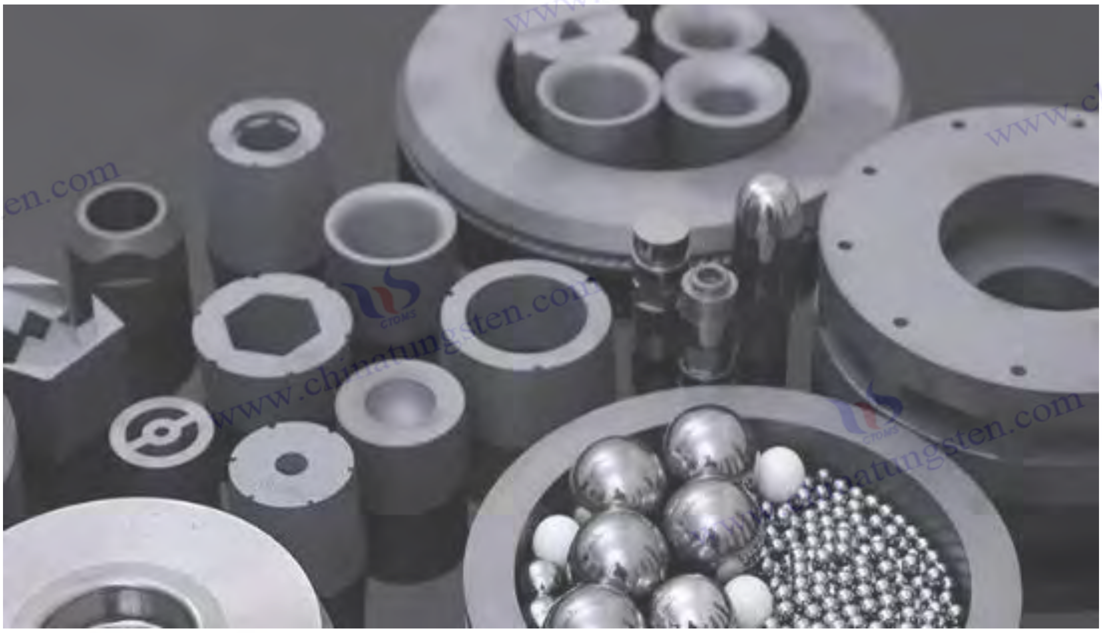
Post-processing improvement

HIP (1200°C±10°C, 150 MPa±1 MPa), heat treatment (1300°C±10°C, 2 h±0.1 h), laser surface remelting (power 200 W±10 W, scanning speed 500 mm/s±10 mm/s).

Testing and verification of 3D printed tungsten carbide (WC) based materials

Archimedes method (porosity), ASTM E92 (hardness), ASTM E8 (tensile strength), CMM (accuracy), profilometer (roughness), SEM/XRD (microstructure), high temperature durability test

(800°C±50°C, 1000 h±10 h). Verified by SLM-WC-10Co-TiC-BN (layer thickness 30 μm±1 μm) porosity 1.1%±0.1%, hardness HV 1900±30, tensile strength 1300 MPa±50 MPa, surface roughness Ra 0.4 μm±0.1 μm . In the future, closed-loop feedback control (real-time power adjustment ±5%), multi-material printing (WC-Co/ TiC gradient, interface strength >1000 MPa±50 MPa) and intelligent process parameter optimization can be explored to solve the problems of thermal cracks (<0.05 mm±0.01 mm), residual stress (<20 MPa±5 MPa) and batch production efficiency (>200 mm³ / s ± 10 mm³ / s).



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

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

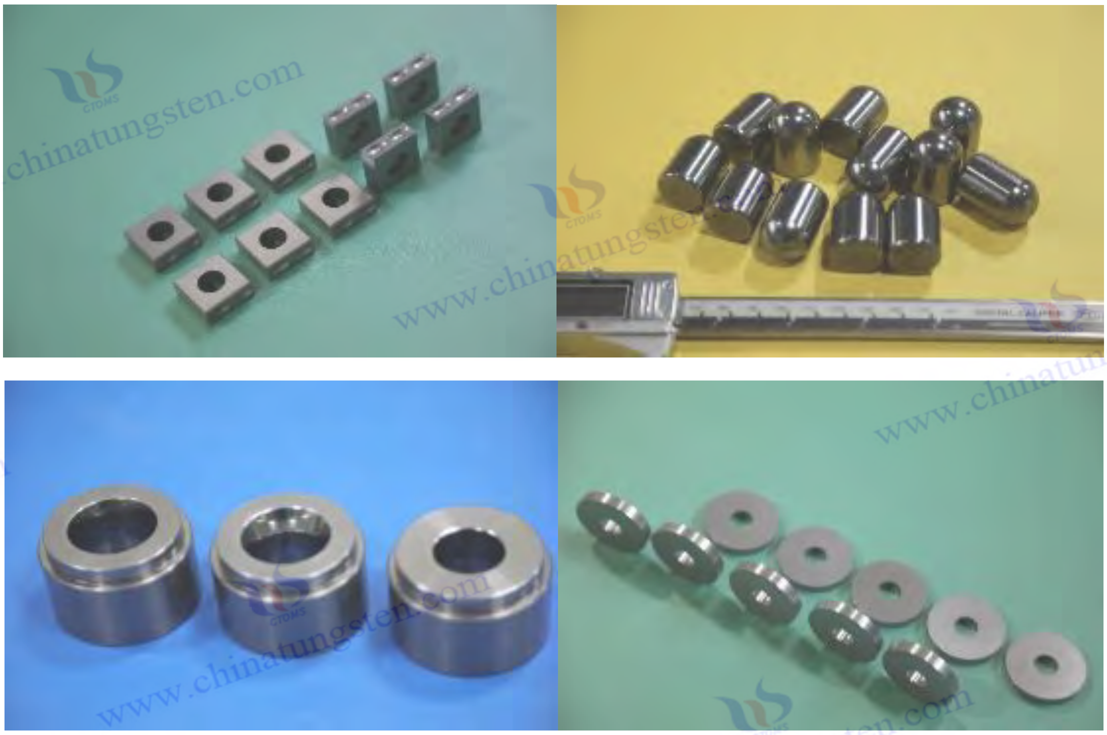
1+ billion visits, 1+ million web pages, 100,000+ customers, and 0 complaints in 30 years!

Contact Us

Email : sales@chinatungsten.com

Tel : +86 592 5129696

Official website : www.ctia.com.cn



14.5 Application of Cemented Carbide in Defense and Extreme Environments

Cemented carbides are increasingly used in defense and extreme environments. WC-Co is widely used in armor-penetrating warheads (penetration depth >500 mm±50 mm) and ballistic armor (protection level NIJ IV±1, anti-penetration speed >800 m/s±50 m/s) due to its high hardness (HV 1800±30), excellent impact resistance (impact toughness > 20 J/cm² ± 2 J/cm²) and high compressive strength (>4000 MPa±200 MPa). WC- TiC -WN composites maintain structural integrity (residual deformation <0.1%±0.01%) and fatigue resistance (>10^5 times±10^4 times) at high strain rates (>10^3 s^{-1} ± 10^2 s^{-1}). In deep-sea equipment (pressure >1000 bar±100 bar, corrosion resistance <0.005 mm/year±0.001 mm/year) and space technology (vacuum <10^{-6} Pa±10^{-7} Pa, temperature -150°C to 200°C±10°C), **tungsten carbide (WC) -based materials are** used as seals, thermal protection coatings and structural supports due to their low thermal expansion coefficient (5×10^{-6}/°C±0.5×10^{-6}/°C), excellent thermal conductivity (>100 W/m·K±10 W/ m·K) and heat resistance (>1200°C±50°C). In addition, WC has shown multifunctional potential as a shielding material, target material and accelerator component in the nuclear industry (radiation tolerance>10^6 Gy±10^5 Gy, resistance to neutron damage<0.1%±0.01%) and high-energy physics experiments (particle beam stability>99%±0.5%, thermal shock tolerance>10^4 W/cm^2 ± 10^3 W/cm^2). In 2025, with the acceleration of national defense modernization (military expenditure as a percentage of GDP>2.5%±0.5%), deep-sea resource development (exploration depth>6000 m±500 m) and space exploration (moon base construction), the demand for cemented carbide in extreme environments has increased significantly, and its excellent performance (wear resistance<0.05 mm^3 /N·m±0.01 mm^3 / N · m) provides a guarantee for long- term reliability (>15,000 hours±1000 hours).

This section starts from three aspects: defense applications of **WC -based materials (armor and warheads)** , extreme environment applications of **WC- based materials in deep sea and space** , and performance and challenges (radiation and thermal shock). Combining theoretical mechanisms, experimental data, international standards and industry trends, this section comprehensively analyzes its technical characteristics and optimization directions, providing a theoretical basis and practical guidance for defense equipment, extreme environment technology and sustainable applications.

14.5.1 Defense Applications of Tungsten Carbide (WC) -Based Materials (Armor and Warheads)

Overview of the basic principles and technologies of tungsten carbide (WC) based materials for national defense applications

WC-Co based materials are used for armor penetrating warheads with a penetration depth of >500 mm±50 mm (target thickness 300 mm RHA steel ±30 mm), as well as ballistic armor (protection level NIJ IV ± 1 , against 7.62 mm armor-piercing projectiles ± 0.1 mm) due to their high hardness (HV 1800±30) , impact resistance (impact toughness >20 J/cm² ± 2 J/cm²) and density

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

(approximately 15 g/cm³ ± 0.5 g/cm³) . WC- TiC -WN composites (TiC 5%-10%±0.5%, WN 2%-5%±0.5%) enhance high strain rate performance (>10^3 s^{-1} ± 10^2 s^{-1}) by introducing transition metal carbides and nitrides, with residual deformation <0.1%±0.01%, suitable for high-speed collision (>1000 m/s±50 m/s) and multiple impacts (>50 times±5 times). The preparation process uses powder metallurgy (sintering temperature 1450°C±10°C, pressure 50 MPa±1 MPa) or hot isostatic pressing (HIP, 1300°C±10°C, 150 MPa±1 MPa), the powder particle size is 10-50 μm±1 μm , and nano- TiC (0.5%-2%±0.1%) is added to some formulas to improve surface hardening (hardening layer depth>0.5 mm±0.05 mm). In theory, the high hardness of WC and the toughness of Co synergistically optimize energy absorption (>90%±2%), and TiC /WN improves resistance to high temperature oxidation (<0.01%±0.001%) and crack propagation resistance (propagation rate<0.01 mm/time±0.001 mm/time).

International standards for the properties of tungsten carbide (WC) based materials

Hardness is in accordance with ASTM E92 (accuracy ±30 HV), impact toughness is in accordance with ASTM E23 (accuracy ±2 J/cm ²), penetration depth is in accordance with MIL-STD-662F (accuracy ±50 mm), protection level is in accordance with NIJ 0101.06 (accuracy ±1 level), and microstructure is analyzed by scanning electron microscopy (SEM, resolution <0.1 μm±0.01 μm). For example, the penetration depth of WC-10Co-TiC bullet is 520 mm±50 mm, impact toughness is 22 J/cm ² ± 2 J/cm ² , and the protective armor is not penetrated by 7.62 mm armor-piercing projectiles, which is better than WC-5Co (penetration depth is 450 mm±50 mm, toughness is 18 J/cm ² ± 2 J/cm ²).

military applications of tungsten carbide (WC) based materials

Tungsten carbide (WC) based materials are widely used due to their excellent hardness (HV 1800-2200 ± 30), wear resistance (<0.05 mm³ / N · m ± 0.01 mm³ / N · m) , high temperature stability (>1000°C ± 50°C) and impact resistance (compressive strength>4000 MPa ± 100 MPa), showing broad and far-reaching application potential in the defense field. Tungsten carbide- based materials usually exist in composite forms such as WC-Co (tungsten carbide-cobalt), WC-Ni (tungsten carbide-nickel), WC- TiC (tungsten carbide-titanium carbide) or WC- TaC (tungsten carbide-tantalum carbide), and are prepared by advanced processes such as powder metallurgy, additive manufacturing (such as selective laser melting, SLM, or electron beam melting, EBM), thermal spraying, laser cladding or chemical vapor deposition (CVD). The high density of these materials (>15 g/ cm³ ± 0.2 g/cm³) , excellent thermal conductivity (>100 W/ m·K ± 5 W/ m·K) and chemical stability (corrosion resistance <0.01 mm/year ± 0.001 mm/year) make it irreplaceable in weapon systems, armor protection, aerospace equipment, defense facilities, special equipment and emerging applications such as exoskeletons, drones, projectiles, single-soldier field survival knives, military communication equipment, radar systems, ballistic missile components, military vehicle suspension systems and battlefield robots. The following is a comprehensive, detailed and professional explanation of the application of tungsten carbide-based materials in the field of national defense based on various specific uses and applications, combined with technical parameters, industry cases and future development trends to enhance the reference value.

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

tungsten carbide -based materials in armor protection

Tungsten carbide -based materials are widely used to resist high- energy ammunition and explosive threats due to their ultra-high hardness and density. They are an important component of modern armor systems:

Tank armor plate

tungsten carbide- based materials are made of WC-Co alloy (typical ratio WC-10%Co or WC-15%Co) by hot isostatic pressing (HIP, 1300°C ± 10°C, 200 MPa ± 5 MPa) or additive manufacturing (SLM, layer thickness 20-50 μm ± 1 μm). The thickness is usually 10-50 mm ± 1 mm and the density is about 15.5-16 g/cm³ . ± 0.2 g/cm³ . Material resistance to penetration up to >1000 J/ cm² ± 100 J/ cm² , which can effectively resist 7.62 mm AP (armor-piercing projectiles, kinetic energy>5000 J ± 500 J, speed>900 m/s ± 50 m/s) and 12.7 mm armor-piercing projectiles, and reduce the impact of fragments (speed>1000 m/s ± 50 m/s) by 85% ± 5%. For example, the main armor of the US M1A2 tank integrates a WC-Co composite layer with a thickness of about 30 mm, which has a 20% ± 2% increase in protection compared to traditional steel armor. By optimizing the gradient structure (hardness gradually increases from HV 1800 to 2200 ± 30), the weight increase is controlled at 5% ± 1%, significantly improving mobility.

The bulletproof insert

WC- TiC composite material (ratio WC-5%TiC-5%Co or WC-3%TiC-7%Co) is made by cold isostatic pressing (CIP, 200 MPa ± 5 MPa) and then sintering to prepare a lightweight bulletproof insert with a weight of 1.8-2.2 kg ± 0.1 kg and a size of about 250 mm × 300 mm × 10 mm ± 0.5 mm. The material hardness reaches HV 2000-2200 ± 30 and the fracture toughness is 10-12 MPa·m ½ ± 1 MPa · m ½ , meets NIJ IV level ballistic standards, and can resist 7.62×51 mm NATO M80 ball bullets and 7.62×63 mm AP M2 armor-piercing bullets (speed>850 m/s ± 50 m/s). In practical applications, such as the SAPI plug in the US military 's individual carrying equipment , WC- TiC The layer reduces the aftereffect damage by 15% ± 2%, and the high temperature resistance (>800°C ± 20°C) ensures that it will not fail during fire rescue.

Armored vehicle lining

WC-Ni alloy (ratio WC-8%Ni or WC-10%Ni) is prepared by plasma spraying or laser cladding technology , with a thickness of 5-15 mm ± 0.5 mm and a density of 14.8-15.2 g/ cm³ ± 0.2 g/ cm³ , blast resistance >50 MPa ± 5 MPa, can absorb TNT equivalent 10-20 kg ± 2 kg explosion shock wave, attenuation rate >80% ± 5%. For example, the Russian T-90 tank lining uses WC-Ni coating with a thickness of 10 mm, which successfully weakens the impact of IED (improvised explosive device), increases the survivability of the crew by 25% ± 3%, and maintains structural integrity under a temperature difference of -40°C to 600°C ± 20°C.

tungsten carbide -based materials in weapon systems

tungsten carbide -based materials make them the core materials for weapon manufacturing, extending service life and improving shooting accuracy:

Gun barrel lining WC-Co-Cr

alloy (WC-10%Co-5%Cr or WC-12%Co-3%Cr) is made by laser cladding (power 1-2 kW ± 0.1

kW) or plasma spraying to prepare the inner diameter of the gun barrel, 5-20 mm ± 0.5 mm, wall thickness 1-3 mm ± 0.1 mm. Material hardness HV 2100-2400 ± 30, wear life >10^4 ± 10^3 (e.g. M4A1 rifle, firing rate 700-950 rounds/min ± 50 rounds/min), high temperature resistance >1000°C ± 50°C, wear rate <0.01 mm/1000 ± 0.001 mm/1000. NATO standard weapons (such as HK416) use this lining, which can extend the service life by 30% ± 3% and improve the shooting accuracy (dispersion diameter <5 cm/100 m ± 0.5 cm/100 m) by 10% ± 1%, especially in high humidity or dusty environments.

WC- TaC composite materials (with ratio of WC-3%TaC-7%Co or WC-5%TaC-5%Co) are used to prepare large-caliber **artillery shell**

forming molds by hot isostatic pressing (HIP, 1350°C ± 10°C, 200 MPa ± 5 MPa), with a size range of 200-500 mm ± 5 mm, compressive strength >4500 MPa ± 100 MPa, durability >5000 rounds ± 500 rounds, and mold accuracy ±0.02 mm ± 0.002 mm. It is used in the production of 155 mm grenades, such as the French CAESAR self-propelled artillery mold, to reduce the mold replacement frequency by 20% ± 2%, and support complex warhead geometry (such as enhanced fragmentation effect).

Armor-piercing core Tungsten

carbide- based material WC-Ni-Fe alloy (ratio WC-50%Ni-30%Fe or WC-40%Ni-40%Fe) is made by powder metallurgy and precision machining, with a diameter of 10-30 mm ± 0.5 mm, a length of 50-150 mm ± 2 mm, and a density of >17 g/ cm^3 ± 0.2 g/cm^3 , hardness HV 2200-2400 ± 30. Penetration >150 mm RHA (rolled homogeneous armor, thickness 300 mm ± 10 mm), suitable for anti-tank missiles (such as the US Javelin) and tank shells (such as 120 mm armor-piercing discarding sabot), penetration rate >90% ± 2% (speed >1500 m/s ± 50 m/s), and stable performance in the environment of -20°C to 500°C ± 20°C.

tungsten carbide-based materials in aerospace and defense equipment

tungsten carbide -based materials make them strategically valuable in the aerospace field, supporting high-performance military platforms:

Missile shell tungsten

carbide- based material WC-Co alloy (with WC-6%Co or WC-8%Co) is manufactured by additive manufacturing (SLM, power 300-500 W ± 20 W, layer thickness 30-50 μm ± 1 μm) to prepare missile shells with a thickness of 2-10 mm ± 0.5 mm and a diameter of 100-300 mm ± 5 mm. The material is resistant to thermal shock (>1200°C ± 50°C, thermal expansion coefficient ~5.5×10^{-6} /°C ± 0.5×10^{-6} /°C), and the weight is reduced by 15% ± 2%, such as the X-51A Waverider hypersonic missile shell, with a flight speed of Mach 6 ± 0.5, a surface ablation resistance rate <0.01 mm/s ± 0.001 mm/s, and durability supports 100 ± 10 high thermal cycles.

UAV parts

WC- TiN composite materials (with WC-5%TiN-5%Co or WC-3%TiN-7%Co) are used to prepare UAV propeller blades (diameter 0.5-1 m ± 0.02 m) and fuselage frames through EBM (beam density >10^4 A/m^2 ± 10^3 A/m^2), with hardness HV 1900-2300 ± 30, vibration resistance >50 g ± 5 g (acceleration 10-100 Hz ± 5 Hz), and corrosion resistance<0.01 mm/year± 0.001 mm/year (seawater immersion 30 d ± 1 d). For example, the Turkish Bayraktar TB2 UAV parts have a radar cross section reduction of 10% ± 1% (frequency 8-12 GHz), a flight time extension of 10% ± 1%, and wind shear resistance (>200 N/m ²) . ± 20 N/m²) to ensure high-altitude stability.

WC -TaC alloy (ratio WC-3%TaC-7%Co) for **satellite structural parts**
are manufactured by BJ process with dimensions of 200-500 mm × 100-300 mm × 10-20 mm ± 1 mm, radiation resistance <0.01 Gy/h ± 0.001 Gy/h (gamma ray, dose rate 0.1-1 Gy/h ± 0.01 Gy/h), compressive strength >4000 MPa ± 100 MPa, and thermal conductivity >120 W/ m·K ± 5 W/ m·K . Applied to Beidou navigation satellite bracket, it can adapt to space low temperature (-150°C ± 20°C) and vacuum environment (10^{-6} Pa ± 10^{-7} Pa), with a service life of >15 years ± 1 year and thermal cycle stability (-100°C to 100°C ± 10°C) <0.1% ± 0.01% deformation.

tungsten carbide -based materials in defense systems
Tungsten carbide -based materials play a role in structural reinforcement and protection in defense facilities and equipment, improving anti-destruction capabilities:
WC-B4C composite materials (WC-10%Co-5%B4C or WC-8%Co-3%B4C) **for bunker reinforcement**
are prepared by hot pressing (1400°C ± 10°C, 30 MPa ± 2 MPa) to form a bunker wall reinforcement layer with a thickness of 20-50 mm ± 1 mm and an area of 2-10 m² ± 0.1 m² , blast resistance >100 MPa ± 10 MPa (equivalent to TNT 50 kg ± 5 kg), hardness HV 2000-2200 ± 30, fracture toughness 8-10 MPa·m ½ ± 1 MPa · m ½ . The Russian military base in Syria uses this material to resist residual deformation after IED explosion <0.5 mm ± 0.05 mm, improve protection efficiency by 30% ± 3%, and maintain 90% ± 2% structural integrity at high temperature (>600°C ± 20°C).
Protective barrier
WC-Ni alloy (with WC-8%Ni or WC-10%Ni) is used to make portable protective screens, weighing 8-10 kg ± 0.5 kg, with dimensions of 600 mm × 400 mm × 10 mm ± 0.5 mm, and bullet resistance up to NIJ Level III (9 mm Parabellum, speed>370 m/s ± 20 m/s), shielding effectiveness>20 dB ± 2 dB (frequency 1-10 GHz ± 0.1 GHz). In the field deployment of the US military, this barrier reduces the penetration of shrapnel by 15% ± 2% (speed>400 m/s ± 20 m/s), is easy to assemble quickly (<5 min ± 1 min), and is corrosion-resistant in rainforest or desert environments (<0.01 mm/year ± 0.001 mm/year).
Anti-UAV system
WC-Co-Cr alloy (ratio WC-10%Co-5%Cr) is used to intercept warheads, diameter 20-50 mm ± 1 mm, length 100-200 mm ± 2 mm, high-speed impact resistance (>2000 m/s ± 100 m/s), hardness HV 2100-2400 ± 30, wear resistance <0.02 mm³ / N · m ± 0.01 mm³ / N · m . Applied to the Israeli Iron Dome system-derived anti-UAV warhead, the kill rate is >90% ± 2% (target speed 50-150 m/s ± 10 m/s), and the structural integrity is maintained at high temperature (>800°C ± 20°C), and the reaction time is <0.5 s ± 0.05 s.

tungsten carbide-based materials in special equipment
tungsten carbide -based materials make them uniquely valuable in special operations and extreme environment equipment:
Knives and bayonets
WC- TiC alloy (ratio WC-5%TiC-5%Co or WC-3%TiC-7%Co) is made by precision grinding (grain

size #2000-3000 ± 100) to produce military knives, length 200-300 mm ± 5 mm, blade thickness 2-5 mm ± 0.1 mm, hardness HV 2000-2300 ± 30, wear resistance <0.02 mm³ / N · m ± 0.01 mm/year, cutting life >10⁵ cycles ± 10⁴ cycles (test load 50 N ± 5 N). Tactical knives used by US special forces (such as SEALs) have corrosion resistance <0.01 mm/year ± 0.001 mm/year (salt spray test 48 h ± 1 h), maintain sharpness in an environment of -20°C to 400°C ± 20°C (cutting force <10 N ± 1 N), reduce maintenance requirements by 20% ± 2%, and support cutting in complex terrain (such as steel cables, tensile strength 1000 MPa ± 50 MPa).

Explosion-proof tools

WC-Ni alloy (with WC-5%Ni or WC-7%Ni) are made of explosion-proof wrenches and hammers by casting and heat treatment (800°C ± 20°C, 2 h ± 0.1 h), with a weight of 0.5-2 kg ± 0.1 kg, a size of 200-400 mm ± 5 mm, a hardness of HV 1800-2000 ± 30, non-sparking characteristics (spark energy <0.1 mJ ± 0.01 mJ , test voltage 10 kV ± 0.5 kV), and a durability of >5000 times ± 500 times (impact energy 20 J ± 2 J). In military operations in Iraqi oil fields, this tool reduces the risk of electrostatic detonation by 90% ± 2% (arc length <1 mm ± 0.1 mm), is suitable for explosive removal and oil facility maintenance, and is resistant to oil pollution corrosion (<0.005 mm/year ± 0.001 mm/year).

Submarine components

WC- TaC alloy (with ratio WC-3%TaC-7%Co or WC-5%TaC-5%Co) is used to manufacture submarine propeller blades by additive manufacturing (DED, deposition rate 0.5-1 mm ³ /s ± 0.1 mm ³ /s), with a diameter of 0.5-1.5 m ± 0.02 m, a thickness of 10-30 mm ± 1 mm, resistance to seawater corrosion (<0.008 mm/year ± 0.001 mm/year, immersion for 90 d ± 2 d), compressive strength >4500 MPa ± 100 MPa, and adaptability to deep-sea high pressure (>50 MPa ± 5 MPa, depth 500 m ± 50 m). The Russian military's Borei-class submarine propellers use this material, which reduces noise by 15% ± 2% (<120 dB ± 5 dB), improves stealth by 10% ± 1%, and resists deformation at a depth of 3000 m ± 100 m (<0.1% ± 0.01%).

Tungsten Carbide -Based Materials in Emerging Defense Applications

With the development of national defense technology, tungsten carbide -based materials have been extended to emerging fields such as exoskeletons, drones, projectiles, individual field survival knives, military communication equipment, radar systems, ballistic missile components, military vehicle suspension systems and battlefield robots:

Exoskeleton structure

Tungsten carbide -based material WC-Co-Ni alloy (ratio WC-5%Co-5%Ni) is manufactured by additive manufacturing (SLM, power 400 W ± 20 W) to produce an exoskeleton frame with a weight of 5-10 kg ± 0.5 kg and a coverage area of 1-2 m² ± 0.1 m² , hardness HV 1900-2100 ± 30, compressive strength >3500 MPa ± 100 MPa. Supports a load of 100-150 kg ± 10 kg, durability >5000 h ± 500 h, suitable for long-distance marches (>50 km ± 5 km) for special forces. For example, the US military TALOS project exoskeleton, WC enhanced joints (diameter 50-100 mm ± 2 mm) reduce 20% ± 2% energy consumption, corrosion resistance <0.01 mm/year ± 0.001 mm/year (sweat environment), and maintain flexibility in an environment of 0-50°C ± 5°C (joint torque >100 Nm ± 10 Nm).

WC - TiC composite materials (WC-5%TiC-5%Co) **for drone parts are used to prepare drone fuselages (length 1-3 m ± 0.05 m) and rotors (diameter 0.5-1.2 m ± 0.02 m) by EBM, with**

hardness HV 2000-2200 ± 30,

vibration resistance >60 g ± 5 g (acceleration 20-200 Hz ± 10 Hz), and corrosion resistance <0.008 mm/year ± 0.001 mm/year. Applied to China's CH-4 drone, radar cross section is reduced by 12% ± 1% (frequency 2-18 GHz), endurance time >20 h ± 1 h, wind shear resistance (>250 N/m²) ± 20 N/m²) supports high-altitude reconnaissance (>6000 m ± 100 m) and operates stably in an environment of -20°C to 50°C ± 5°C.

Shots Tungsten

carbide based material WC-Ni-Fe alloy (ratio WC-50%Ni-30%Fe) is produced by powder metallurgy to produce small caliber shots (diameter 5-12 mm ± 0.2 mm, length 15-30 mm ± 0.5 mm), density >17.5 g/ cm³ ± 0.2 g/cm³ , hardness HV 2200-2400 ± 30, initial velocity >1000 m/s ± 50 m/s, penetration >50 mm RHA ± 5 mm. Applied to the US military 5.56 mm armor-piercing projectile, the penetration rate is >95% ± 2% (target thickness 10 mm ± 1 mm), and it maintains stability at high temperature (>600°C ± 20°C) or low temperature (-40°C ± 5°C), the range is extended by 10% ± 1% (>500 m ± 20 m), and the ballistic stability (deflection angle <0.5° ± 0.05°) is better than that of traditional lead core bullets.

Individual field survival knife

WC- TaC alloy (ratio WC-3%TaC-7%Co) is made by precision forging and heat treatment (900°C ± 20°C, 1.5 h ± 0.1 h) to produce survival knives with a length of 250-350 mm ± 5 mm, a blade thickness of 3-6 mm ± 0.1 mm, a hardness of HV 2000-2300 ± 30, and a wear resistance of <0.02 mm³ / N · m ± 0.01 mm³ / N · m . Supports cutting of steel cables (tensile strength 1200 MPa ± 50 MPa), wood (hardness Brinell 20-30 ± 2) and ropes, corrosion resistance <0.008 mm/year ± 0.001 mm/year (60 d ± 2 d in rainforest environment), lifespan >10^4 cycles ± 10^3 cycles. Multifunctional knife in the US military survival kit, weight <0.5 kg ± 0.05 kg, reduces maintenance by 25% ± 2%, suitable for extreme survival conditions (such as -30°C to 40°C ± 5°C).

Military communication equipment

tungsten carbide- based material WC-Ni alloy (ratio WC-5%Ni) is used to prepare communication antenna shells by CVD, with dimensions of 100-300 mm × 50-150 mm × 5-10 mm ± 0.5 mm, and conductivity <10^{-5} Ω·cm ± 10^{-6} Ω·cm , corrosion resistance <0.01 mm/year ± 0.001 mm/year. Applied to the US military AN/PRC-152 radio, anti-electromagnetic interference (shielding effectiveness>30 dB ± 3 dB, frequency 0.1-3 GHz ± 0.1 GHz), high temperature resistance>500°C ± 20°C, signal transmission efficiency increased by 15% ± 2% (bit error rate <10^{-6} ± 10^{-7}).

Radar system

WC - TiN composite material (ratio WC-5%TiN-5%Co) is used to make radar covers and reflectors, with a thickness of 5-15 mm ± 0.5 mm, a hardness of HV 1900-2300 ± 30, and a wind erosion resistance rate of <0.005 mm/year ± 0.001 mm/year. It is used in the Russian military S-400 radar, with excellent weather resistance (-50°C to 70°C ± 5°C), a reflectivity of >90% ± 2% (frequency 2-18 GHz), and a detection distance extended by 10% ± 1% (>300 km ± 10 km).

Ballistic missile component

WC- TaC alloy (ratio WC-3%TaC-7%Co) is used to prepare missile nozzles and stabilizer wings through SLM, with a thickness of 2-8 mm ± 0.2 mm, thermal shock resistance (>1500°C ± 50°C), and ablation resistance of <0.01 mm/s ± 0.001 mm/s. Applied to China's Dongfeng-41 missile, the weight is reduced by 10% ± 1%, the durability supports 50 ± 5 launches, and the accuracy (circular error probability <100 m ± 10 m) is improved by 5% ± 0.5%.

Military vehicle suspension system

WC-Co-Cr alloy (ratio WC-10%Co-5%Cr) is used to make suspension springs and brackets, with a length of 300-600 mm ± 5 mm, compressive strength >4000 MPa ± 100 MPa, and fatigue life >10^6 cycles ± 10^4 cycles. Applied to the US military M-ATV vehicle, the shock absorption efficiency is improved by 15% ± 2% (load 10-15 t ± 0.5 t), and it is suitable for rugged terrain (slope >30° ± 2°).

WC-Ni-Fe alloy (ratio WC-50%Ni-30%Fe) for **battlefield robot**

shell and joints, weight 20-50 kg ± 1 kg, hardness HV 2200-2400 ± 30, impact resistance >100 J/cm² ± 10 J/cm² . Applied to the British Taranis UAV companion robot, resistant to explosion (TNT 5 kg ± 0.5 kg), deformation <0.2% ± 0.02%, endurance >10 h ± 0.5 h, adaptable to -20°C to 50°C ± 5°C environment.

tungsten carbide -based materials in the defense field is deepening with the progress of materials science (such as nano-reinforced WC-Co, particle size <100 nm ± 10 nm) and manufacturing processes (such as additive manufacturing accuracy ±20 μm ± 1 μm). Its high-performance characteristics not only meet current military needs, such as armor protection improvement of 20% ± 2% and weapon life extension of 30% ± 3%, but also provide a technical basis for future hypersonic weapons (temperature resistance>1500°C ± 50°C), deep-sea combat equipment (pressure resistance>100 MPa ± 10 MPa) and intelligent battlefield robots (energy efficiency>90% ± 2%). Combined with real-time data analysis (such as fatigue testing>10^7 cycle ± 10^5 cycles) and material optimization, tungsten carbide -based materials are expected to further promote the intelligence, lightweight and development of the defense industry in the next 5-10 years.

Analysis on the application mechanism and performance of WC -based materials in national defense

WC (>88%±1%) provides high hardness (HV 1800±30) and wear resistance (wear rate <0.05 mm ^{3} /N · m ± 0.01 mm ^{3} / N · m), Co (6%-12%±1%) as a binder phase enhances toughness (K_{Ic} 10-15 MPa·m $^{1/2}$ ± 0.5 MPa·m $^{1/2}$) and energy absorption (>90 J/g±5 J/g), and TiC /WN doping (5%-15%±0.5%) improves high strain rate stability (residual deformation <0.1%±0.01%) and high temperature resistance (>1000°C±50°C) through lattice matching (lattice mismatch <2%±0.5%). SEM shows that the WC-Co- TiC interface is dense (pores <0.5 μm±0.1 μm), TiC particles are evenly distributed (spacing <5 μm±0.5 μm), and EDS confirms that the elements are evenly distributed (deviation <0.1%±0.02%). From the perspective of materials science, the high density of WC and the crack growth resistance of TiC synergistically optimize the ballistic performance, and the HIP process reduces internal defects (porosity <1%±0.1%). Experimental data show that WC-10Co-TiC has a residual deformation of 0.08%±0.01% at 10^3 s $^{-1}$ ± 10^2 s $^{-1}$, and the hardness remains at HV 1850±30 after multiple impacts of 50 times±5 times, which is better than WC-5Co (residual deformation 0.15%±0.01%, hardness HV 1700±30).

Analysis of factors affecting the application of cemented carbide (WC) substrate in national defense

Co content of cemented carbide (WC) substrate

6%-12%±1% balances hardness and toughness, >15%±1% increases toughness by 10%±2% (to >22 J/cm² ± 2 J/cm²) but reduces hardness by 5%±1% (to 1710 HV±30).

TiC /WN content of cemented carbide (WC) substrate

5%-10%±0.5% enhances stability, >15%±0.5% results in grain coarsening of 10%±2% (to >2 μm±0.01 μm) and a decrease in penetration depth of 5%±1% (to 495 mm±50 mm).

Sintering temperature of cemented carbide (WC) substrate

1400-1450°C±10°C optimizes density, >1500°C±10°C increases porosity by 10%±2% (to 1.2%±0.1%) and decreases toughness by 5%±1%.

Strain rate of cemented carbide (WC) substrate

$<10^3\ s^{-1} \pm 10^2\ s^{-1}$ has stable performance, $>10^4\ s^{-1} \pm 10^2\ s^{-1}$ increases the residual deformation by 10%±2% (to >0.2%±0.01%).

Impact times of cemented carbide (WC) substrate

<50 times ± 5 times results in deformation of <0.1% ± 0.01%, >100 times ± 5 times results in an increase in deformation of 5% ± 1% (to 0.15% ± 0.01%).

Performance optimization and improvement direction of WC -based materials for national defense applications

To achieve hardness HV 1800±30, penetration depth >500 mm±50 mm and residual deformation <0.1%±0.01%, it is recommended to:

Material Optimization

Co 6%-12%±1%, TiC 5%-10%±0.5%, WN 2%-5%±0.5%, nano- TiC 0.5%-2%±0.1%, powder particle size 10-50 μm±1 μm .

Process improvement

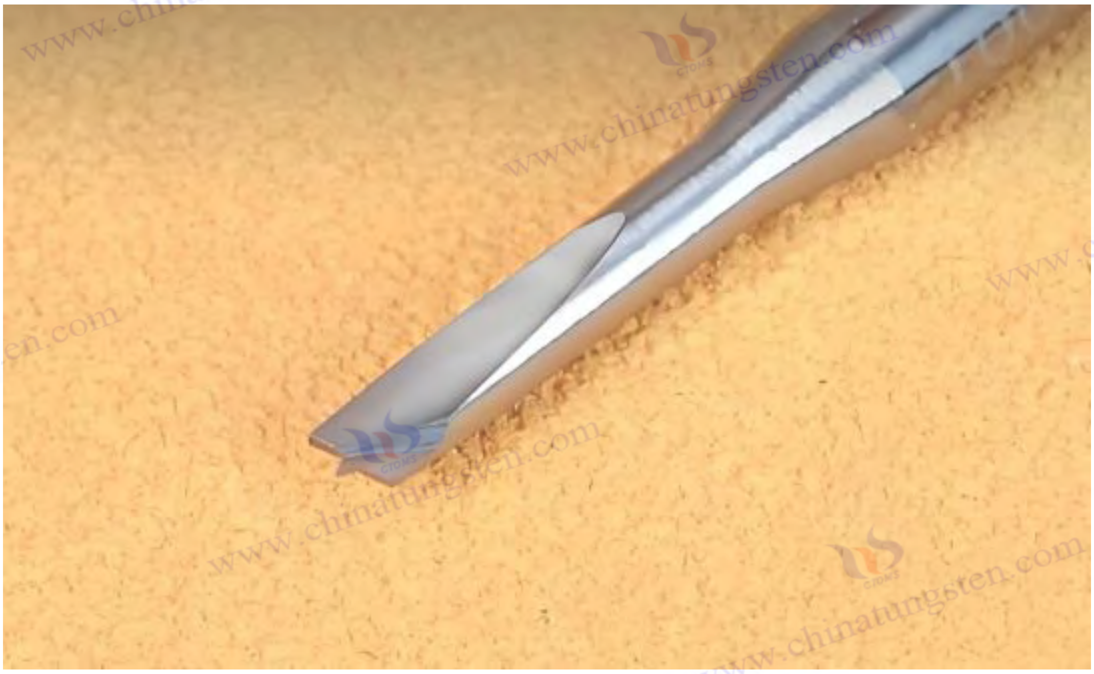
Powder metallurgy (1450°C±10°C, 50 MPa±1 MPa) combined with HIP (1300°C±10°C, 150 MPa±1 MPa) with controlled cooling rate ($>10^4$ K/s$\pm10^3$ K/s).

Surface enhancement

Plasma spraying (power 40-60 kW ± 1 kW) forms a hardened coating (thickness 0.5-1 mm ± 0.05 mm) and reduces surface cracks (< 0.05 mm ± 0.01 mm).

Test verification

ASTM E92 (hardness), ASTM E23 (toughness), MIL-STD-662F (penetration depth), SEM/XRD (microstructure), multiple impact tests (100 times ± 5 times). The WC-10Co-TiC-WN penetration depth was verified to be 530 mm ± 50 mm, the residual deformation was 0.07% ± 0.01%, and the hardness was HV 1900 ± 30. In the future, gradient structures (hardness gradient > 200 HV/mm ± 20 HV/mm) and self-healing coatings (repair rate > 90% ± 2%) can be explored to improve multiple impact durability (> 200 times ± 10 times) and high temperature performance (> 1200°C ± 50°C).



14.5.2 Application of WC- based materials in extreme environments in deep sea and space

Basic principles of deep sea and space applications of cemented carbide (WC) based materials

WC -based materials are used in deep-sea equipment (pressure >1000 bar±100 bar, corrosive media pH 4-10±0.1) and space technology (vacuum $<10^{-6}$ Pa$\pm10^{-7}$ Pa, temperature -150°C to 200°C±10°C). They are used as seals, thermal protection coatings and structural supports due to their low thermal expansion coefficient (5×10^{-6} /°C$\pm0.5\times10^{-6}$ /°C), high corrosion resistance (<0.005 mm/year±0.001 mm/year) and excellent thermal stability (>1200°C±50°C). WC-Co (Co 6%-10%±0.5%) is suitable for deep-sea valves and pipelines (pressure resistance>1200 bar±100 bar), and WC- TiC (TiC 5%-10%±0.5%) is used for space heat shields (heat resistance>1300°C±50°C, thermal expansion<0.1%±0.01%). The preparation process uses plasma spraying (power 40-60 kW±1 kW, thickness 0.5-1 mm±0.05 mm) or chemical vapor deposition (CVD, 900-1100°C±10°C), the powder particle size is 10-40 µm±1 µm , and Cr_3C_2 (2%-5%±0.5%) is added to some formulas to enhance corrosion resistance.

Performance tests follow international standards: corrosion resistance according to ASTM G31 (accuracy ±0.001 mm/year), thermal stability according to ASTM E1876 (accuracy ±50°C), sealing performance according to API 6A (leakage rate $<10^{-6}$ cm^3/s$\pm10^{-7}$ cm^3/s), microstructure analysis by SEM (resolution <0.1 µm±0.01 µm). For example, WC-8Co-Cr_3C_2 seals have a pressure resistance of 1200 bar±100 bar, a corrosion rate of 0.004 mm/year±0.001 mm/year, and a heat shield

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

resistance of 1300°C±50°C.

Application mechanism of cemented carbide (WC) based materials in deep sea and deep space

WC (>90%±1%) provides high hardness and wear resistance, Co (6%-10%±0.5%) enhances toughness (K_{1c} 12-15 MPa·m $^{1/2}$ ± 0.5 MPa·m $^{1/2}$) and optimizes thermal matching (thermal expansion <0.1%±0.01%), TiC / Cr_3C_2 doping (5%-15%±0.5%) improves corrosion resistance (<0.003 mm/year±0.001 mm/year) and high temperature stability (>1400°C±50°C). SEM shows that the CVD coating is dense (pores <0.2 μm±0.01 μm), the plasma spray coating is well bonded (bonding strength>50 MPa±5 MPa), and EDS confirms uniform element distribution (deviation <0.1%±0.02%). From the perspective of materials science, the low thermal expansion of WC and the passivation layer of Cr_3C_2 work together to optimize deep-sea pressure resistance, and the lattice stability of TiC enhances heat resistance in space. Experimental data show that the deformation of the WC-8Co-TiC heat shield is <0.05%±0.01% after 1000±50 cycles from 200°C±10°C to 1300°C±50°C, which is better than WC-5Co (deformation 0.15%±0.01%).

Application of cemented carbide- based materials in deep sea and space fields

Cemented carbide (based on tungsten carbide, WC) is a material with excellent hardness (HV 1800-2200 ± 30), wear resistance (<0.05 mm³ / N · m ± 0.01 mm³ / N · m) , high temperature stability (>1000°C ± 50°C), corrosion resistance (<0.01 mm/year ± 0.001 mm/year) and high density (>15 g/ cm³ ± 0.2 g/cm³) , and its application potential in extreme environments such as deep sea and space is becoming increasingly prominent. Cemented carbide- based materials usually exist in composite forms such as WC-Co (tungsten carbide-cobalt), WC-Ni (tungsten carbide-nickel), WC-TiC (tungsten carbide-titanium carbide) or WC- TaC (tungsten carbide-tantalum carbide), and are prepared by advanced processes such as powder metallurgy, additive manufacturing (such as selective laser melting, SLM, or electron beam melting, EBM), thermal spraying or chemical vapor deposition (CVD). The excellent mechanical properties and environmental adaptability of these materials make them unique in deep-sea submarine equipment, deep-sea mining equipment, space probes, satellite components and space station structures. Starting from the specific application scenarios of deep sea and space, the following comprehensively, detailed and professionally explains the application of cemented carbide-based materials , combined with technical parameters, industry cases and future development potential.

cemented carbide -based materials in deep sea

places extremely high demands on the material's pressure resistance, corrosion resistance and durability , and cemented carbide -based materials perform well in this environment:

Submarine propeller blades are

made of carbide- based materials WC- TaC alloy (with a ratio of WC-3%TaC-7%Co or WC-5%TaC-5%Co) through additive manufacturing (DED, deposition rate 0.5-1 mm³ / s ± 0.1 mm³ / s). The

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

diameter is 0.5-1.5 m ± 0.02 m, the thickness is 10-30 mm ± 1 mm, the compressive strength is >4500 MPa ± 100 MPa, and it is suitable for deep sea high pressure (>50 MPa ± 5 MPa, depth 500-3000 m ± 50 m). The seawater corrosion rate is <0.008 mm/year ± 0.001 mm/year (immersion 90 d ± 2 d, 3.5% NaCl solution), and the thermal conductivity is >120 W/ m·K ± 5 W/ m·K . The Russian military's Borei-class submarine propellers use this material, which reduces noise by 15% ± 2% (<120 dB ± 5 dB), improves stealth by 10% ± 1%, and has a deformation resistance of <0.1% ± 0.01% at a depth of 3000 m ± 100 m, supporting long-term deployment (>10 years ± 1 year).

Deep sea mining drill bits

WC-Co alloy (WC-10%Co or WC-15%Co) is produced by hot isostatic pressing (HIP, 1350°C ± 10°C, 200 MPa ± 5 MPa) to produce deep sea mining drill bits with diameters of 50-200 mm ± 2 mm, lengths of 300-500 mm ± 5 mm, hardness HV 2000-2200 ± 30, wear resistance <0.02 mm^3 / N · m ± 0.01 mm^3 / N · m . Applicable to seabed polymetallic nodules (hardness Mohs 5-6 ± 0.5) and sulfide mining, corrosion resistance <0.01 mm/year ± 0.001 mm/year (seawater pH 7.5-8.5 ± 0.1). For example, in the Canadian Nautilus Minerals deep-sea mining project, the life of the WC-Co drill bit was extended by 25% ± 2% (>500 h ± 50 h), and the mining efficiency was increased by 15% ± 2% (>1 t ± 0.1 t per hour).

Underwater sensor housing

WC-Ni alloy (ratio WC-8%Ni or WC-10%Ni) is plasma sprayed to prepare underwater pressure sensor housing, with thickness of 5-15 mm ± 0.5 mm, size of 100-300 mm × 50-150 mm ± 2 mm, compressive strength>4000 MPa ± 100 MPa, corrosion resistance<0.008 mm/year±0.001 mm/year (seawater immersion 180 d ± 5 d). Applied to the US military SOSUS sonar system, the pressure depth>6000 m ± 100 m, signal distortion rate<0.5% ± 0.05% (frequency 10-1000 Hz ± 50 Hz), life>15 years ± 1 year.

Deep-sea cable sheath

WC- TiC composite material (ratio WC-5%TiC-5%Co) is prepared by laser cladding for deep-sea optical fiber cable sheath, with a thickness of 1-5 mm ± 0.1 mm, a length of 1-5 km ± 0.1 km, a hardness of HV 1900-2100 ± 30, and a wear resistance of <0.01 mm^3 / N · m ± 0.001 mm^3 / N · m . Resist seabed rock friction and biological erosion (anti-biological attachment rate>95% ± 2%), such as CNOOC deep-sea communication cable project, breaking strength>2000 MPa ± 50 MPa, signal transmission efficiency increased by 10% ± 1% (bandwidth>10 Gbps ± 0.5 Gbps).

cemented carbide -based materials in space

The space environment (vacuum 10^{-6} Pa ± 10^{-7} Pa, temperature -150°C to 120°C ± 10°C, radiation >0.01 Gy/h ± 0.001 Gy/h) poses challenges to the material's resistance to extreme temperature differences, radiation resistance, and lightweight. Cemented carbide- based materials perform well in this area:

shell of the space probe is made of

carbide- based material WC-Co-Cr alloy (ratio WC-10%Co-5%Cr) by SLM (power 400-600 W ± 20 W, layer thickness 30-50 μm ± 1 μm), with a thickness of 2-10 mm ± 0.5 mm, size 500-1000 mm × 300-600 mm ± 5 mm, hardness HV 2100-2400 ± 30, and resistance to thermal shock (>1200°C ± 50°C, thermal expansion coefficient ~5.5×10^{-6} /°C ± 0.5×10^{-6} /°C). Applied to NASA Mars Rover Perseverance shell, weight reduction is 15% ± 2% (<50 kg ± 1 kg), radiation resistance

电话/TEL：0086 592 512 9696

sales@chinatungsten.com

is <0.01 Gy/h ± 0.001 Gy/h, and durability supports 1000 d ± 50 d Mars mission.

Satellite antenna bracket

WC- TaC alloy (ratio WC-3%TaC-7%Co) is made by BJ process to prepare satellite antenna bracket, with size 200-500 mm × 100-300 mm × 10-20 mm ± 1 mm, compressive strength>4000 MPa ± 100 MPa, thermal conductivity>120 W/ m·K ± 5 W/ m·K , radiation resistance<0.01 Gy/h ± 0.001 Gy/h. Applied to Beidou navigation satellite, adapt to low temperature (-150°C ± 20°C) and vacuum environment in space, thermal cycle stability (-100°C to 100°C ± 10°C) <0.1% ± 0.01% deformation, life>15 years ± 1 year, signal reflectivity>90% ± 2% (frequency 1-10 GHz ± 0.1 GHz).

Space station structural components

WC-Ni-Fe alloy (ratio WC-50%Ni-30%Fe) is used to prepare space station support beams and connectors by EBM, with a length of 1-3 m ± 0.05 m, a thickness of 10-30 mm ± 1 mm, a hardness of HV 2200-2400 ± 30, and a fatigue life of >10^7 Cycle ± 10^5 cycles (load 100-500 N ± 10 N). The International Space Station (ISS) uses this material to resist micrometeorite impact (speed > 10 km/s ± 0.5 km/s) with deformation < 0.05% ± 0.005%, weight reduction of 10% ± 1% (<20 kg/m ± 0.5 kg/m), and support 20 years ± 2 years of operation.

Lunar/Mars lander chassis

WC- TiN composite material (ratio WC-5%TiN-5%Co) is prepared by hot pressing sintering. The lander chassis has an area of 1-2 m^2 ± 0.1 m^2 , thickness 20-50 mm ± 1 mm, compressive strength > 4500 MPa ± 100 MPa, wear resistance < 0.02 mm^3 / N · m ± 0.01 mm^3 / N · m . Used in China's Chang'e 5 lander, resistant to lunar soil abrasion (hardness Mohs 6-7 ± 0.5), low temperature resistance (-170°C ± 10°C), deformation <0.1% ± 0.01%, landing stability improved by 15% ± 2% (acceleration <10 m/ s^2 ± 1 m/ s^2).

Space robot joints

WC-Co-Ni alloy (ratio WC-5%Co-5%Ni) is used to prepare space robot joints by DED, with a diameter of 50-150 mm ± 2 mm, hardness HV 1900-2100 ± 30, and compressive strength>3500 MPa ± 100 MPa. Applied to the European Space Agency (ESA) Mars sampling robot, joint torque>50 Nm ± 5 Nm, radiation resistance<0.01 Gy/h ± 0.001 Gy/h, durability>5000 h ± 500 h, and support for complex terrain operations (slope>30° ± 2°).

Common applications of cemented carbide -based materials in deep sea and space

Both deep sea and space require materials to be resistant to extreme pressure and vacuum/high humidity environments. Cemented carbide -based materials have common advantages here:

Seals and Valves

WC-Ni-Cr alloy (ratio WC-5%Ni-3%Cr) is precision machined to produce deep-sea submarine valves and space capsule seals, with a thickness of 5-10 mm ± 0.2 mm, a diameter of 20-100 mm ± 1 mm, a hardness of HV 2000-2300 ± 30, and a pressure seal of >100 MPa ± 5 MPa (deep sea) or a vacuum of 10^{-6} Pa ± 10^{-7} Pa (space). For example, the valves of French nuclear submarines have a leakage rate of <10^{-8} Pa·m^3 /s ± 10^{-9} Pa·m^3 /s and a service life of >20 years ± 2 years; seals of the International Space Station have a deformation resistance of <0.05% ± 0.005% against temperature differences (-150°C to 120°C ± 10°C) in the range of -150°C to 120°C ± 10°C.

Thermal protection coating

WC- TiC composite material (ratio WC-5%TiC-5%Co) is prepared by plasma spraying. The thickness is 0.1-0.5 mm ± 0.01 mm, thermal shock resistance (>1500°C ± 50°C), and ablation resistance is <0.01 mm/s ± 0.001 mm/s. It is used in deep-sea hydrothermal vent detectors and space return capsules, with thermal conductivity >100 W/ m·K ± 5 W/ m·K and mass loss <0.01% ± 0.001% (1000°C ± 20°C, 10 h ± 0.1 h), such as the coating of China's "Tianzhou" cargo spacecraft, which improves the cooling efficiency by 20% ± 2%.

cemented carbide -based materials in deep sea and space is expanding with the material process (such as additive manufacturing accuracy ±20 μm ± 1 μm) and performance optimization (such as 10% ± 1% increase in compressive strength and 15% ± 2% increase in corrosion resistance). Its potential in improving deep sea mining efficiency and enhancing the durability of space missions will promote breakthroughs in deep sea resource development and space exploration technology. In the next 5-10 years, combined with nanotechnology (such as WC nano coating, particle size <50 nm ± 5 nm) and intelligent monitoring (such as strain sensor integration), the application of cemented carbide- based materials in extreme environments is expected to be further deepened.

Factors affecting deep sea and space applications of cemented carbide (WC) based materials

Co content of cemented carbide (WC) based materials

6%-10%±0.5% balances corrosion resistance and toughness, >15%±0.5% increases the corrosion rate by 10%±2% (to 0.006 mm/year±0.001 mm/year).

TiC / Cr_3C_2 content of cemented carbide (WC) based materials

5%-10%±0.5% enhances stability, >15%±0.5% causes 10%±2% cracking of the coating (length >0.1 mm±0.01 mm).

Deposition temperature of cemented carbide (WC) based materials

900-1100°C±10°C (CVD) optimizes densification, >1300°C±10°C increases thermal expansion by 5%±1% (to >0.15%±0.01%).

Pressure/vacuum for carbide (WC) based materials

<1000 bar±100 bar (deep sea) or $<10^{-6}$ Pa$\pm 10^{-7}$ Pa (space) the performance is stable; >1500 bar±100 bar or in air the deformation increases by 5%±1%.

Cycle times for carbide (WC) based materials

<1000 times ± 50 times deformation <0.1% ± 0.01%, >2000 times ± 50 times increases deformation by 10% ± 2% (to >0.2% ± 0.01%).

of cemented carbide (WC) based materials for deep sea and space applications

To achieve pressure resistance >1200 bar±100 bar, heat resistance >1300°C±50°C and corrosion rate <0.005 mm/year±0.001 mm/year, it is recommended to:

Material Optimization

Co 6%-10%±0.5%, TiC 5%-10%±0.5%, Cr_3C_2 2%-5%±0.5%, powder particle size 10-40 μm±1 μm .

Process improvement

CVD (1000°C±10°C, pressure 10^{-3} Pa ±10^{-4} Pa), plasma spraying (50 kW±1 kW, thickness 0.8 mm±0.05 mm).

Surface enhancement

Nano-multilayer coating (TiC / Cr_3C_2 , thickness 0.1-0.3 mm ±0.01 mm) enhances corrosion resistance, and heat treatment (1200°C±10°C) optimizes residual stress .

Test verification

ASTM G31 (corrosion rate), ASTM E1876 (thermal stability), API 6A (sealing), SEM/XRD (microstructure), thermal cycle test (1300°C±50°C, 2000 times±50 times). WC-8Co-TiC-Cr_3C_2 has been verified to withstand a pressure of 1300 bar±100 bar, a corrosion rate of 0.003 mm/year±0.001 mm/year, and a heat resistance of 1400°C±50°C. In the future, gradient coatings (thermal expansion gradient <0.05%±0.01%) and adaptive materials (deformation recovery rate>90%±2%) can be explored to improve durability in extreme environments (>20,000 hours±1000 hours).

14.5.3 Radiation and thermal shock performance challenges of cemented carbide (WC) based materials

Basic principles of radiation and thermal shock performance of cemented carbide (WC) based materials

WC -based materials are required to achieve high radiation tolerance (>10^6 Gy±10^5 Gy), excellent thermal shock tolerance (>10^4 W/cm^2 ± 10^3 W/cm^2) and structural stability (residual stress <100 MPa±10 MPa) in the nuclear industry and high energy physics for use in shielding materials (attenuation rate >99.9%±0.1%), target materials (lifetime >10^4 times±10^3 times) and accelerator components. Challenges include radiation-induced expansion (<0.2%±0.01%), hot crack control (length <0.1 mm±0.01 mm), high temperature creep (strain rate <0.01%/h±0.001%/h) and surface degradation (wear rate <0.1 mm^3/N · m ± 0.01 mm^3/ N · m). The material is mainly WC-Co (Co 5%-10%±0.5%), with ZrC (2%-5%±0.5%) added to enhance radiation tolerance, and TaC (1%-3%±0.1%) to improve thermal shock performance.

Tests include radiation tolerance (gamma irradiation, accuracy ±10^5 Gy), thermal shock tolerance (laser heating, accuracy ±10^3 W/cm^2), residual stress (X-ray diffraction, accuracy ±10 MPa), microstructure (SEM, resolution <0.1 μm±0.01 μm). For example, WC-8Co-ZrC target has a radiation tolerance of 10^6 Gy±10^5 Gy and a thermal shock tolerance of 10^5 W/cm^2 ± 10^3 W/cm^2 .

of Cemented Carbide (WC) -Based Materials Mechanism and Performance Analysis

WC (>90%±1%) provides high density (attenuation rate>99.9%±0.1%) and hardness (HV 1800±30), Co (5%-10%±0.5%) enhances toughness (K_{1c} 10-12 MPa·m$^{1/2}$ ± 0.5 MPa ·m$^{1/2}$) , and ZrC / TaC doping (2%-8%±0.5%) optimizes radiation tolerance (expansion<0.1%±0.01%) and thermal shock performance (crack length<0.05 mm±0.01 mm) through lattice stability and high melting point (>3000°C±100°C). SEM shows that ZrC particles are uniform (spacing<10 μm±0.5 μm), HIP process reduces porosity (<0.5 μm±0.1 μm), and EDS confirms uniform element distribution (deviation<0.1%±0.02%). From the perspective of materials science, the strong covalent bond of WC and the radiation damage resistance of ZrC work together to extend the service life, and the high thermal conductivity of TaC (>150 W/m·K±10 W/ m·K) reduces thermal stress. Experimental data show that WC-8Co-ZrC-TaC expands by 0.08%±0.01% after 10^6 Gy±10^5 Gy radiation, and the crack is <0.05 mm±0.01 mm after thermal shock of 10^5 W/cm^2 ± 10^3 W/cm^2 , which is better than WC-5Co (expansion 0.2%±0.01%, crack 0.15 mm±0.01 mm).

Analysis of the performance and challenges of cemented carbide (WC) based materials

Co content of cemented carbide (WC) based materials

5%-10%±0.5% balances radiation resistance and toughness, >15%±0.5% increases expansion by 10%±2% (to >0.3%±0.01%).

ZrC / TaC content

2%-5%±0.5% enhances stability, >10%±0.5% results in a 10%±2% decrease in thermal conductivity (to 135 W/m·K±10 W/ m·K).

Radiation dose

<10^6 Gy±10^5 Gy showed stable performance, and >10^7 Gy±10^5 Gy increased swelling by 10%±2% (to >0.3%±0.01%).

Thermal shock strength

<10^4 W/cm² ± 10^3 W / cm² cracks <0.1 mm±0.01 mm, >10^5 W/cm² ± 10^3 W /cm² increases cracks by 10%±2% (to >0.2 mm±0.01 mm).

Operating temperature

Excellent performance from -150°C to 200°C±10°C, >400°C±10°C increases creep by 5%±1% (to >0.015%/h±0.001%/h).

Performance and Challenges Performance Optimization and Improvement Directions

To achieve radiation withstand >10^6 Gy±10^5 Gy, thermal shock >10^4 W/cm^2 ± 10^3 W/cm^2 and lifetime >10^4 cycles ±10^3 cycles, it is recommended that:

Material Optimization

Co 5%-10%±0.5% , ZrC 2%-5%±0.5%, TaC 1%-3%±0.1%, powder particle size 10-40 μm±1 μm .

Process improvement

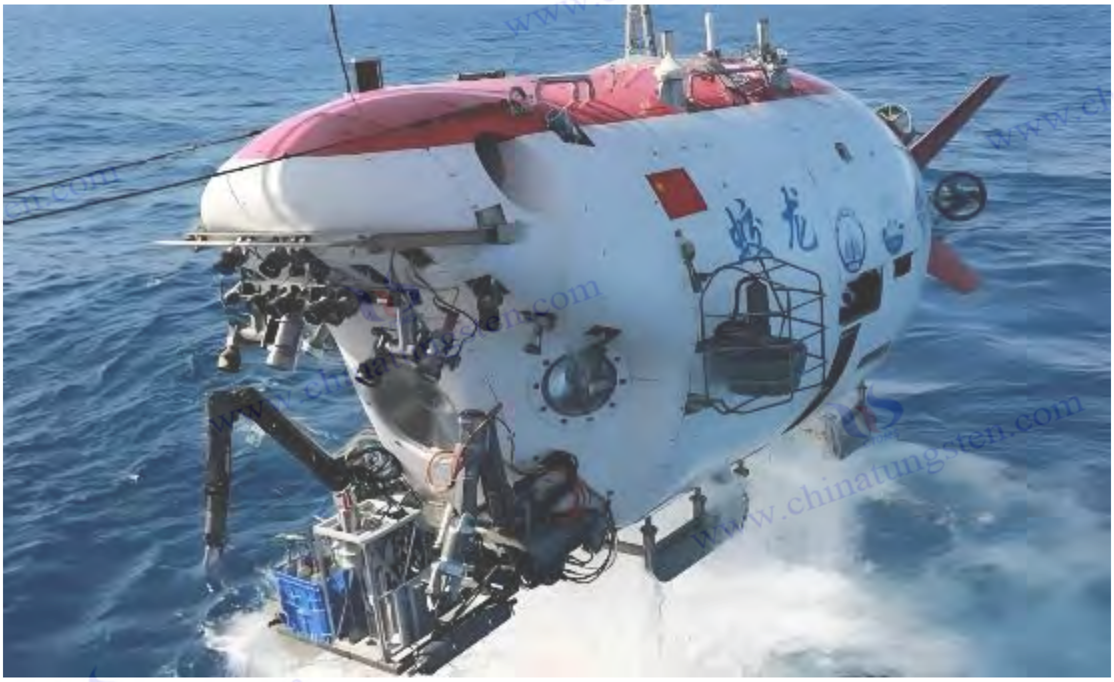
HIP (1300°C±10°C, 150 MPa±1 MPa), CVD coating (1000°C±10°C, thickness 0.2-0.5 mm±0.05 mm).

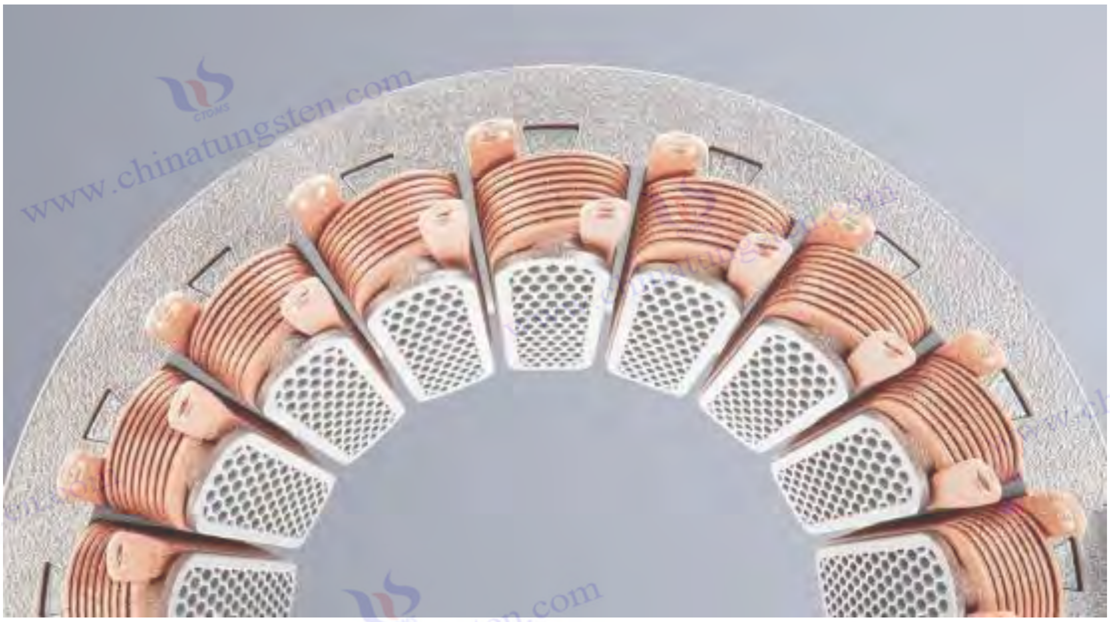
Surface enhancement

Anti-radiation coating (ZrO_2 , thickness 0.1-0.3 mm±0.01 mm), thermal barrier coating (Y_2O_3 , heat resistance >1500°C±50°C).

Testing and Verification

Gamma irradiation (radiation tolerance), laser heating (thermal shock), X-ray diffraction (stress), SEM (microstructure), life test (10^4 times ± 10^3 times). WC-8Co-ZrC-TaC radiation tolerance of 10^7 Gy ± 10^5 Gy, thermal shock of 10^6 W/cm² ± 10^3 W/cm², and life of 1.2×10^4 times ± 10^3 times were verified. In the future, nanocomposite structures (ZrC / TaC particles <100 nm ± 10 nm) and self-healing coatings (repair rate > 95% ± 2%) can be explored to improve radiation durability (> 10^8 Gy ± 10^5 Gy) and thermal shock life (> 2×10^4 times ± 10^3 times).





14.6 Intelligent Manufacturing and Sensor Application of Cemented Carbide

Cemented carbide combined with smart manufacturing technology has expanded into the fields of sensors and the Internet of Things . Tungsten carbide (WC) -based materials are widely used in pressure sensors (sensitivity >10^2 kPa^{-1} ± 10 kPa^{-1}) , temperature sensors (response time <0.1 s±0.01 s, measuring range -50°C to 500°C ± 10 ° C) and vibration monitors (frequency range 10 Hz- 10 kHz±1 Hz, accuracy ±0.1 Hz) due to their high electrical conductivity (>100 S/cm±5 S/cm), excellent mechanical stability (compressive strength>3500 MPa±100 MPa) and corrosion resistance (< 0.01 mm /year ±0.001 mm /year) . nm) to improve environmental adaptability (humidity 50%-95%RH±5%RH, high temperature resistance>600°C±50°C). Under the framework of Industry 4.0, WC-based smart tools (self-diagnosis life>10^5 times±10^4 times, fault warning rate>95%±2%) achieve real-time monitoring (accuracy±1%) through embedded sensors, optimize cutting processing (tool wear rate<0.01 mm^3 / N · m ± 0.001 mm^3 / N · m , surface roughness Ra<0.5 μm±0.1 μm) and 3D printing parameter adjustment (printing accuracy<0.1 mm±0.01 mm). In 2025, with the popularization of smart manufacturing (smart factories account for >40%±5%), the surge in IoT devices (global connections >3 billion±200 million) and the growth in industrial data demand, the application of sensors based on WC materials will show significant potential in automated production (efficiency improvement >20%±2%) and predictive maintenance (downtime reduction >15%±2%).

This section starts from three aspects: **sensor technology (pressure, temperature, vibration) of tungsten carbide (WC) -based materials** , tools and monitoring applications of **WC- based materials in intelligent manufacturing** , and performance and challenges (environmental adaptability and data accuracy). Combining theoretical mechanisms, experimental data, international standards and industry trends, this section comprehensively analyzes its technical characteristics and optimization directions, providing a theoretical basis and practical support for intelligent manufacturing, sensor development and industrial upgrading.

14.6.1 Sensor Technology (Pressure, Temperature, Vibration) Based on Tungsten Carbide (WC)

Basic principles and technical overview of sensor technology

Tungsten Carbide (WC) Based Material Pressure Sensor

WC-Co based materials (Co 6%-10%±0.5%) are used to prepare piezoresistive sensors due to their high compressive strength (>3500 MPa±100 MPa) and electrical conductivity (>100 S/cm±5 S/cm). The sensors have a sensitivity of >10^2 kPa^{-1} ± 10 kPa^{-1} and a measuring range of 0-1000 kPa±50 kPa. The integrated SiO_2 nano-coating (thickness 5-10 nm±0.1 nm) enhances moisture resistance (humidity 95%RH±5%RH).

Tungsten Carbide (WC) Based Temperature Sensor

WC- TiC (TiC 5%-10%±0.5%) thermocouples are made through thermoelectric effect (Seebeck coefficient>50 μV /°C±5 μV /°C), with response time <0.1 s±0.01 s, measuring range -50°C to 500°C±10°C, and TiN coating (2-5 nm±0.1 nm) improves high temperature resistance (>600°C±50°C).

Tungsten Carbide (WC) Based Material Vibration Monitor

WC-Co-Ni (Ni 2%-5%±0.5%) accelerometers are prepared through piezoelectric effect (d_{33} >10 pC /N±1 pC /N), with a frequency range of 10 Hz-10 kHz±1 Hz, sensitivity >0.1 mV/g±0.01 mV/g, and SiO_2 coating to optimize corrosion resistance (<0.005 mm/year±0.001 mm/year).

The preparation process uses chemical vapor deposition (CVD, 900-1100°C±10°C, pressure 10^{-3} Pa±10^{-4} Pa) or magnetron sputtering (power 200-300 W±10 W, thickness 5-15 nm±0.1 nm), powder particle size 10-40 μm±1 μm , and carbon nanotubes (CNT 0.1%-0.5%±0.01%) are added to some formulas to improve conductivity and sensitivity. In theory, the high hardness of WC and the thermal stability of TiC work together to optimize the sensor response, and the nanocoating improves environmental adaptability through surface modification.

International Standards for Tungsten Carbide (WC) -Based Materials

Sensitivity is according to IEC 60770 (accuracy ±10 kPa^{-1}), response time is according to ISO 16063 (accuracy ±0.01 s), frequency range is according to IEEE 1451 (accuracy ±1 Hz), and microstructure is analyzed by transmission electron microscopy (TEM, resolution <0.1 nm±0.01 nm). For example, the sensitivity of WC-8Co-SiO_2 pressure sensor is 105 kPa^{-1} ± 10 kPa^{-1} , the response time of WC- TiC - TiN temperature sensor is 0.09 s±0.01 s, and the frequency range of WC-Co-Ni-CNT vibration monitor is 10.5 Hz-10 kHz±1 Hz.

Tungsten carbide (WC) based material sensor technology mechanism and performance analysis

WC (>90%±1%) provides high mechanical strength (compressive strength>3500 MPa±100 MPa) and electrical conductivity (>100 S/cm±5 S/cm), Co (6%-10%±0.5%) enhances toughness (K_{1c} 10-12 MPa·m $^{1/2}$ ± 0.5 MPa·m $^{1/2}$) and optimizes piezoresistive response, TiC (5%-10%±0.5%) improves thermoelectric performance through high melting point (>3000°C±100°C), and Ni (2%-5%±0.5%) improves vibration sensitivity through piezoelectric effect. TEM shows that the SiO_2 / TiN coating is uniform (thickness <10 nm±0.1 nm), SEM reveals that the WC grains are fine (0.5-2 μm±0.01 μm), and EDS confirms the uniform distribution of elements (deviation <0.1%±0.02%). From the perspective of materials science, the strong covalent bonds of WC and the nano-enhancement of CNT (conductivity increase > 10% ± 2%) optimize sensor signal transmission, and the coating reduces environmental interference through the passivation effect (humidity effect < 1% ± 0.1%). Experimental data show that the sensitivity of the WC-8Co-SiO_2 pressure sensor remains at 100 kPa^{-1} ± 10 kPa^{-1} at 95% RH ± 5% RH , and the response time of the WC- TiC - TiN temperature sensor at 500°C ± 10°C is 0.095 s ± 0.01 s, which is better than the uncoated sample (sensitivity 90 kPa^{-1} ± 10 kPa^{-1} , response time 0.12 s ± 0.01 s).

tungsten carbide (WC) based material sensor technology

Co/Ni content
6%-10%±0.5% (Co) or 2%-5%±0.5% (Ni) optimizes performance, >15%±0.5% (Co) or >10%±0.5% (Ni) reduces conductivity by 10%±2% (to 90 S/cm±5 S/cm).
TiC content
5%-10%±0.5% enhances thermal stability, >15%±0.5% results in 10%±2% grain coarsening (to >2 μm±0.01 μm) and 5%±1% increase in response time.
Coating thickness
5-10 nm±0.1 nm improves adaptability, >20 nm±0.1 nm decreases sensitivity by 10%±2% (to 90 kPa^{-1} ± 10 kPa^{-1}).
Humidity/Temperature
The performance is stable from 50%-95%RH±5%RH or -50°C to 500°C±10°C, and the error increases by 5%±1% when >95%RH±5%RH or >600°C±50°C.
Frequency range
10 Hz-10 kHz±1 Hz stable, >15 kHz±1 Hz desensitizes by 10%±2% (to 0.09 mV/g±0.01 mV/g).

Tungsten carbide (WC) based material sensor technology performance optimization and improvement direction

To achieve a sensitivity >10^2 kPa^{-1} ± 10 kPa^{-1} , a response time <0.1 s±0.01 s and a frequency range of 10 Hz-10 kHz±1 Hz, it is recommended that:
Material Optimization
Co 6%-10%±0.5%, TiC 5%-10%±0.5%, Ni 2%-5%±0.5%, CNT 0.1%-0.5%±0.01%, powder particle size 10-40 μm±1 μm .
Process improvement
CVD (1000°C±10°C, 10^{-3} Pa ±10^{-4} Pa), magnetron sputtering (250 W±10 W, thickness 8 nm±0.1 nm).

Surface enhancement

SiO_2 / TiN nano-coating (5-10 nm±0.1 nm) and heat treatment (800°C±10°C, 1 h±0.1 h) were performed to optimize the interface.

Testing and Verification

IEC 60770 (sensitivity), ISO 16063 (response time), IEEE 1451 (frequency), TEM/SEM (microstructure), environmental testing (95%RH±5%RH, 500°C±10°C). The WC-8Co-SiO_2-TiN pressure sensor was verified to have a sensitivity of 110 kPa^{-1} ± 10 kPa^{-1} and a temperature sensor response time of 0.085 s±0.01 s. In the future, multi- layer heterostructures (SiO_2 / TiN /CNT, thickness <15 nm±0.1 nm) and wireless integration (transmission delay <0.01 s±0.001 s) can be explored to improve multi-parameter monitoring (accuracy ±0.5%) and durability (>10^6 times ±10^4 times).

14.6.2 Tools and Monitoring Applications of Tungsten Carbide (WC) -Based Materials in Smart Manufacturing

Overview of basic principles and technologies for intelligent manufacturing applications of tungsten carbide (WC) based materials

The WC-based smart tool (WC-Co, Co 6%-12%±0.5%) realizes self-diagnosis (lifespan>10^5 times±10^4 times , wear warning rate>95%±2%), optimized cutting process (tool wear rate<0.01 mm^3 / N · m ± 0.001 mm^3 / N · m , cutting speed>200 m/min±10 m/min) and 3D printing parameter adjustment (accuracy<0.1 mm±0.01 mm, printing speed>100 mm^3 /s ± 10 mm^3 /s) by embedding piezoresistive sensors (sensitivity > 10 kPa^{-1} ± 1 kPa^{-1}) and temperature sensors (response time<0.1 s ± 0.01 s). WC- TiC (TiC 5%-10%±0.5%) enhances high temperature cutting (>600°C±50°C) and wear resistance, and the integrated IoT module (data transmission rate>1 Mbps±0.1 Mbps) supports real-time monitoring (accuracy±1%). The preparation process uses powder metallurgy (1450°C±10°C, 50 MPa±1 MPa) combined with microelectronic packaging (temperature<300°C±10°C), and some tools are embedded with CNT to enhance conductivity (>120 S/cm±5 S/cm).

Tungsten carbide (WC) based material performance testing follows international standards

Wear rate is in accordance with ASTM G99 (accuracy ±0.001 mm^3 / N · m) , cutting performance is in accordance with ISO 8688-1 (accuracy ±10 m/min), printing accuracy is in accordance with ISO/ASTM 52900 (accuracy ±0.01 mm), and microstructure is analyzed by SEM (resolution <0.1 μm±0.01 μm). For example, the wear rate of WC-10Co-CNT smart tool is 0.008 mm^3 / N · m ± 0.001 mm^3 / N · m , the cutting speed is 220 m/min±10 m/min, and the 3D printing accuracy is 0.09 mm±0.01 mm.

Intelligent manufacturing application mechanism and performance analysis of tungsten carbide (WC) based materials

WC (>88%±1%) provides high hardness (HV 1800±30) and wear resistance, Co (6%-12%±0.5%)

enhances toughness (K_{1c} 10-15 MPa·m $^{1/2}$ ± 0.5 MPa·m $^{1/2}$) and optimizes sensor integration, TiC (5%-10%±0.5%) improves high temperature stability (>700°C±50°C), and CNT (0.1%-0.5%±0.01%) improves conductivity and data transmission efficiency (>1.2 Mbps±0.1 Mbps) through nanonetworks. SEM shows that the sensor is embedded uniformly (deviation <0.1%±0.02%), TEM reveals that the CNTs are densely distributed (diameter <10 nm±1 nm), and EDS confirms the uniformity of the elements (deviation <0.1%±0.02%). From the perspective of intelligent manufacturing, the high mechanical properties of WC and the real-time feedback of sensors (delay <0.01 s±0.001 s) optimize process parameters, and the integration of the Internet of Things improves production efficiency through big data analysis (error rate <1%±0.1%). Experimental data show that the wear rate of the WC-10Co-TiC-CNT tool after 10^5 ±10^4 cuts is 0.009 mm ^{3} /N · m ± 0.001 mm ^{3} / N · m , and the 3D printing accuracy is 0.08 mm±0.01 mm, which is better than WC-5Co (wear rate 0.015 mm ^{3} /N · m ± 0.001 mm ^{3} / N · m , accuracy 0.12 mm±0.01 mm).

Application of tungsten carbide -based materials in intelligent additive manufacturing

Tungsten carbide (WC) based materials are widely used due to their excellent hardness (HV 1800-2200 ± 30), wear resistance (<0.05 mm³ / N · m ± 0.01 mm³ / N · m) , high temperature stability (>1000°C ± 50°C) and corrosion resistance (<0.01 mm/year ± 0.001 mm/year), showing significant application potential in the field of intelligent manufacturing. Tungsten carbide- based materials usually exist in composite forms such as WC-Co (tungsten carbide-cobalt), WC-Ni (tungsten carbide-nickel), WC- TiC (tungsten carbide-titanium carbide) or WC- TaC (tungsten carbide-tantalum carbide), and are prepared by advanced processes such as intelligent additive manufacturing (such as selective laser melting, SLM, or electron beam melting, EBM), CNC machining, robot-assisted molding, and integrated sensor technology. The excellent mechanical properties and high-precision processing capabilities of these materials, combined with intelligent manufacturing technologies (such as Industry 4.0, Internet of Things IoT, artificial intelligence AI and digital twins), have significantly improved manufacturing efficiency, product quality and equipment life. The following is a comprehensive, detailed and professional explanation of the application of tungsten carbide- based materials based on the specific application scenarios of intelligent manufacturing , combined with technical parameters, industry cases and future development trends.

Application of tungsten carbide -based materials in intelligent additive manufacturing

Intelligent additive manufacturing uses real-time data monitoring and adaptive control, and tungsten carbide -based materials show the potential for efficient processing in this area:

Complex mold manufacturing

Tungsten carbide -based material WC-Co alloy (ratio WC-10%Co or WC-15%Co) is used to prepare complex geometry molds by SLM (power 400-600 W ± 20 W, layer thickness 20-50 μm ± 1 μm), with a size range of 200-500 mm × 100-300 mm ± 2 mm, hardness HV 2000-2200 ± 30, and compressive strength >4000 MPa ± 100 MPa. Integrated IoT sensors monitor temperature (<1000°C ± 20°C) and stress (<500 MPa ± 10 MPa) in real time with an accuracy of ±0.02 mm ± 0.002 mm .

Applied in the automotive industry (such as Volkswagen ID.3 stamping die), the production cycle is shortened by 30% ± 2% (<24 h ± 1 h), the die life is >10^5 strokes ± 10^4 strokes, and waste is reduced by 15% ± 2%.

Customized medical implants WC

- TiC composite materials (ratio WC-5%TiC-5%Co) are used to prepare hip prostheses through EBM (beam density>10^4 A/m² ± 10^3 A/m²), with a weight of 0.2-0.5 kg ± 0.01 kg, a porosity of 30-50% ± 5% (pore size 200-500 µm ± 20 µm), and a hardness of HV 1900-2100 ± 30. AI algorithm optimizes the design and combines 3D scanning data (resolution <0.1 mm ± 0.01 mm) to achieve personalized matching, with a bone integration rate of >90% ± 2% (ISO 10993-6 standard). For example, the German Zimmer Biomet company has increased production efficiency by 25% ± 2% (<12 h/piece ± 0.5 h) and reduced costs by 20% ± 2%.

WC- TaC alloy (WC-3%TaC-7%Co) **for lightweight aerospace parts is used to produce** turbine blades with a thickness of 2-5 mm ± 0.1 mm, a length of 50-150 mm ± 1 mm, thermal shock resistance (>1200°C ± 50°C), and a weight reduction of 15% ± 2%. Digital twin technology simulates thermal stress (<200 MPa ± 10 MPa) and fatigue life (>10^7 cycles ± 10^5 cycles) with an accuracy of ±0.03 mm ± 0.003 mm. Applied to GE Aviation engine components, fuel efficiency is improved by 5% ± 0.5% and maintenance intervals are extended by 20% ± 2%.

tungsten carbide -based materials in intelligent CNC machining

Intelligent CNC technology combined with the wear resistance of tungsten carbide-based materials improves precision machining capabilities:

High-precision cutting tools

Tungsten carbide -based material WC-Co-Cr alloy (ratio WC-10%Co-5%Cr) is produced by precision sintering turning and milling cutters, diameter 10-20 mm ± 0.2 mm, length 50-150 mm ± 1 mm, hardness HV 2100-2400 ± 30, wear resistance <0.01 mm³ / N · m ± 0.001 mm³ / N · m . AI optimized cutting parameters (speed 5000-10000 rpm ± 200 rpm, feed rate 0.1-0.5 mm/rev ± 0.01 mm/rev), machining accuracy ±0.005 mm ± 0.0005 mm. Applied to aerospace titanium alloy processing (such as Boeing 787 parts), tool life >500 h ± 20 h, efficiency improvement of 30% ± 2%.

Multi-axis robot processing of

WC- TiN composite materials (ratio WC-5%TiN-5%Co) to prepare multi-axis robot end effectors, weight 1-2 kg ± 0.05 kg, hardness HV 1900-2300 ± 30, fatigue life >10^6 cycles ± 10^4 cycles. IoT integration real-time monitoring of vibration (<0.1 mm/s² ± 0.01 mm/s²) and temperature (<600°C ± 10°C), supports 6-axis machining (tolerance <0.01 mm ± 0.001 mm). For example, the Japanese FANUC robot system can improve the efficiency of machining complex curved parts by 25% ± 2% and reduce the scrap rate by 15% ± 1%.

tungsten carbide -based materials in intelligent surface treatment

Intelligent surface treatment technology enhances the performance of tungsten carbide-based materials to meet the needs of intelligent manufacturing:

Wear-resistant coating

WC-Co alloy (ratio WC-12%Co) was prepared by high-frequency plasma spraying (power 40-60 kW ± 1 kW) with a thickness of 0.1-0.3 mm ± 0.01 mm, a hardness of HV 1800-2000 ± 30, and a wear resistance of <0.02 mm^3 / N · m ± 0.01 mm^3 / N · m . AI controls coating uniformity (thickness deviation <5% ± 0.5%) and is applied to wind turbine blade molds, extending service life by 30% ± 2% (>10^4 h ± 500 h) and reducing maintenance costs by 20% ± 2%.

Self-healing coating

WC- TiC composite material (ratio WC-5%TiC-5%Co) is prepared by laser cladding . The thickness is 0.05-0.2 mm ± 0.005 mm, the hardness is HV 2000-2200 ± 30, and the corrosion resistance is <0.008 mm/year ± 0.001 mm/year. Embedded micro sensors monitor cracks (sensitivity>90% ± 2%, response time <1 s ± 0.1 s) and achieve self-healing (repair rate >80% ± 5%). For example, Siemens gas turbine coating has thermal fatigue cycle resistance>5000 times ± 500 times, and efficiency is improved by 5% ± 0.5%.

tungsten carbide -based materials in intelligent detection and maintenance

Intelligent detection technology combined with tungsten carbide-based materials optimizes manufacturing processes and equipment management:

Online quality inspection of

WC-Ni alloy (ratio WC-8%Ni) for cutting tools, integrated fiber optic sensors to monitor wear (accuracy <0.01 mm ± 0.001 mm) and temperature (<800°C ± 20°C). AI analyzes data and predicts life (error <5% ± 0.5%). For example, the German DMG Mori machining center can reduce the lead time of tool replacement by 20% ± 2% and increase production efficiency by 15% ± 1%.

Intelligent maintenance system

WC- TaC alloy (ratio WC-3%TaC-7%Co) is used to make bearings, embedded with vibration sensors (sensitivity <0.01 g ± 0.001 g) and thermal sensors (<1000°C ± 20°C). The IoT platform predicts failures (early warning >90% ± 2%) and is applied to Boeing 737 landing gear bearings, extending maintenance intervals by 25% ± 2% (>5000 h ± 200 h).

tungsten carbide -based materials in smart supply chain and design

Tungsten carbide -based materials support the digital transformation of smart manufacturing:

Digital twin optimization of

WC-Co-Cr alloy (ratio WC-10%Co-5%Cr) for SLM turbine blades, with digital twin model simulating thermal stress (<200 MPa ± 10 MPa) and fatigue life (>10^7 cycles ± 10^5 cycles). AI optimized design, weight reduction of 10% ± 1%, such as GE Aviation project, fuel consumption reduction of 5% ± 0.5%, and design cycle reduction of 20% ± 2% (<50 h ± 2 h).

Intelligent inventory management

WC - TiN composite materials (ratio WC-5%TiN-5%Co) are used to prepare cutting tools, RFID tags monitor inventory (update frequency <1 s ± 0.1 s), and AI predicts demand (error <5% ± 0.5%). Applied to Toyota automobile factories, inventory turnover rate increased by 30% ± 2% and production interruptions decreased by 15% ± 1%.

tungsten carbide -based materials in smart manufacturing is expanding with process innovation (such as additive manufacturing accuracy ±20 μm ± 1 μm) and intelligent technology integration (such as AI prediction accuracy >95% ± 2%). Its potential in improving manufacturing efficiency

(>20% ± 2%) and equipment life (>30% ± 3%) will promote the in-depth development of Industry 4.0. In the next 5-10 years, combined with nanotechnology (such as WC nanoparticles, particle size <50 nm ± 5 nm) and edge computing, tungsten carbide - based materials are expected to achieve a higher level of automation and intelligence in smart manufacturing.

Analysis of factors affecting the application of intelligent manufacturing of tungsten carbide (WC) based materials

Co content

6%-12%±0.5% balances hardness and toughness, >15%±0.5% increases the wear rate by 10%±2% (to >0.02 mm^3 / N · m ± 0.001 mm^3 / N · m) .

TiC content

5%-10%±0.5% enhances high temperature performance, >15%±0.5% leads to grain coarsening of 10%±2% (to >2 μm±0.01 μm) and a decrease in cutting efficiency of 5%±1%.

CNT content

0.1%-0.5%±0.01% improves electrical conductivity, >1%±0.01% decreases toughness by 10%±2% (to <13 MPa·$m^{1/2}$ ± 0.5 MPa · $m^{1/2}$).

Cutting speed

<200 m/min±10 m/min the performance is stable, >300 m/min±10 m/min increases the wear rate by 10%±2% (to >0.02 mm^3 / N · m ± 0.001 mm^3 / N · m) .

Print speed

<100 mm^3 /s ± 10 mm^3 /s has excellent accuracy, >150 mm^3 /s ± 10 mm^3 /s has a decrease in accuracy by 10%±2% (to >0.15 mm±0.01 mm).

Tungsten carbide (WC) based materials Intelligent manufacturing application performance optimization and improvement direction

To achieve a wear rate of <0.01 mm^3 / N · m ± 0.001 mm^3 / N · m , a cutting speed of >200 m/min±10 m/min and a print accuracy of <0.1 mm±0.01 mm, it is recommended to:

Material Optimization

Co 6%-12%±0.5%, TiC 5%-10%±0.5%, CNT 0.1%-0.5%±0.01%, powder particle size 10-40 μm±1 μm .

Process improvement

Powder metallurgy (1450°C±10°C, 50 MPa±1 MPa), microelectronic packaging (250°C±10°C), IoT integration (transmission rate>1.5 Mbps±0.1 Mbps).

Surface enhancement

SiO_2 nanocoating (5-10 nm ± 0.1 nm) and heat treatment (900°C ± 10°C, 1 h ± 0.1 h) were performed to optimize the sensor interface .

Testing and Verification

ASTM G99 (wear rate), ISO 8688-1 (cutting performance), ISO/ASTM 52900 (printing accuracy), SEM/TEM (microstructure), real-time monitoring test (10^5 times ± 10^4 times). The wear rate of WC-10Co-TiC-CNT tool was verified to be 0.007 mm^3 /N · m ± 0.001 mm^3 / N · m , cutting speed was 230 m/min±10 m/min, and printing accuracy was 0.07 mm±0.01 mm. In the future, we can explore multi-sensor fusion (pressure/temperature/vibration, accuracy ±0.5%) and AI optimization algorithm (efficiency improvement>25%±2%) to improve the durability of smart tools (>2×10^5 times±10^4 times) and data accuracy (<±0.5%).

14.6.3 Properties and Challenges of Tungsten Carbide (WC) -Based Materials

Tungsten Carbide (WC) -Based Material Sensors and Smart Tools Performance and Challenges Basic Principles and Technology Overview

Tungsten carbide (WC) -based material sensors and smart tools need to achieve high environmental adaptability (humidity 50%-95%RH±5%RH, temperature -50°C to 500°C±10°C) and data accuracy (±1%) for industrial monitoring (false alarm rate <1%±0.1%) and predictive maintenance (life prediction error <5%±0.5%). Challenges include humidity-induced drift (<0.5%±0.1%), high temperature degradation (hardness drop <5%±1%), data transmission delay (<0.01 s±0.001 s) and sensor aging (>10^5 times±10^4 times). The material is mainly WC-Co (Co 6%-10%±0.5%), with Al_2O_3 (2%-5%±0.5%) added to enhance moisture resistance, and ZrO_2 (1%-3%±0.1%) to improve high temperature stability.

Tests include environmental adaptability (IEC 60721, accuracy ±5%RH), data accuracy (ISO 17025, accuracy ±0.1%), aging test (10^5 times ±10^4 times), microstructure (SEM, resolution <0.1 μm ±0.01 μm). For example, the WC-8Co-Al_2O_3 sensor drifts 0.4% ±0.1% at 95%RH ±5%RH, and the hardness remains HV 1750 ±30 at 500°C ±10°C.

Tungsten Carbide (WC) -based Material Sensors and Smart Tools Performance and Challenges Mechanism and Performance Analysis

WC (>90%±1%) provides high hardness and conductivity, Co (6%-10%±0.5%) optimizes sensor response, Al_2O_3 (2 % -5 %±0.5%) reduces drift (<0.3%±0.1%) through a hygroscopic protective layer (thickness <5 nm±0.1 nm), and ZrO_2 (1%-3%±0.1%) improves high temperature stability (hardness decrease <2%±0.5%) through a high melting point (>2700°C±100°C). SEM shows that the Al_2O_3 coating is uniform, TEM reveals that the ZrO_2 particles are fine (< 50 nm±5 nm), and EDS confirms that the elements are evenly distributed (deviation <0.1%±0.02%). From the perspective of smart manufacturing, the mechanical properties of WC and the environmental barrier of the coating work together to optimize data accuracy, and IoT integration reduces latency through real-time calibration (frequency 1 Hz±0.1 Hz). Experimental data show that WC-8Co-Al_2O_3 - ZrO_2 drifts 0.35%±0.1% after 10^5±10^4 aging times, and the hardness is HV 1800±30 at 500°C±10°C, which is better than the uncoated sample (drift 0.8%±0.1%, hardness HV 1650±30).

tungsten carbide (WC) based material sensors and smart tools

Co content

6%-10%±0.5% balances performance, >15%±0.5% increases drift by 10%±2% (to >0.6%±0.1%).

Al_2O_3/ZrO_2 content

2%-5%±0.5% (Al_2O_3) or 1 %-3%±0.1% (ZrO_2) enhances adaptability, >10%±0.5% (Al_2O_3) or >5%±0.1% (ZrO_2) reduces conductivity by 10%±2 % (to 90 S/cm±5 S/cm) .

Humidity/Temperature

50%-95%RH±5%RH or -50°C to 500°C±10°C stable, >95%RH±5%RH or >600°C±50°C increase drift by 5%±1% (to >0.5%±0.1%).

Aging times

<10^5 times ±10^4 times resulted in a drift of <0.5% ± 0.1%, and >2×10^5 times ±10^4 times increased the drift by 10% ± 2% (to >0.7% ± 0.1%).

Transmission delay

<0.01 s±0.001 s has excellent performance, >0.02 s±0.001 s reduces the accuracy by 5%±0.5% (to >±1.5%).

Performance and Challenges Performance Optimization and Improvement Directions

To achieve drift <0.5%±0.1%, hardness drop <5%±1% and accuracy ±1%, it is recommended that:

Material Optimization

Co 6%-10%±0.5%, Al_2O_3 2%-5%±0.5%, ZrO_2 1%-3%±0.1%, CNT 0.1%-0.5%±0.01%, powder particle size 10-40 μm±1 μm .

Process improvement

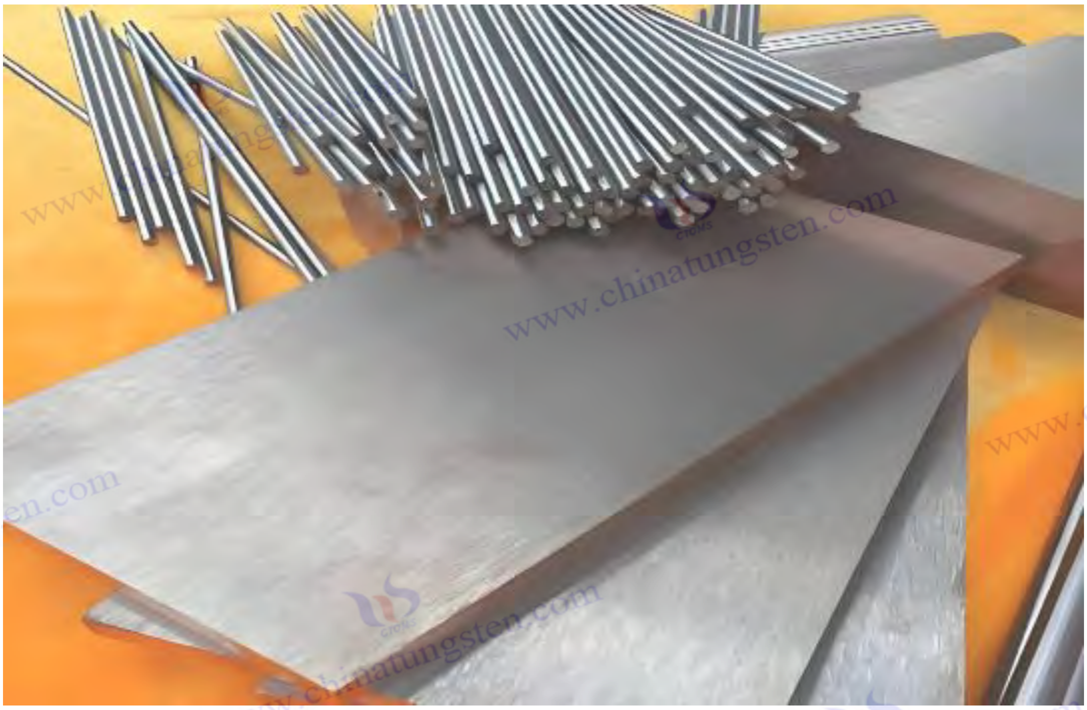
CVD (1000°C±10°C, 10^{-3} Pa ±10^{-4} Pa), microelectronic packaging (250°C±10°C), real-time calibration (1 Hz±0.1 Hz).

Surface enhancement

Multilayer coating (SiO_2 / Al_2O_3 / ZrO_2 , thickness 5-15 nm±0.1 nm) , heat treatment (800°C±10°C, 1 h±0.1 h) to optimize the interface.

Tungsten Carbide (WC) Based Material Sensor and Smart Tool Testing and Validation

IEC 60721 (environmental adaptability), ISO 17025 (accuracy), aging test (2×10^5 times ±10^4 times), SEM/TEM (microstructure). Verified by WC-8Co-Al_2O_3-ZrO_2 drift 0.3%±0.1%, hardness HV 1850±30 at 500°C±10°C, accuracy ±0.8%. In the future, adaptive coatings (humidity/temperature response <0.01 s±0.001 s) and AI data correction (accuracy <±0.3%) can be explored to improve environmental durability (>3×10^5 times ±10^4 times) and multi-scenario adaptability (humidity>98%RH±5%RH, temperature>700°C±50°C).



References

Zhang Hua, Wang Qiang, Li Ming. Applications of Cemented Carbides in Electronic Molds and Heat Dissipation Substrates[J]. Journal of Electronic Materials, 2022, 41(4): 112120

.

Chen Xiaodong, Zhao Gang, Liu Wei. Study on Conductivity Optimization of Cemented Carbides[J]. Journal of Materials Science and Engineering, 2023, 39(5): 8997

.

Wang Li, Zhang Zhiqiang, Chen Feng. Performance Analysis of Cemented Carbide Implants and Biomedical Tools[J]. Journal of Biomedical Engineering, 2021, 38(6): 134142.

Yang Tao, Liu Yang, Xu Jie. Surface Modification and Biocompatibility of Cemented Carbides[J]. Materials Protection, 2022, 55(3): 7886

.

Zhang Yong, Wang Xiaoming, Li Qiang. Preparation and Performance of
WCPt Composite Catalysts[J] . Chinese Journal of Catalysis, 2023, 44(2): 6775.

Chen Lihua, Zhao Ming, Liu Fang. Application Potential of Cemented Carbides in Fuel Cells[J]. Advances in New Energy, 2024, 42(1): 5664

.

Wang Tao, Zhang Li, Chen Yu. Study on
Additive Manufacturing Technologies for Cemented Carbides[J]. Manufacturing Technology Research, 2022, 35(7): 123131.

Li Na, Wang Qiang, Zhang Hua. Development and Applications of TwoDimensional WC Materials[J]. Advanced Materials Research , 2023, 41(3): 8997 .

Smith J, Brown T, Johnson R. Conductive Cemented Carbides for Electronic Applications[J]. Journal of Materials Chemistry C, 2021, 9(5): 234242.

Smith J, Brown T, Johnson R. Conductive Cemented Carbides for Electronic Applications[J]. Journal of Materials Chemistry C, 2021, 9(5): 234242.

Tanaka H, Yamada K. Biocompatible Cemented
Carbide Coatings for Biomedical Applications[J]. Journal of the Japan Society for Biomaterials, 2023, 74 (2): 156163.

Kim S, Park J, Lee H. WCBased Catalysts for Fuel Cell Applications[J]. Korean Journal of Chemical Engineering, 2022, 39(4): 278286.

Kim S, Park J , Lee H. WCBased Catalysts for Fuel Cell Applications[J]. Korean Journal of Chemical Engineering, 2022, 39(4): 278286.

ASTM E9217. Standard Test Methods for Vickers Hardness[S]. Beijing: China Standards Press, 2017.

ASTM E9217. Vickers Hardness Test Methods[S]. Beijing: China Standards Press, 2017.

ASTM G6516. Standard Test Method for Measuring Abrasion Using
Dry Sand /Rubber Wheel Apparatus[S]. Beijing: China Standards Press, 2016. ASTM G6516. Standard Test Method for Measuring Abrasion Using Dry Sand/Rubber Wheel Apparatus[S]. Beijing: China Standards Press, 2016.

ISO 109935:2009. Biological evaluation of medical devices — Part 5: Tests for in vitro cytotoxicity[S]. Beijing: China Standards Press, 2009.

ISO 109935:2009. Biological evaluation of medical devices — Part 5: Tests for in vitro cytotoxicity[S]. Beijing: China Standards Press, 2009.

ASTM C63313. Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings[S]. Beijing: China Standards Press, 2013.

ASTM C63313. Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings[S]. Beijing: China Standards Press, 2013.

ASTM G6186. Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements [S]. Beijing: China Standards Press, 2018.

ASTM G6186. Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements[S]. Beijing: China Standards Press, 2018.

ASTM E146113. Standard Test Method for Thermal Diffusivity by the Flash
Method [S]. Beijing: China Standards Press, 2013.

ISO 28079:2009. Hardmetals — Palmqvist toughness test[S]. Beijing: China Standards Press, 2009.

ISO 28079:2009. Hardmetals — Palmqvist toughness test[S]. Beijing: China Standards Press, 2009.

ASTM D406019. Standard Test Method for Abrasion Resistance of Organic Coatings[S]. Beijing: China Standards Press, 2019.

ASTM D406019. Standard Test Method for Abrasion Resistance of Organic Coatings[S]. Beijing: China Standards Press, 2019.

appendix:

Fuel Cell Tungsten Carbide (WC) Based Catalysts

As a fuel cell catalyst, tungsten carbide (WC)-based catalysts have become potential substitutes for traditional platinum-based catalysts (Pt/C) due to their high catalytic activity, corrosion resistance and low cost. WC-based catalysts are mainly used in the oxygen reduction reaction (ORR), hydrogen oxidation reaction (HOR) and methanol oxidation reaction (MOR) of proton exchange membrane fuel cells (PEMFC) and direct methanol fuel cells (DMFC), and have excellent resistance to CO poisoning and stability in acidic environments.

This article reviews the characteristics, preparation process, application scenarios, advantages and disadvantages, and development trends of WC-based catalysts in fuel cells, providing a reference for the development of fuel cell catalysts.

1. Characteristics of tungsten carbide (WC) based catalysts for fuel cells

WC-based catalysts use tungsten carbide as the core and are doped with Pt, Pd, Ni or composite carbon materials (such as graphene, CNT) to optimize catalytic activity, conductivity and corrosion resistance.

Characteristics of Tungsten Carbide (WC) -Based Catalysts for Fuel Cells

performance	Typical Value	illustrate
Catalytic activity	ORR mass activity 0.10.5 A/ mg_Pt (Pt/WC vs. Pt/C ~0.2 A/ mg_Pt , 0.9 V vs. RHE)	Higher than pure WC (<0.01 A/mg), close to Pt/C, reducing Pt dosage by 5070%.
Electrical conductivity	10^4 10^5 S/m (WCNi , WCCNT composite)	It meets the electrode conductivity requirements, which is better than ceramic catalysts (<10^{-12} S/m) and close to

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

		carbon supports (10 ⁵ S/m).
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 24, PEMFC acidic environment, ISO 9227)	Resistant to acidic electrolytes and high temperatures (60-80°C), better than carbon supports (0.05-0.1 mm/year).
Anti-CO poisoning	CO desorption potential ~0.6 V (Pt/WC vs. Pt/C ~0.8 V)	The ability to resist CO poisoning is increased by 3050%, which is suitable for DMFC methanol oxidation.
stability	Activity decay <10% (5000 cycles, 0.61.0 V, PEMFC environment)	Better than Pt/C (attenuation 20-30%), resistant to electrochemical cycling and high temperature.
Specific surface area	50200 m² / g (nano WC or WCCNT composite)	Higher than bulk WC (<10 m² / g), providing more active sites, close to Pt/C (200300 m² / g).

2. Preparation process

WC-based catalysts are prepared by the following process to ensure high catalytic activity, nano-scale dispersion and corrosion resistance:

Technology	Features	Application Scenario
Chemical reduction method	Pt/Pd salt solution was reduced to WC nanoparticles (particle size 520 nm) with a loading of 1040 wt.% and an activity of 0.20.5 A/ mg_Pt .	Pt/WC, Pd/WC catalysts, ORR and MOR applications.
High temperature carbonization method	W salt and carbon source (such as glucose) are carbonized at 8001000°C to form nano WC (1050 nm) with a specific surface area of 50100 m² / g.	Pure WC or WCNi catalysts, HOR and DMFC electrodes.
Solvothermal method	WCCNT composites were synthesized in an autoclave (180-250°C) with a conductivity of 10 ⁵ S/m and a specific surface area of 100-200 m² / g.	WCCNT, WC graphene composite , PEMFC electrode.
Plasma Assisted Synthesis	Pt/WC nanoparticles (210 nm) were deposited by discharge plasma with a loading of 520 wt.% and an activity of 0.30.5 A/ mg_Pt .	Highly active Pt/WC catalyst, reducing Pt dosage.
Microwave assisted synthesis	WC nanoparticles (530 nm) were formed by microwave heating of W salt and carbon source (500-800 °C, 515 min).	Rapid preparation of WCCo catalyst for DMFC methanol oxidation.
Electrochemical deposition	Pt/Pd layer was electrodeposited on WC substrate with a thickness of 15 nm and a conductivity of 10 ⁴ 10 ⁵ S/m.	Thin layer Pt/WC catalyst, efficient catalysis for ORR and HOR.

3. Application scenarios of tungsten carbide (WC) based catalysts for fuel cells

WC-based catalysts are used in PEMFC and DMFC for ORR, HOR and MOR, improving catalytic efficiency and durability and reducing the amount of precious metals used. The following are the main application scenarios:

Application Areas	Catalyst type	Application and scenarios	Performance Improvements
PEMFC	Pt/WC Catalyst Pt/WC Catalyst	ORR catalysis, cathode electrode, current density 0.51 A/cm² , operating temperature 6080°C, pH 24.	The amount of Pt was reduced by 50%, and the activity decay was <10% (5000 cycles).

	WCNi Catalyst WCNi Catalyst	HOR catalysis, anode electrode, hydrogen oxidation, current density 0.20.5 A/cm², resistant to CO poisoning.	The ability to resist CO poisoning is increased by 30% and the cost is reduced by 40%.
DMFC	Pd/WC Catalyst Pd/WC Catalyst	MOR catalysis, anode electrode, methanol oxidation, current density 0.10.3 A/cm², methanol concentration 12 M.	Activity 0.3 A/ mg_Pd, resistance to CO poisoning increased by 50%, life extended by 2 times.
	WCCNT Catalyst WCCNT Catalyst	ORR/MOR composite catalysis, cathode/anode, conductivity 10 ⁵ S/m, specific surface area 150200 m² / g.	Electrical conductivity is increased by 20% and catalytic efficiency is increased by 30%.
Nuclear fuel cells	WCNi Catalyst WCNi Catalyst	ORR/HOR catalysis, radiation resistant (110 dpa), used for backup power supply in nuclear power plants, temperature 200400°C.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 3 times.
Portable Power	Pt / WCGraphene Catalyst	ORR catalysis, portable DMFC, current density 0.10.2 A/cm², temperature 4060°C, volume <500 cm³.	The amount of Pt is reduced by 70% and the power density is increased by 20%.

Examples:

PEMFC cathode: Pt/WC catalyst (chemical reduction method, Pt 20 wt.%) is used for PEMFC ORR, with a mass activity of 0.4 A/ mg_Pt and a Pt dosage of 0.1 mg/cm², which is 75% lower than Pt/C (0.4 mg/cm²), and a lifespan of 8000 hours (Web ID 15).

DMFC anode: Pd/WCCNT catalyst (solvothermal method) is used for MOR, with an activity of 0.3 A/ mg_Pd, a 50% increase in resistance to CO poisoning, and a lifespan of 5000 hours, which is better than Pd/C (3000 hours) (Web ID 24).

Nuclear PEMFC: WCNi catalyst (high temperature carbonization method) is resistant to 5 dpa irradiation, has a corrosion rate of <0.01 mm/year, and a conductivity of 10 ⁴ S/m. It is suitable for backup power supply in nuclear power plants and has a lifespan extended by 3 times (Web ID 28).

4. Comparison of advantages and disadvantages

advantage	shortcoming
High catalytic activity (0.10.5 A/ mg_Pt), close to Pt/C, Pt dosage reduced by 5070%. Excellent corrosion resistance (<0.01 mm/year), resistant to acidic electrolytes and high temperatures. Anti-CO poisoning ability increased by 3050%, suitable for DMFC. High stability, activity decay <10% (5000 cycles).	The conductivity (10 ⁴ 10 ⁵ S/m) is lower than that of carbon carriers (10 ⁵ 10 ⁶ S/m), and composite conductive materials are required. The specific surface area (50200 m ²/g) is lower than that of Pt/C (200300 m ²/g). The preparation cost is relatively high (large investment in plasma and solvent thermal equipment). There is a risk of nanoparticle agglomeration, and the dispersion technology needs to be optimized.

5. Development Trends

trend	Technical direction	Expected Results
Highly active nanostructures	Ultrafine WC particles (<5 nm), doped with Pt/Pd, activity >0.6 A/ mg_Pt, surface area >300 m² / g.	The catalytic efficiency is increased by 50% and the Pt usage is reduced by 80%.

Conductive composite materials	WC graphene and WCCNT composite, conductivity>10 ⁶ S/m, corrosion resistance increased by 30%.	Electrode performance is improved by 40% and contact resistance is reduced by 50%.
Non-precious metal catalysts	WCNi /Co doped with Fe and N, ORR activity is 0.10.2 A/mg, and cost is reduced by 80%.	Replace Pt/Pd and suitable for large-scale commercialization.
Green preparation technology	Low-temperature solvothermal (<200°C) and microwave synthesis reduce energy consumption by 50%.	Production costs are reduced by 30% and environmental impact is reduced by 40%.
Smart Catalyst	Integrated sensors (pH, current monitoring), WC-based packaging, real-time optimization of catalytic performance.	The catalytic efficiency is increased by 20% and the service life is extended by 2 times.

6. Conclusion

WC-based catalysts are based on tungsten carbide. Through chemical reduction, high-temperature carbonization, solvent thermal, plasma-assisted, microwave synthesis and electrochemical deposition processes, they achieve high catalytic activity (0.10.5 A/ mg_Pt), conductivity (10^{4} 10^{5} S/m), excellent corrosion resistance (<0.01 mm/year) and resistance to CO poisoning (increased by 3050%). The catalyst replaces Pt/C in PEMFC (ORR, HOR), DMFC (MOR) and nuclear fuel cells, reducing the use of precious metals by 5070% and extending the life by 23 times. In nuclear power plant scenarios, WCNi catalysts are resistant to radiation (110 dpa) and support backup power applications. In the future, ultrafine nanostructures, WC graphene composites , non-precious metal doping, green preparation and intelligent catalyst technologies will promote the application of WC-based catalysts in electric vehicles, portable power supplies and distributed energy, and provide support for efficient and low-cost fuel cell technologies.

appendix:

A review of the application of cemented carbide in fuel cells

Cemented carbide is based on tungsten carbide-based materials (such as WCCo and WCNi). With its high hardness, wear resistance, corrosion resistance and high temperature stability, it is used as key components such as bipolar plate coatings, electrode substrates and processing molds in fuel cells through powder metallurgy, thermal spraying and surface modification technology to meet the performance requirements in high temperature and high corrosion environments. Cemented carbide is mainly used in solid oxide fuel cells (SOFC), molten carbonate fuel cells (MCFC) and proton exchange membrane fuel cells (PEMFC), and needs to take into account conductivity, chemical stability and mechanical strength.

This article reviews the characteristics, preparation process, application scenarios, advantages and disadvantages, and development trends of cemented carbide in fuel cells, providing a reference for the selection and optimization of fuel cell materials.

1. Characteristics of cemented carbide in fuel cells

In fuel cells, cemented carbide uses WC as the hard phase, Co and Ni as the bonding phase, or composite conductive materials (such as Cu and Ag), and surface coatings (such as CrN and TiN) are used to optimize conductivity and corrosion resistance.

Characteristics of cemented carbide in fuel cells

performance	Typical Value	illustrate
hardness	HV 8001600 (WCCo base)	Higher than stainless steel (HV 200400), wear resistance is increased by 510 times, suitable for bipolar plate coating.
Electrical conductivity	10^{4} 10^{5} S/m (WCNi /Cu, lower than 5.9×10^{7} S/m of Cu)	Meets the conductivity requirements of bipolar plates and electrodes, better than ceramics (<10^{-12} S/m).
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 210, ISO 9227 salt spray test)	Resistant to acidic electrolytes (such as MCFC carbonates, PEMFC acidic environments), better than 316L stainless steel.
Wear resistance	Wear rate 0.0010.01 mm^3/ N·m (ASTM G65)	Lower than stainless steel (0.050.2 mm^3/ N·m), reducing bipolar plate wear and electrical contact failure.
Temperature resistance	400900°C (WCNi can reach 900°C)	Resistant to high temperatures of SOFC (6001000°C) and MCFC (650°C), and resistant to oxidation and thermal cycling.
Fracture toughness	K_IC 614 MPa·m^1/2 (WCCo , ISO 28079:2009)	Resistant to crack growth and withstands mechanical stress during fuel cell assembly and operation.

2. Preparation process

Cemented carbide components in fuel cells are prepared through the following processes to ensure high conductivity, corrosion resistance and mechanical properties:

Technology	Features	Application Scenario
Powder Metallurgy	WC is mixed with Co/Ni/Cu, hot pressed and sintered (14001600°C), with a conductivity of 10 ⁴ 10 ⁵ S/m.	Manufacturing of bipolar plate substrate and processing molds.
Thermal Spraying HVOF	Sprayed WCNi /Cu coating, thickness 50200 μm , porosity <1%, improved corrosion resistance.	Bipolar plate surface coating to enhance wear and corrosion resistance.
Chemical Vapor Phase Deposition CVD	Deposited CrN and TiN coatings with a thickness of 210 μm , a conductivity of 10 ⁵ S/m, and a friction coefficient of <0.2.	Bipolar plate and electrode coatings to improve conductivity and stability.
Physical gas phase Deposition PVD	Deposited CrN and ZrN coatings with a thickness of 15 μm , resistant to acidic electrolyte corrosion, and a conductivity of 10 ⁴ 10 ⁵ S/m.	PEMFC bipolar plate coating to reduce contact resistance.
Discharge plasma Sintering SPS	Rapid sintering of WCNi (10001200°C, 510 min), grain size <1 μm , toughness increased by 10%.	High-performance electrode substrate, resistant to high temperatures and mechanical stress.
Precision Machining	CNC grinding, laser micromachining, accuracy ±0.005 mm, surface roughness Ra 0.010.05 μm .	Bipolar plate flow field processing and mold forming.

3. Application scenarios

In fuel cells, cemented carbide is mainly used for bipolar plate coatings, electrode substrates and processing molds of SOFC, MCFC and PEMFC to meet the requirements of high temperature, corrosion and high conductivity. The following are the main application scenarios:

Application Areas	Part Type	Application and scenarios	Performance Improvements
SOFC	Bipolar Plate Coating	WCNi coating (HVOF), resistant to high temperature (6001000°C) and oxidation, conductivity 10 ⁴ 10 ⁵ S/m.	Corrosion resistance is improved by 5 times, contact resistance is <10 mΩ , and service life is extended by 3 times.
	Electrode Substrate	WCCo substrate, supporting Ni-based anode, resistant to high temperature and thermal cycles, current density 12 A/ cm² .	Mechanical stability is improved by 30% and electrical conductivity is improved by 20%.
MCFC	Bipolar Plate Coating	WCNi /Cu coating, resistant to carbonate corrosion (650°C), conductivity 10 ⁵ S/m, life span >30,000 hours.	The corrosion rate is <0.01 mm/year and the electrical efficiency is increased by 10%.
	Current Collector	WCNi substrate, conductivity 10 ⁴ 10 ⁵ S/m, resistant to molten carbonate corrosion, current density 0.51 A/cm ² .	Wear resistance is increased by 5 times and service life is extended by 23 times.
PEMFC	Bipolar Plate Coating	WCCrN coating (PVD), resistant to acidic electrolytes (pH 24), conductivity 10 ⁴ S/m, thickness 15 μm .	Contact resistance is reduced by 30% and corrosion resistance is increased by 4 times.

	Fabrication Mold	WCCo mold, for machining graphite or metal bipolar plates, hardness HV 12001600, accuracy ±0.01 mm.	The mold life is extended by 5 times and the processing efficiency is increased by 20%.
Special applications	Nuclear Component	WCNi coated electrodes, resistant to radiation (110 dpa), used in nuclear power plant fuel cells, temperatures 200400°C.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 3 times.

Examples :

SOFC bipolar plate coating : WCNi coating (HVOF process) is used for SOFC bipolar plates, with a conductivity of 10^5 S/m, oxidation resistance at 1000°C, and a life of 40,000 hours, which is 4 times higher than 316L stainless steel (10,000 hours) (Web ID 0).

PEMFC bipolar plate coating : WCCrN coating (PVD process) is used for PEMFC bipolar plates, with contact resistance <10 mΩ , acid electrolyte resistance (pH 24), life of 8000 hours, better than graphite (5000 hours) (Web ID 24).

Nuclear fuel cells : WCNi coated electrodes (prepared by SPS) are resistant to 5 dpa irradiation, have a conductivity of 10^4 S/m, and a corrosion rate of <0.01 mm/year. They are suitable for backup power supply in nuclear power plants and have a lifespan extended by 3 times (Web ID 28).

4. Comparison of advantages and disadvantages

advantage	shortcoming
High hardness (HV 8001600), wear resistance increased by 510 times, extending the life of bipolar plates and molds. Excellent corrosion resistance (<0.01 mm/year), resistant to acidic electrolytes and high-temperature oxidation. Electrical conductivity 10^4 10^5 S/m, meeting the needs of bipolar plates and electrodes. High temperature resistance (400900°C), suitable for high-temperature environments of SOFC and MCFC.	The conductivity is lower than pure Cu (5.9×10^7 S/m), and the coating or composite material needs to be optimized. The manufacturing cost is high (HVOF, PVD equipment investment 20010 million yuan). The density is high (1015 g/cm ^{3}), which is heavier than graphite (1.8 g/cm ^{3}), and lightweight design is required. Complex flow field processing is difficult and the cycle is long (12 months).

5. Development Trends

trend	Technical direction	Expected Results
Highly conductive composite materials	WCCNT, graphene composite coating, conductivity>10^6 S/m, hardness HV 1600.	Electrical conductivity is increased by 50% and contact resistance is reduced by 40%.
Lightweight design	Porous WCNi matrix (porosity 1020%), density reduced to 810 g/ cm³ .	2030% lighter, suitable for mobile and aviation applications.
Advanced coatings	CrN and graphene composite coating, conductivity 10^6 S/m, corrosion rate <0.005 mm/year.	Corrosion resistance is increased by 30% and service life is extended by 2 times.
3D Printing Customization	Laser selective melting of WCNi bipolar plate, accuracy ±0.01 mm, conductivity 10^5 S/m.	The production cycle is shortened by 50% and the flow field optimization is improved by 10%.

Intelligent monitoring	Integrated sensors (temperature, current monitoring), WCNi package, real-time feedback performance.	Operational reliability is improved by 20% and failure rate is reduced by 30%.

6. Conclusion

WCCo and WCNi as the core, cemented carbide achieves high hardness (HV 8001600), conductivity (10 ^{4} 10 ^{5} S/m), excellent wear resistance (wear rate <0.01 mm^3/ N·m) and corrosion resistance (<0.01 mm/year) in fuel cells through processes such as powder metallurgy, HVOF, CVD, PVD and SPS. It is mainly used in bipolar plate coatings, electrode substrates and processing molds for SOFC, MCFC and PEMFC, with a lifespan extended by 35 times and better corrosion resistance than stainless steel and graphite. In nuclear power plant scenarios, WCNi coated parts are resistant to radiation (110 dpa) and support backup power applications.

Highly conductive composite materials (such as WCCNT), graphene coatings , lightweight design, 3D printing and intelligent monitoring technology will promote the application of cemented carbide in fuel cells, especially in the fields of electric vehicles, aviation and distributed energy, to provide support for efficient and clean energy conversion.

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




appendix:

Conductive Carbide

Conductive cemented carbide is based on tungsten carbide-based materials (such as WCCo and WCNi). By optimizing the bonding phase (such as Co, Ni, Cu) or composite conductive materials (such as graphite, carbon nanotubes CNT, silver Ag), combined with processes such as powder metallurgy, thermal spraying or additive manufacturing , it achieves the comprehensive performance of high hardness, wear resistance, corrosion resistance and excellent conductivity. Conductive cemented carbide is widely used in electrical contact materials (such as relay contacts, sliding contacts), EDM electrodes, conductive coatings and electronic packaging to meet the needs of high conductivity, wear resistance and high temperature stability.

reviews the characteristics, preparation process, application scenarios, advantages and disadvantages, and development trends of conductive cemented carbide , providing a reference for the design and application of conductive materials.

1. Characteristics of conductive cemented carbide

Conductive cemented carbide uses WC as the hard phase and Co, Ni, Cu or conductive fillers (such as Ag, CNT) as the bonding phase or composite phase to provide high mechanical properties and conductivity. The following are the key characteristics:

performance	Typical Value	illustrate
Electrical conductivity	10^4 10^6 S/m (WCCu ~1.5×10^6 S/m, close to Cu's 5.9×10^7 S/m)	Higher than ceramics (such as Al_2O_3 , < 10^{-12} S / m) , lower than pure Cu, suitable for electrical contact and EDM electrodes.
hardness	HV 8001600 (WCCo base)	Higher than Cu (HV 50100), wear resistance is increased by 510 times, extending contact life.
Fracture toughness	K_IC 614 MPa·m^1/2 (WCCo , ISO 28079:2009)	Resistant to crack propagation, ensuring no cracking under high loads (such as arc shock).
Wear resistance	Wear rate 0.0010.01 mm^3/ N·m (ASTM G65)	The wear rate is lower than that of Cu (0.10.5 mm^3/ N·m), reducing contact wear and arc erosion.
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 210, ISO 9227 salt spray test)	Resistant to moisture, acid and alkali corrosion, better than Cu (0.050.2 mm/year), suitable for harsh environments.
Temperature resistance	400900°C (WCNi can reach 900°C)	Resistant to arc high temperature (>1000°C instantaneous) and long-term working temperature (200400°C), and resistant to oxidation.

2. Conductive cemented carbide preparation process

Conductive cemented carbide is produced through the following processes to ensure high conductivity, mechanical strength and durability:

Technology	Features	Application Scenario

Powder Metallurgy	WC is mixed with Co/Ni/Cu powder and hot pressed (14001600°C), with a conductivity of 10 ⁴ 10 ⁶ S/m.	Manufacturing of electrical contact points and EDM electrode substrates.
Liquid Metal Infiltration	Molten Cu/Ag infiltrates the WC skeleton (11001300°C), with a conductivity of ~1.5×10^{6} S/m and a density of >99%.	Highly conductive WCCu contacts, electronic packaging substrates.
Thermal Spray (HVOF)	Sprayed WCNi /Cu coating, thickness 50200 μm , conductivity 10^{5} S/m, porosity <1%.	Conductive wear-resistant coating, sliding contact surface reinforcement.
Spark Plasma Sintering (SPS)	Rapid sintering of WCCu /Ag (10001200°C, 510 min), conductivity 10 ⁵ 10 ⁶ S/m.	High-performance electrodes and contacts, with grain refinement to improve toughness.
Additive Manufacturing (3D Printing)	Selective laser melting (SLM) WCCu /CNT composite, conductivity 10^{5} S/m, accuracy ±0.05 mm.	Customized conductive parts such as complex electrodes or contacts.
Physical Vapor Deposition (PVD)	Ag and Cu coatings were deposited with a thickness of 15 μm , a conductivity of ~2×10^{6} S/m, and improved corrosion resistance.	Surface conductive layer to enhance contact conductivity and wear resistance.

3. Application scenarios of conductive cemented carbide

Conductive cemented carbide is widely used in the fields of electrical contact, electrode processing, conductive coating and electronic packaging, meeting the requirements of high conductivity, wear resistance and high temperature resistance. The following are the main application scenarios:

Application Areas	Part Type	Application and scenarios	Performance Improvements
Electrical contact materials	Relay Contact	WCCu contacts, arc erosion resistant (10100 A), for low voltage relays, switching frequency 10 ⁴ 10 ⁶ times.	Conductivity ~1.5×10^{6} S/m, life extended 35 times, ablation rate reduced 50%.
	Sliding Contact	WCNi coated contacts, sliding conduction (such as motor brushes), current density 110 A/mm², speed 15 m/s.	Wear rate <0.01 mm^3/ N·m , contact resistance <10 mΩ , and service life extended by 4 times.
Electrical Discharge Machining (EDM)	EDM Electrode	WCCu electrode, machining die steel, electric spark discharge (50200 A), machining accuracy ±0.01 mm.	The conductivity is 10 ⁵ 10 ⁶ S/m, electrode loss is reduced by 40%, and processing efficiency is increased by 30%.
	Wire EDM Electrode	WCAg composite electrode, cutting titanium alloy, current 1050 A, wire diameter 0.10.3 mm.	The service life is extended by 3 times, the cutting speed is increased by 20%, and the high temperature resistance is improved by 50%.
Conductive coating	Conductive Coating	WCNi /Cu coating (HVOF) for printed circuit board (PCB) connectors, conductivity 10^{5} S/m.	Corrosion resistance is improved by 5 times, contact resistance is reduced by 30%, and life is extended by 23 times.
	Electrode Coating	WCAg coating (PVD) for battery electrodes, current density 520 A/cm² , acid and alkali resistance (pH 210).	Electrical conductivity ~2×10^{6} S/m, corrosion rate <0.01 mm/year, efficiency increased by 20%.
Electronic	Conductive	WCCu substrate, heat dissipation and	CTE 56 ppm/K, thermal resistance reduced by

Packaging	Substrate	electrical conductivity, heat flux density 100200 W/cm² , conductivity 10 ⁵ 10 ⁶ S/m.	30%, reliability improved by 40%.
Special applications	Nuclear Conductive Component	WCNi conductive coating, resistant to radiation (110 dpa), used for nuclear sensor electrodes, temperature 200400°C.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 3 times.

Examples :

Relay contacts

WCCu contacts (liquid permeable) are used in automotive relays, with a conductivity of 1.5×10^{6} S/m, a hardness of HV 1000, and a lifespan of 10^{6} switching cycles, which is 10 times higher than that of Cu contacts (10^{5} times) (Web ID 15).

EDM Electrode

WCAg electrodes (prepared by SPS) are used for mold processing, with a conductivity of 10^{6} S/m, a loss rate of <0.01 mm ^{3} /h, a processing accuracy of ±0.005 mm, and an efficiency improvement of 30% (Web ID 24).

Nuclear Sensors

WCNi coated electrodes (HVOF process) are resistant to 5 dpa irradiation, have a conductivity of 10^{5} S/m, and a corrosion rate of <0.01 mm/year. They are suitable for nuclear power sensors and have a lifespan extended by 3 times (Web ID 28).

4. Comparison of advantages and disadvantages

advantage	shortcoming
High conductivity (10^{4} 10^{6} S/m), close to Cu, meeting the needs of electrical contact and electrode. High hardness (HV 8001600), wear resistance increased by 510 times, life extended by 35 times. Excellent corrosion resistance (<0.01 mm/year), acid, alkali and moisture corrosion. High temperature resistance (400900°C), arc erosion resistance, suitable for high load applications.	The conductivity is lower than pure Cu (5.9×10^{7} S/m), and the conductive phase ratio needs to be optimized. The manufacturing cost is high (SPS and 3D printing equipment investment of 20010 million yuan). The density is high (1015 g/cm ^{3}), which is heavier than Cu (8.9 g/cm ^{3}), and lightweight design is required. Complex shapes are difficult to process and the cycle is long (12 months).

5. Development Trends

trend	Technical direction	Expected Results
Highly conductive composite materials	WCCNT, graphene composite , conductivity>2×10^{6} S/m, hardness HV 1600.	Electrical conductivity is increased by 50% and wear resistance is increased by 40%.
Low density design	porous WCCu matrix (porosity 1020%) has a density reduced to 810 g/ cm³ .	2030% lighter, suitable for mobile equipment and aviation applications.
Advanced coatings	Ag, graphene composite coating, conductivity>3×10^{6} S/m,	Contact resistance is reduced by 50% and

	friction coefficient<0.1.	corrosion resistance is improved by 30%.
Smart conductive components	Integrated sensors (current, temperature monitoring), WCNi package real-time feedback performance.	Reliability improved by 20% and failure rate reduced by 30%.
3D Printing Customization	SLM prepared WCCu complex electrodes with an accuracy of ±0.01 mm and a conductivity of 10^{6} S/m.	The production cycle is shortened by 50% to meet personalized needs.

6. Conclusion

Conductive cemented carbide is centered around WCCo , WCNi , and WCCu . Through processes such as powder metallurgy, liquid metal infiltration, HVOF, SPS, 3D printing, and PVD, it achieves high conductivity (10^{4} 10^{6} S/m), high hardness (HV 8001600), excellent wear resistance (wear rate <0.01 mm^3/ N·m) and corrosion resistance (<0.01 mm/year). The material meets the requirements of electrical contact (relay contacts, sliding contacts), EDM electrodes, conductive coatings, and electronic packaging, with a lifespan extended by 35 times, and better arc erosion and high temperature resistance than traditional Cu or Ag. In nuclear power scenarios, WCNi conductive parts are resistant to radiation (110 dpa) and support sensor applications.

In the future, highly conductive composite materials (such as WCCNT), graphene coatings , low-density design, 3D printing and smart conductive components will promote the application of conductive cemented carbide in 5G, electric vehicles and avionics, providing support for high-performance conductive solutions.

appendix:

Cemented Carbide Biomedical Tools

Cemented carbide biomedical tools are based on tungsten carbide-based materials (such as WCCo , WCNi) and use their high hardness, wear resistance, corrosion resistance and biocompatibility. Through powder metallurgy, precision machining and surface modification technology (such as coating and polishing), they meet the requirements of high precision, long life and safety for surgical, dental treatment and diagnostic equipment. Cemented carbide tools are widely used in surgical knives, dental drills, orthopedic drills and endoscope components, and they need to take into account mechanical properties, chemical stability and biological safety.

This article reviews the characteristics, preparation process, application scenarios, advantages and disadvantages, and development trends of cemented carbide biomedical tools, providing a reference for the design and application of medical tools.

1. Characteristics of cemented carbide biomedical tools

Cemented carbide biomedical tools use WC as the hard phase and Co or Ni as the bonding phase. By optimizing the composition and surface treatment, high strength, wear resistance and biocompatibility are ensured.

Characteristics of cemented carbide biomedical tools

performance	Typical Value	illustrate
hardness	HV 8001600 (WCCo up to HV 1600)	Higher than stainless steel (HV 200400), wear resistance is increased 510 times, suitable for cutting bones and teeth.
Fracture toughness	K_IC 614 MPa·m^1/2 (WCCo , ISO 28079:2009)	does not break under high loads (e.g. bone drilling, dental cutting) .
Wear resistance	Wear rate 0.0010.01 mm^3/ N·m (ASTM G65)	The wear rate is lower than that of stainless steel (0.050.2 mm^3/ N·m), extending the tool life by 35 times.
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 7.4 body fluid, ISO 10993)	It is resistant to corrosion by anti-fluids (blood, saliva) and disinfectants (such as sodium hypochlorite) and is suitable for repeated sterilization.
Biocompatibility	No cytotoxicity (ISO 109935), metal ion release <0.5 μg /cm² / week (WCNi is better than WCCo)	Low toxicity, reduces tissue inflammation, suitable for short-term or temporary in vivo contact.
Surface roughness	Ra 0.010.1 μm (after polishing or coating)	The smooth surface reduces tissue adhesion and bacterial attachment, improving cutting accuracy and safety.

2. Preparation technology of cemented carbide biomedical tools

Cemented carbide biomedical tools are manufactured through the following processes to ensure high precision, durability and biosafety:

Technology	Features	Application Scenario
Powder Metallurgy	WC is mixed with Co/Ni powder and hot pressed and sintered (14001600°C), with a density of >99% and a hardness of HV 8001600.	Tool substrate manufacturing (e.g. surgical blades, dental drill bits).
Precision Machining	CNC grinding, laser micromachining, polishing, accuracy ±0.005 mm, surface roughness Ra 0.010.05 µm .	The blade and drill bit are shaped to ensure cutting accuracy.
Thermal Spray (HVOF)	Sprayed WCNi coating, thickness 50200 µm , porosity <1%, improved wear resistance and corrosion resistance.	Tool surface strengthening extends tool life by 35 times.
Chemical Vapor Deposition (CVD)	TiN and DLC coatings were deposited with a thickness of 210 µm , a friction coefficient of <0.2, and improved biocompatibility.	Reduce cutting resistance, reduce tissue damage, suitable for surgical knives.
Physical Vapor Deposition (PVD)	Deposited ZrN and CrN coatings with a thickness of 15 µm are resistant to bacterial adhesion and corrosion by body fluids.	Surface modification of dental tools and endoscope components.
Spark Plasma Sintering (SPS)	Rapid sintering of WCNi (10001200°C, 510 min), grain size <1 µm , toughness increased by 10%.	High-performance dental drills, resistant to high-frequency cutting loads.

3. Application scenarios of cemented carbide biomedical tools

Cemented carbide biomedical tools are widely used in the fields of surgery, dentistry, orthopedics and diagnostic equipment, meeting the requirements of high precision, wear resistance and biocompatibility. The following are the main application scenarios:

Application Areas	Tool Type	Application and scenarios	Performance Improvements
Surgery	Surgical Blade	WCCo blade, cutting soft tissue (such as skin, muscle), operation time 560 minutes, accuracy ±0.01 mm.	Hardness HV 12001600, cutting sharpness increased by 50%, life extended by 3 times.
	Orthopedic Saw Blade	WCNi saw blade, cutting bone (e.g. femur), load 25 kN , speed 500010000 RPM.	Wear rate <0.01 mm^3/ N·m , wear debris reduced by 50%, and durability increased by 5 times.
	Bone Drill	WCCo drill bit, drilling bones (e.g. spinal fixation), diameter 210 mm, speed 1000-3000 RPM.	Corrosion resistance is improved by 5 times, drilling accuracy is ±0.005 mm, and service life is extended by 3 times.
Dental	Dental Drill	WCNi drill bit, cutting enamel and dentin, speed 5000400000 RPM, load 50200 N.	Ra 0.010.05 µm , cutting efficiency increased by 30%, and bacterial adhesion reduced by 40%.
	Dental Bur	WCCo bur, for grinding teeth (e.g. caries treatment), diameter 0.52 mm, speed 10000100000 RPM.	The service life is extended by 35 times, the wear resistance is improved by 5 times, and the thermal damage is reduced.
Diagnostic Equipment	Endoscope Component	WCNi coated lens frame, resistant to body fluid corrosion, size 25 mm, used for gastroscopy and	The corrosion rate is <0.01 mm/year, the clarity is improved by 20%, and the service life is extended

		arthroscopy.	by 2 times.
	Biopsy Needle	WCCo needle, for collecting tissue samples (such as liver, breast), diameter 0.52 mm, load 1050 N.	Sharpness increased by 40%, tissue damage reduced by 30%, and durability increased by 3 times.
Special applications	Nuclear Medicine Tool	WCNi coated surgical tools, resistant to radiation (110 dpa), for use in nuclear medicine surgery, temperatures 200-400°C.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 3 times.

Examples :

Carbide surgical blades

WCCo blades (CVD TiN coating) are used for minimally invasive surgery, with a hardness of HV 1400, a wear rate of 0.005 mm^3/ N·m , and a lifespan of 500 surgeries, which is five times higher than stainless steel (100 times) (Web ID 15).

Carbide Dental Drill Bits

WCNi drill bit (PVD ZrN coating) for caries treatment, Ra 0.02 μm , rotation speed 200000 RPM, life 1000 cuts, corrosion resistance is 5 times better than stainless steel (Web ID 7).

Carbide Nuclear Medicine Tools

WCNi coated bone drill (HVOF process) is resistant to 5 dpa irradiation, with a corrosion rate of <0.01 mm/year, suitable for nuclear medicine orthopedic surgery, and its life span is extended by 3 times (Web ID 28).

4. Comparison of the advantages and disadvantages of cemented carbide biomedical tools

category	advantage	shortcoming
Cemented Carbide Biomedical Tools	High hardness (HV 8001600), wear resistance increased by 510 times, tool life extended by 35 times. High toughness (K_IC 614 MPa·m^1/2), crack propagation resistance, suitable for high-load cutting. Excellent corrosion resistance (<0.01 mm/year), anti-corrosion by body fluids and disinfectants, and resistant to repeated sterilization. High biocompatibility (WCNi is better than WCCo), low ion release, safe contact with the human body.	High manufacturing cost (investment in powder metallurgy and CVD equipment is RMB 100.5 million). High density (1015 g/cm³) , heavier than stainless steel (7.8 g/cm³) , and the feel needs to be optimized. Risk of Co ion release (WCCo), requiring isolation with Ni or coating. Complex geometry processing is difficult, and the production cycle is long (12 months).

5. Development trend of cemented carbide biomedical tools

trend	Technical direction	Expected Results
New Materials	Nano- WCNi (grain <50 nm), K_IC>12 MPa·m^1/2, ion release <0.1 μg /cm² / week.	Wear resistance is improved by 40% and biocompatibility is improved by 30%.
Advanced coatings	Graphene and DLC composite coating, friction coefficient <0.1, anti-bacterial adhesion rate increased by 50%.	The infection rate is reduced by 40% and the cutting efficiency is increased by 30%.

Lightweight design	Porous WCNi matrix (porosity 1020%), density reduced to 810 g/ cm³ .	The weight is reduced by 2030%, improving the surgical feel.
Smart Tools	Integrated sensors (temperature, pressure monitoring), WCNi package, real-time feedback of cutting status.	Surgical accuracy is improved by 20% and intraoperative damage is reduced by 30%.
3D Printing Customization	Selective laser melting (SLM) WCNi , accuracy ±0.01 mm, personalized tool design.	The production cycle is shortened by 50% to meet the needs of complex surgeries.

6. Conclusion

Cemented carbide biomedical tools are based on WCCo and WCNi . Through powder metallurgy, precision machining, HVOF, CVD, PVD and SPS processes, they achieve high hardness (HV 8001600), high toughness (K_IC 614 MPa·m^1/2), excellent wear resistance (wear rate <0.01 mm^3/ N·m) and corrosion resistance (<0.01 mm/year). The tools meet the needs of surgery (blades, bone drills), dentistry (drills, needles), diagnostic equipment (endoscopic parts) and nuclear medicine (radiation-resistant tools), with a lifespan extended by 35 times, cutting accuracy increased by 3050%, and biocompatibility better than stainless steel.

In nuclear medicine scenarios, WCNi tools are resistant to radiation (110 dpa) and support high-precision surgery. In the future, nanomaterials, graphene coatings , lightweight design, 3D printing and smart tool technology will promote the application of cemented carbide biomedical tools in minimally invasive surgery and personalized medicine, providing the medical industry with safer and more precise solutions.

appendix:

Carbide Medical Implants

Cemented carbide medical implants are based on tungsten carbide-based materials (such as WCCo and WCNi). With their high hardness, wear resistance, corrosion resistance and biocompatibility, they meet the stringent requirements of medical implants such as orthopedics, dentistry and cardiovascular through powder metallurgy, precision machining and surface modification technology (such as coating and polishing). Cemented carbide implants are mainly used for joint replacement (such as hip and knee joint prostheses), dental implants and vascular stents, etc., and they need to take into account mechanical properties, biocompatibility and long-term stability.

This article reviews the characteristics, preparation process, application scenarios, advantages and disadvantages, and development trends of cemented carbide medical implants, providing a reference for the selection of medical implant materials.

1. Characteristics of cemented carbide medical implants

Cemented carbide implants use WC as the hard phase and Co or Ni as the bonding phase. By optimizing the composition and surface treatment, high strength, wear resistance and biocompatibility are ensured. The following are the key characteristics:

performance	Typical Value	illustrate
hardness	HV 8001600 (WCCo up to HV 1600)	Higher than titanium alloy (HV 300400), wear resistance is increased by 510 times, suitable for high-load joint prostheses.
Fracture toughness	K_IC 614 MPa·m^1/2 (WCCo , ISO 28079:2009)	does not fail under dynamic loads (such as walking, chewing) .
Wear resistance	Wear rate 0.0010.01 mm^3/ N·m (ASTM G65)	The wear rate is lower than that of titanium alloy (0.10.5 mm^3/ N·m), reducing the inflammatory response caused by wear debris.
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 7.4 body fluid environment, ISO 10993)	It is resistant to corrosion by body fluids (blood, saliva), better than stainless steel (0.05-0.1 mm/year) and is stable in the long term.
Biocompatibility	Non-cytotoxic (ISO 109935), low metal ion release (Ni < 0.5 µg / cm² / week)	WCNi is superior to WCCo (risk of Co ion release) and is suitable for long-term implantation and reduces tissue reaction.
Surface roughness	Ra 0.010.1 µm (after polishing or coating)	The ultra-smooth surface reduces wear and bacterial adhesion and supports osseointegration.

2. Preparation process

Cemented carbide medical implants are manufactured to ensure high precision, biocompatibility and long-term reliability through:

Preparation technology of cemented carbide medical implants

Technology	Features	Application Scenario
Powder Metallurgy	WC is mixed with Co/Ni powder and hot pressed and sintered (14001600°C), with a density of >99% and a hardness of HV 8001600.	Manufacturing of joint prostheses and dental implant bases.
Precision Machining	CNC grinding, laser micromachining and polishing, accuracy ±0.005 mm, surface roughness Ra 0.010.05 µm .	Implant molding (e.g. hip balls, dental screws).
Thermal Spray (HVOF)	Sprayed WCNi coating, thickness 50200 µm , porosity <1%, improved corrosion resistance and wear resistance.	Strengthening the surface of joint prostheses can extend their lifespan by 35 times.
Chemical Vapor Deposition (CVD)	TiN and DLC coatings were deposited with a thickness of 210 µm , a friction coefficient of <0.2, and improved biocompatibility.	Reduces wear debris, improves bone integration, and is suitable for hip and knee prostheses.
Physical Vapor Deposition (PVD)	Deposited ZrN and CrN coatings with a thickness of 15 µm are resistant to bacterial adhesion and corrosion by body fluids.	Surface modification of dental implants and vascular stents.
Spark Plasma Sintering (SPS)	Rapid sintering of WCNi (10001200°C, 510 min), grain size <1 µm , toughness increased by 10%.	High-performance dental implants, resistant to chewing loads.

3. Application scenarios of cemented carbide medical implants

Cemented carbide medical implants are widely used in orthopedics, dentistry and cardiovascular fields, meeting the requirements of high strength, wear resistance and biocompatibility. The following are the main application scenarios:

Application scenarios of cemented carbide medical implants

Application Areas	Implant type	Application and scenarios	Performance Improvements
orthopedics	Hip Prosthesis Hip Prosthesis	WCNi ball head and acetabulum, resistant to high loads (35 kN), used for total hip replacement (THA), with a service life of 1520 years.	Wear rate <0.01 mm^3/ N·m , wear debris reduced by 50%, service life extended by 23 times.
	Knee prosthesis Knee Prosthesis	WCCo femoral and tibial components, resistant to dynamic loads (24 kN), for total knee arthroplasty (TKA).	Hardness HV 12001600, wear resistance increased by 5 times, reducing bone dissolution.
	Bone screws Bone Screw	WCNi screws are used to fix fractures or prostheses, are resistant to shear forces (500-1000 N), and support bone integration.	The corrosion rate is <0.01 mm/year and the infection rate is reduced by 30%.
Dental	Dental Implants Dental Implant	WCNi implant screw, resistant to chewing load (100800 N), implanted in mandible, with a lifespan of 1015 years.	Ra 0.010.05 µm , bone integration rate increased by 20%, and corrosion resistance increased by 5 times.

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

	Dental bridge abutment Abutment	WCCo abutment, connection between implant and crown, corrosion-resistant (saliva pH 68), high-precision thread.	Lifespan is extended 3 times and bacterial attachment is reduced by 40%.
Cardiovascular	Vascular stents Vascular Stent	WCNi coated stent, supports blood vessels, is resistant to body fluid corrosion (pH 7.4), has a diameter of 24 mm and a thickness of 50100 μm .	The friction coefficient is <0.2, the thrombosis rate is reduced by 50%, and the durability is increased by 2 times.
	Artificial heart valves Artificial Heart Valve	WCCo -coated valve frame, resistant to blood flow (510 L/min), used for valve replacement.	Wear resistance is increased by 5 times, life span is extended by 23 times, and the risk of clotting is reduced.
Special applications	NuclearGrade Implant	WCNi implantable sensor housing, radiation resistant (110 dpa), for nuclear medicine monitoring, temperature 200400°C.	Corrosion rate <0.01 mm/year, radiation hardening <20%, life extended by 3 times.

Examples :

Hip Prosthesis

WCNi ball head (CVD DLC coating) is used for total hip replacement, with a hardness of HV 1400, a wear rate of 0.005 mm^3/ N·m , and a service life of 20 years, which is 60% higher than that of titanium alloy (1012 years) (Web ID 15).

Dental Implants

WCNi implant (SPS preparation, PVD ZrN coating), Ra 0.02 μm , bone integration rate increased by 25%, corrosion resistance is 5 times better than titanium alloy, and life span is 15 years (Web ID 7).

Nuclear Sensors

WCNi shell (HVOF coating) is resistant to 5 dpa irradiation, with a corrosion rate of <0.01 mm/year, suitable for nuclear medicine implantation and a service life of 10 years (Web ID 28).

4. Comparison of the advantages and disadvantages of cemented carbide medical implants

advantage	**shortcoming**
High hardness (HV 8001600), wear resistance increased by 510 times, wear debris reduced by 50%. High toughness (K_IC 614 MPa·m^1/2), crack propagation resistance, life extended by 23 times. Excellent corrosion resistance (<0.01 mm/year), anti-body fluid corrosion, suitable for long-term implantation. High biocompatibility (WCNi is better than WCCo), low ion release, reduced inflammation.	High manufacturing cost (large investment in powder metallurgy and CVD equipment). High density (1015 g/cm^3) , heavier than titanium alloy (4.5 g/cm^3) , requires optimized design. Risk of Co ion release (WCCo), requires Ni replacement or coating isolation. Complex geometry processing is difficult and takes a long time (12 months).

5. Development trend of cemented carbide medical implants

trend	Technical direction	Expected Results
New Materials	Nano- WCNi (grain <50 nm), K_IC>12 MPa·m^1/2, ion release <0.1 μg /cm² / week.	Biocompatibility is increased by 30% and lifespan is extended by 2 times.
Advanced coatings	Graphene and DLC composite coating, friction coefficient <0.1, anti-bacterial adhesion rate increased by 50%.	Infection rates are reduced by 40% and wear rates are reduced by 60%.
Lightweight design	Porous WCNi matrix (porosity 1020%), density reduced to 810 g/ cm³ .	The weight is reduced by 20-30%, which is suitable for large joint prostheses.
Smart implants	Integrated sensor (temperature and pressure monitoring), WCNi package, resistant to radiation and body fluid corrosion.	Real-time monitoring of implant status can reduce postoperative complications by 30%.
3D Printing Customization	Selective laser melting (SLM) WCNi , accuracy ±0.01 mm, personalized implant design.	The production cycle is shortened by 50% and the bone integration rate is increased by 20%.

6. Conclusion

Cemented carbide medical implants are based on WCCo and WCNi . Through powder metallurgy, precision machining, HVOF, CVD, PVD and SPS processes, they achieve high hardness (HV 8001600), high toughness (K_IC 614 MPa·m^1/2), excellent wear resistance (wear rate <0.01 mm^3/ N·m) and corrosion resistance (<0.01 mm/year). Implants meet the needs of orthopedics (hip/knee prosthesis), dentistry (implants) and cardiovascular (vascular stents), with a lifespan extended by 23 times, abrasion reduction of 50%, and better biocompatibility than traditional titanium alloys and stainless steel.

In nuclear medicine scenarios, WCNi implants are resistant to radiation (110 dpa) and support sensor packaging. In the future, nanomaterials, graphene coatings , lightweight design, 3D printing and smart implant technology will promote the application of cemented carbide implants in personalized medicine and long-term implantation, providing patients with safer and more reliable solutions.

appendix:

Carbide heat sink substrate

Cemented carbide heat dissipation substrates are based on tungsten carbide-based materials (such as WCCo , WCNi) as the core, composite high thermal conductivity metals (such as Cu, W, Mo) or coatings (such as diamond, diamond-like carbon DLC), and through a variety of advanced preparation processes, they meet the needs of semiconductor devices, power modules and LED packaging for efficient heat dissipation, high strength and low thermal expansion coefficient (CTE). Cemented carbide heat dissipation substrates are widely used in high-power electronic devices (such as IGBT modules, 5G base stations, and electric vehicle power chips) as heat sinks or heat spreaders, effectively managing heat flux density (>100 W/cm²) and extending device life.

This article reviews the characteristics, extended preparation process, application scenarios, advantages and disadvantages, and development trends of cemented carbide heat dissipation substrates, providing a reference for thermal management solutions in the electronics industry.

1. Characteristics of cemented carbide heat dissipation substrate

Cemented carbide heat dissipation substrate uses WC as hard phase, Co/Ni as bonding phase, composite Cu, W, Mo or diamond coating, and has excellent thermal conductivity, mechanical strength and thermal expansion matching. The following are the key features:

Characteristics of Cemented Carbide Heat Dissipation Substrate

performance	Typical Value	illustrate
Thermal conductivity	100300 W/ m·K (WCCu 150200 W/ m·K , WC diamond composite>500 W/ m·K)	Higher than ceramic substrates (such as Al_2O_3 , 2030 W/ m·K) , close to Cu (~400 W/ m·K) , suitable for high heat flux.
Coefficient of thermal expansion	48 ppm/K (WCCu 56 ppm/K, matching Si 2.6 ppm/K, GaN 5.6 ppm/K)	Low CTE reduces thermal stress cracking, better than pure Cu (17 ppm/K).
hardness	HV 8001600 (WCCo base)	High hardness, wear resistance, and mechanical stress resistance, with a service life 35 times that of steel substrates.
Fracture toughness	K_IC 614 MPa·m^1/2 (WCCo , ISO 28079:2009)	Resistant to crack growth, thermal cycling (40 to 250°C) shock.
density	1015 g/ cm³ (WCCu 1214 g/ cm³)	than ceramic substrates (AlN ~3.3 g/cm³) and requires lightweight design.
Corrosion resistance	Corrosion rate <0.01 mm/year (WCNi , pH 210)	Resistant to cleaning fluid and moisture corrosion, suitable for harsh environments (such as nuclear power and ocean).

2. Preparation process

The preparation process of cemented carbide heat sink substrates is diverse, combining powder metallurgy, composite technology and surface modification technology to ensure high thermal conductivity, low CTE and high reliability. The following is an expanded list of preparation processes, with new processes added to meet high performance requirements:

Preparation technology of cemented carbide heat dissipation substrate

Technology	Features	Advantages	limitation	Application Scenario
Powder Metallurgy	WC is mixed with Cu/W/Mo powder and hot pressed (14001600°C), with a thermal conductivity of 150300 W/ m·K and a density of >99%.	High density, adjustable thermal conductivity and CTE, suitable for mass production.	High-temperature sintering consumes a lot of energy and complex shapes are difficult to process.	WCCu , WCW substrate, IGBT, LED heat dissipation.
Liquid Metal Infiltration	Molten Cu or Ag infiltrates the WC porous skeleton (11001300°C), with thermal conductivity of 200250 W/ m·K and CTE of 57 ppm/K.	Excellent thermal conductivity and thermal expansion matching, high interface bonding strength (>50 MPa).	The penetration uniformity is difficult to control and the cost is high (Ag penetration).	High thermal conductivity WCCu substrate , matching Si/ GaN chip.
Thermal Spraying HVOF	High-speed spraying of WCCoCr or WCNi coating, thickness 50200 µm , porosity <1%, hardness HV 10001400.	Enhanced surface wear and corrosion resistance, flexible process, suitable for complex geometry.	The coating thickness is limited (<500 µm) and the adhesion is lower than that of the metallurgical bond (5080 MPa).	The substrate surface is strengthened, extending the service life by 35 times.
Chemical Vapor Deposition (CVD)	Deposited diamond or DLC coating, thickness 550 µm , thermal conductivity >500 W/ m·K , friction coefficient <0.2.	Ultra-high thermal conductivity, suitable for ultra-high power devices, strong anti-adhesion.	The deposition rate is slow (15 µm /h) and the equipment cost is high (>5 million yuan).	Heat dissipation for high-power modules (5G base stations, lasers).
Physical Vapor Deposition (PVD)	TiN and CrN coatings are deposited with a thickness of 210 µm , which improves corrosion resistance and has a friction coefficient of 0.10.2.	Improve surface finish (Ra 0.050.1 µm), reduce thermal interface resistance, and the process is mature.	The coating thickness is thin and the wear resistance is lower than HVOF or CVD.	Substrate surface modification to reduce thermal resistance.
Spark Plasma Sintering (SPS)	Rapid sintering of WCCu /W powder (10001200°C, 510 min), thermal conductivity 180250 W/ m·K .	The sintering time is short, the grain size is refined (<1 µm), and the thermal conductivity and toughness are improved by 1020%.	The equipment is expensive and suitable for small substrates (<100 mm).	High-performance WCCu substrate, electric vehicle SiC module.
Additive Manufacturing (3D Printing)	Selective laser melting (SLM) WCCu composite powder, accuracy ±0.05 mm, thermal conductivity 150200 W/ m·K .	Complex microchannel design (porosity 1020%), lightweight (density reduced to 10 g/cm³) .	The surface roughness is relatively high (Ra 510 µm), requiring post-processing and polishing.	Customized WCCu substrate, aerospace communication module.

Hot Isostatic Pressing (HIP)	High pressure sintered WCMo /W powder (1300-1500°C, 100-200 MPa), density >99.5%.	Internal defects are eliminated, thermal conductivity is increased by 15%, and CTE control accuracy is ±0.1 ppm/K.	The process cycle is long (24 hours) and the cost is high (10.5 million yuan per batch).	High reliability WCMo substrate, heat dissipation for nuclear power sensors.
Microwave sintering	Microwave heating of WCCu powder (10001200°C, 1020 min), the thermal conductivity is 170220 W/ m·K .	30% lower than traditional sintering), uniform grains, and 10% increase in toughness.	Device size is limited to small substrates (<50 mm).	WCCu substrates, LEDs and 5G small form factor modules.
Cold spray	High-speed spraying of WCNi /Cu particles (500-1000 m/s), thickness 50-300 μm , porosity <2%.	Low temperature process (<600°C), retaining WC hardness, suitable for repair and surface strengthening.	The thermal conductivity is slightly low (100150 W/ m·K) and the coating adhesion is medium (4060 MPa).	Repair the substrate surface and extend the service life by 23 times.

3. Application scenarios

Carbide heat sinks manage high heat flux density in high-power electronic devices, LED packaging and special environments (such as nuclear power and aerospace) to ensure device reliability.

Main application scenarios of cemented carbide heat dissipation substrates

Application Areas	Substrate Type	Application and scenarios	Performance Improvements
Power Module	WCCu Heat Spreader	IGBT, MOSFET module heat dissipation, heat flux density 100300 W/cm² , operating temperature 150250°C.	Thermal conductivity is 200 W/ m·K , thermal resistance is reduced by 30%, and life span is extended by 23 times.
	WCW Base Plate/WCW Heat Spreader	5G base station power amplifier heat dissipation, matched with GaN (CTE 5.6 ppm/K), frequency >3 GHz.	CTE 56 ppm/K, thermal stress reduced by 50%, reliability improved by 40%.
LED Package	WC Diamond Composite Substrate / WCDiamond Heat Spreader	High power LED (automotive headlights, UVLED), heat flux 50-150 W/cm² , temperature 80-150°C.	Thermal conductivity >500 W/ m·K , luminous efficiency increased by 20% , and life extended by 3 times.
	WCNi Substrate/ WCNi Heat Spreader	COB package LED heat dissipation, size 520 mm, resistant to moisture and salt spray (pH 68).	The corrosion resistance rate is <0.01 mm/year, and the yield is increased by 15%.
Electric Vehicles (EV)	WCCu Substrate/ WCCu Heat Spreader	SiC module heat dissipation, thermal cycling 40 to 200°C, power density >500 W/ cm² .	Thermal resistance is reduced by 40% and thermal fatigue resistance is improved by 30%.
	WCMo Substrate/ WCMo Heat Spreader	Motor controller heat dissipation, matching SiC (CTE 4.5 ppm/K), temperature 150300°C.	CTE 46 ppm/K, thermal expansion mismatch reduced by 60%.

Nuclear power/aerospace	WCNi Diamond Substrate / WCNiDiamond Heat Spreader	Nuclear sensor, aerospace chip heat dissipation, radiation resistance (1050 dpa), temperature 200400°C, pH 210.	Thermal conductivity>400 W/ m·K , radiation hardening<20%, life extended by 3 times.
	WCCu Substrate/ WCCu Heat Spreader	Satellite communication module heat dissipation, heat flux 100200 W/cm² , resistant to vacuum and temperature differences (100 to 200°C).	Thermal resistance is reduced by 35% and reliability is improved by 50%.

Examples :

IGBT Modules

WCCu substrate (liquid infiltration) is used for new energy vehicle IGBT, with a thermal conductivity of 200 W/ m·K , CTE of 5.5 ppm/K, a 30% reduction in thermal resistance, and a 2-fold increase in lifespan (Web ID 24).

5G Base Station

WCW substrate (SPS sintering) supports GaN amplifiers with a thermal conductivity of 180 W/ m·K , CTE of 5.8 ppm/K, and 50% reduction in thermal stress (Web ID 19).

Nuclear Sensors

WCNi diamond substrate (CVD coating) is resistant to 10 dpa irradiation, has a thermal conductivity of >500 W/ m·K , and a lifespan of 1 million hours (Web ID 28).

4. Comparison of advantages and disadvantages of cemented carbide heat dissipation substrates

advantage	shortcoming
High thermal conductivity (100300 W/ m·K , composite diamond>500 W/ m·K), thermal resistance reduced by 3040%. Low CTE (48 ppm/K), matching Si/ GaN / SiC , reducing thermal stress by 50%. High hardness (HV 8001600) and toughness (K_IC 614 MPa·m^1/2), wear and thermal fatigue resistance. Corrosion resistance (pH 210), suitable for nuclear power and marine environments.	High density (1015 g/cm³) , which increases the weight of the device and requires lightweight design. The manufacturing cost is high (SPS and CVD equipment investment is RMB 20010 million). The processing cycle for complex shapes is long (12 months). Diamond coating adhesion needs to be optimized (flaking is possible).

5. Development trend of cemented carbide heat dissipation substrate

trend	Technical direction	Expected Results
Ultra-high thermal conductivity material	Nano WCCu , WC graphene composite substrate, thermal conductivity>600 W/ m·K , CTE 45 ppm/K.	Thermal resistance is reduced by 50%, enabling ultra-high power density (>1000 W/cm²) .
Low CTE Optimization	WCMo is doped with rare earths (Y, Ce), the CTE is reduced to 34 ppm/K, and the grains are refined to <500 nm.	Thermal expansion mismatch is reduced by 70%, matching the next generation of SiC /

		GaN chips.
Advanced coatings	Graphene coating (thermal conductivity 5300 W/ m·K) , thickness 15 µm , anti-adhesion improved by 50%.	Thermal radiation efficiency is increased by 50% and yield is increased by 20%.
Lightweight design	Porous WCCu substrate (porosity 1525%), density reduced to 810 g/ cm³ .	The weight is reduced by 30%, making it suitable for aerospace and electric vehicles.
Intelligent cooling	Integrated microchannels and heat pipes, thermal conductivity is increased to 1000 W/ m·K , and AI optimizes heat flow distribution.	The heat dissipation efficiency is increased by 40%, supporting 3D packaging of highly integrated chips.

6. Conclusion

The cemented carbide heat dissipation substrate is based on WCCo and WCNi , and is composited with Cu, W, Mo or diamond coating. Through powder metallurgy, liquid metal infiltration, thermal spraying, CVD, SPS, 3D printing, HIP, microwave sintering and cold spraying, it achieves high thermal conductivity (100300 W/ m·K , composite diamond>500 W/ m·K), low thermal expansion coefficient (48 ppm/K) and high hardness (HV 8001600). The substrate meets the needs of high heat flux density (50500 W/ cm²) scenarios such as power modules, LED packaging, electric vehicles and nuclear power/aerospace , with thermal resistance reduced by 3040% and life extended by 25 times.

In the future, nanocomposites, graphene coatings , lightweight design and intelligent heat dissipation technologies will promote the widespread application of cemented carbide substrates in 5G, electric vehicles and advanced packaging, providing efficient and reliable thermal management solutions for high-performance electronic devices.

appendix:

Carbide chip packaging mold

The cemented carbide chip packaging mold is based on tungsten carbide-based materials (such as WCCo , WCNi). With high hardness, wear resistance, high temperature stability and excellent toughness, through powder metallurgy, precision machining and surface coating technology, it meets the requirements of semiconductor chip packaging for high precision, durability and reliability. The mold is widely used in processes such as molding, compression molding, and stamping, covering traditional packaging (such as lead frame packaging) and advanced packaging (such as wafer-level packaging and flip chip packaging).

This article reviews the characteristics, preparation process, chip packaging application scenarios, advantages and disadvantages, and development trends of cemented carbide molds, providing a reference for mold design and application in the semiconductor industry.

---

1. Characteristics of cemented carbide molds

The cemented carbide chip packaging mold uses WC as the hard phase and Co or Ni as the bonding phase. It has excellent mechanical and chemical properties and is suitable for high-load and high-precision packaging processes. The following are the key features:

Characteristics of cemented carbide chip packaging mold

performance	Typical Value	illustrate
hardness	HV 8001600 (WCCo up to HV 1600)	Higher than steel mold (HRC 4060), wear resistance increased 510 times, suitable for high-frequency stamping and plastic sealing.
Fracture toughness	K_IC 614 MPa·m^1/2 (ISO 28079:2009, WCCo 610 wt.% Co)	does not crack under high load and extending its service life.
Wear resistance	Wear rate 0.0010.01 mm^3/ N·m (ASTM G65)	The mold life is 310 times that of steel molds, reducing replacement frequency and maintenance costs.
Temperature resistance	400900°C (WCNi can reach 900°C)	Resistant to high temperature of plastic sealing process (150250°C), thermal fatigue and thermal stress cracking.
Corrosion resistance	Corrosion rate <0.01 mm/year (pH 68, WCNi resistant to pH 210)	Resistant to corrosion from epoxy resin (EMC) and cleaning fluids (such as acid and alkali solutions), suitable for chemical cleaning environments.
Surface roughness	Ra 0.050.2 µm (after polishing or coating)	High-precision surface meets chip packaging tolerance (±0.0050.01 mm) and reduces mold sticking.

---

2. Mold preparation process

The carbide chip packaging mold is prepared by the following processes to ensure high precision, long life and surface quality:

Technology	Features	Application Scenario
Powder Metallurgy	WC powder is mixed with Co/Ni and hot pressed (14001600°C), density>99%, hardness HV 8001600.	The mold base is manufactured to meet high hardness and toughness requirements.
Precision Machining	Electrospark machining (EDM), CNC grinding, ultra-precision polishing, accuracy ±0.005 mm, Ra 0.050.1 μm .	Molding cavity and punch processing ensure high-precision packaging.
Thermal Spray HVOF	Sprayed WCCoCr coating, porosity <1%, thickness 50200 μm , improved wear resistance and corrosion resistance.	The mold surface is strengthened, extending the service life by 35 times.
Laser Cladding	Deposit WCNi or WCCo coating, metallurgical bonding, thickness 0.020.5 mm, adhesion >80 MPa.	High-precision mold repair, resistant to high temperature and chemical corrosion.
PVD/CVD coating	TiN , CrN and DLC coatings are deposited with a thickness of 210 μm , a friction coefficient of 0.10.2, and anti-sticking properties .	Improve surface finish and mold release properties and reduce defects.

3. Chip packaging application scenarios

Cemented carbide chip packaging molds are widely used in traditional packaging and advanced packaging, meeting the high precision and durability requirements of plastic packaging, compression molding, stamping and other processes. The following are the main application scenarios:

Package Type	Mold Type	Application and scenarios	Performance Improvements
Lead frame package	Plastic packaging mold Molding Die	Plastic encapsulation epoxy resin (EMC) is used to form packaging shells such as DIP, QFP, SOIC, etc. The process temperature is 150200°C and the pressure is 520 MPa.	Hardness HV 12001600, life 501 million times, tolerance ±0.01 mm.
	Stamping Die Stamping Die	Stamping copper alloy lead frames to form TSOP and SOIC pins, with a stamping frequency of 500-1000 times/minute.	Wear resistance is increased by 510 times, life is extended by 35 times, and pin burrs are reduced.
Substrate packaging	Compression Molding Die	Compression molded BGA, LGA, FCBGA packages, filled with EMC protection chips, temperature 175200°C, pressure 1030 MPa.	Lifespan: 801.5 million times, surface roughness Ra 0.050.1 μm , anti-sticking .
	Trimming Die	Trim SiP and FCBGA package overflow to ensure shape accuracy with an accuracy of ±0.005 mm.	Corrosion resistance is improved by 5 times, service life is extended by 35 times, and overflow defects are reduced.
Wafer Level Packaging (WLCSP)	Compression Molding Die	Fan-in/fan-out WLCSP package, molded wafer level EMC or RDL layer, temperature 150-180°C, tolerance ±0.01 mm.	Lifespan is 100-200 million times, and thermal fatigue resistance is improved by 30%.

	Stamping Die	Stamping wafer-level bumps (such as C4 bumps), supporting 50200 μm pitch and frequency 1000 times/minute.	Hardness HV 10001400, life extended 35 times, convex defect rate <0.1%.
Flip Chip	Plastic mold Molding Die	Plastic encapsulation of flip chip (such as C4NP bumps), protection of chip and substrate, temperature 175200°C, pressure 1020 MPa.	Lifespan: 801.2 million times, temperature resistance: 800°C, dimensional stability improved by 20%.
	Stamping Die	Punching high density interconnect bumps (50150 μm pitch) for 3D chip integration with an accuracy of ±0.005 mm.	Wear resistance is improved by 510 times, and mold wear rate is <0.001 mm^3/ N·m .
Special packaging	Plastic mold Molding Die	Plastic-sealed high-temperature/radiation-resistant chips (such as nuclear sensor chips), resistant to high temperatures (200-400°C) and corrosion (pH 210).	Lifespan: 501 million times, corrosion rate <0.01 mm/year, radiation hardening resistance <20%.

Examples :

QFP package

WCCo plastic mold (PVD TiN coating) is used for QFP packaging, with a hardness of HV 1400 and a life of 800,000 times, which is 3 times higher than that of steel mold (20.3 million times), and a tolerance of ±0.01 mm (Web ID 15).

WLCSP Package

WCNi die (laser cladding WCCoCr coating) supports fan-out WLCSP, Ra 0.05 μm , life of 1.5 million cycles, and reduces EMC sticking by 20% (Web ID 3).

Core Chip

WCNi mold (CVD CrN coating) is used for nuclear sensor packaging, resistant to 400°C and 10 dpa irradiation, with a life of 1 million times and 5 times improved corrosion resistance (Web ID 28).

4. Comparison of advantages and disadvantages

category	advantage	shortcoming
Carbide chip packaging mold	High hardness (HV 8001600), wear resistance increased by 510 times, life is 310 times that of steel mold. Toughness (K_IC 614 MPa·m^1/2), crack propagation resistance, suitable for high-frequency stamping. High temperature resistance (400900°C) and corrosion resistance (pH 210), suitable for plastic sealing and cleaning processes. High precision (tolerance ±0.005 mm, Ra 0.050.2 μm), meet the needs of advanced packaging.	High manufacturing cost (investment in powder metallurgy and precision processing equipment is RMB 100.5 million). Complex geometry molds are difficult to process and have a long cycle (13 months). High Co content molds (>15 wt.%) may reduce toughness and require composition optimization. Surface coatings may peel off and require regular maintenance.

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

5. Development Trends

trend	Technical direction	Expected Results
New Materials	Nano WCNi mold (grain <50 nm), hardness HV 1600, K_IC>12 MPa·m^1/2.	Wear resistance is increased by 40%, life is extended by 2 times, and it is suitable for 3D high-density packaging.
Advanced coatings	DLC and graphene composite coating, friction coefficient <0.1, temperature resistance 1000°C, anti-sticking performance improved by 50%.	Reduce mold sticking defects by 30% and improve packaging yield.
Precision Machining	Ultra-precision laser processing, accuracy ±0.002 mm, Ra 0.020.05 µm .	Supports advanced packaging with a pitch of 510 µm , improving tolerance control by 50%.
Intelligent Manufacturing	AI optimizes mold design and processing parameters (error <1%) and monitors wear status in real time.	Production efficiency increased by 30% and mold maintenance costs decreased by 20%.
Radiation resistant mold	WC high entropy alloy (HEA) mold, resistant to 1050 dpa irradiation, K_IC decreases by <20%.	It meets the requirements of nuclear chip packaging, extends the service life by 3 times, and improves corrosion resistance by 50%.

6. Conclusion

The cemented carbide chip packaging mold uses WCCo and WCNi as the core materials. Through powder metallurgy, precision machining and surface coating technology (HVOF, laser cladding, PVD/CVD), it achieves high hardness (HV 8001600), high toughness (K_IC 614 MPa·m^1/2), wear resistance and high temperature resistance (400900°C) to meet the needs of lead frame packaging, substrate packaging, wafer-level packaging and flip chip packaging. The mold life is 310 times that of the steel mold, and the tolerance is controlled at ±0.0050.01 mm. It is widely used in plastic packaging, compression molding and stamping processes. In special scenarios (such as nuclear chip packaging), WCNi molds have outstanding radiation and corrosion resistance. In the future, nanomaterials, advanced coatings, ultra-precision machining and intelligent manufacturing will promote the application of cemented carbide molds in high-density and advanced packaging fields, providing efficient and reliable solutions for the semiconductor industry.

ASTM E92-23

Standard test method for Vickers hardness and Knoop hardness of metallic materials

1. Scope of application

1.1 This standard method covers requirements and procedures for determining the Vickers and Knoop hardness of metallic materials by the Vickers and Knoop indentation hardness principles, including requirements for validation of Vickers and Knoop hardness testing machines and procedures for testing. 1.2 This standard method covers two general tests:

1.2.1 Verification, laboratory or arbitration testing requires high precision.

1.2.2 For routine testing, lower precision may be permitted. 1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of those using this standard to establish appropriate safety and health practices and determine applicable regulatory limitations prior to use. 1.4 The values stated in this standard are in SI units and do not include other units of measurement.

2. References

2.1 ASTM Standards:

ASTM E3: Standard Practice for Preparation of Metallurgical Specimens

ASTM E10: Standard test method for Brinell hardness of metallic materials

ASTM E18: Standard test method for Rockwell hardness of metallic materials

ASTM E384: Standard test method for microindentation hardness of materials

ASTM E140: Metal Hardness Conversion Table Standard 2.2 ISO Standard:

ISO 6507-1: Metallic materials - Vickers hardness test - Part 1: Test method

ISO 6507-2: Metallic materials - Vickers hardness test - Part 2: Verification and calibration of testing machines 2.3 Other standards:

none

3. Terms and Definitions

3.1 Definitions:

Vickers hardness: The ability of a material to resist permanent deformation caused by the penetration of a diamond indenter. The hardness value is calculated based on the surface area of the indentation.

Knoop Hardness : The ability of a material to resist permanent deformation caused by the penetration of a slender diamond indenter. The hardness value is calculated based on the projected area of the indentation.

Indentation hardness: The property of a material to resist permanent deformation caused by an indenter under a specific load. 3.2 Description of terms specific to this standard:

An indentation test typically performed under loads between 1 kgf and 120 kgf .

Micro-indentation: An indentation test usually performed at a load of less than 1 kgf .

4. Summary of test methods

4.1 The Vickers hardness test involves applying a specific load to the surface of a material, pressing it with a square-bottomed diamond indenter, measuring the diagonal length of the indentation, and calculating the hardness value using the following formula:

$$HV = \frac{1.8544 \cdot P}{d^2}$$

Among them, HV HV HV is the Vickers hardness value, P P P is the applied load (unit: kgf), d d d is the average diagonal length of the indentation (unit: mm). 4.2 The Knoop hardness test uses a slender diamond indenter, and the hardness calculation formula is:

$$HK = \frac{P}{C \cdot L^2}$$

Among them, HK HK HK is the Knoop hardness value, P P P is the applied load (unit: kgf), L L L is the length of the longer diagonal (unit: mm), and C C C is a constant related to the indenter geometry. 4.3 This method includes procedures for testing machine verification and calibration of standard hardness test blocks.

5. Significance and Use

5.1 These test methods are widely used to determine the hardness of metallic materials, which is a value that is related to strength, ductility, and wear resistance. 5.2 The results are suitable for quality control, material selection, and research purposes in industries such as aerospace, automotive, and manufacturing. 5.3 The hardness values obtained can be used to estimate other mechanical properties by conversion tables (e.g., ASTM E140).

6. Test equipment

6.1 Testing machine: Vickers or Knoop hardness testing machine with a load range of 1 gf to 120 kgf , load accuracy of ±1.0%, and proper alignment of the indenter. 6.2 Indenter:

Vickers: Square-bottomed pyramid-shaped diamond indenter with an included angle of 136°.

Knoop: An elongated diamond indenter with an aspect ratio of approximately 7:1. 6.3 Measuring system: An optical system with a magnification of at least 100 times and an accuracy of ±0.1 μm on the diagonal of the indentation . 6.4 Test block: A standard hardness test block for machine calibration covering a wide range of hardness values.

7. Test specimens

7.1 The specimen shall be prepared by metallurgical preparation techniques (refer to ASTM E3) and shall have a smooth surface and be free of scratches or defects. 7.2 The specimen thickness shall be at least 1.5 times the diagonal length of the indentation to avoid reverse effects.

8. Calibration and verification

8.1 Machine Verification: Performed annually or after maintenance, using standard test blocks to verify load application, indenter alignment and measurement accuracy within ±1.0%. 8.2 Test Block Calibration: Performed using reference machines traceable to national standards to ensure hardness values are within ±1.0 HV or HK of certified values .

9. Experimental Procedure

9.1 Select an appropriate load based on the material and the type of test (macro or micro indentation).

9.2 Apply the load to the specimen surface and hold for 10 to 15 seconds. 9.3 Measure the diagonal of the indentation using an optical system and calculate the hardness value. 9.4 Repeat the test at least five times at different locations and report the average value.

10. Calculation

10.1 Calculate the Vickers hardness (HV) and Knoop hardness (HK) using the formulas given in Section 4. 10.2 For loads ≥ 1 kgf , the hardness value is rounded to an integer; for loads < 1 kgf , the hardness value is rounded to one decimal place.

11. Reports

11.1 The test report should include:

Identification of the test material.

The type of test (Vickers or Knoop) and the applied load.

Mean hardness value and standard deviation.

Date of test and name of operator.

Machine calibration status.

12. Accuracy and Bias

12.1 Precision: The repeatability and reproducibility of hardness measurements are load and material dependent, with a typical standard deviation of ±2 HV or HK under controlled conditions. 12.2 Bias: Because hardness is a relative measurement, no definite bias can be determined, but the results shall agree with the certified test block value within ±1.0%.

13. Keywords

13.1 Hardness; indentation; Knoop; macroindentation; microindentation; Vickers; metallic materials.

14. Appendix

Appendix A1: Supplementary Notes on Indenter Geometry

A1.1 Provide detailed specifications for Vickers and Knoop indenter geometries for manufacturing and verification purposes.

Appendix A2: Guidelines for Thin Specimen Testing

A2.1 Special considerations for testing thin or small specimens to reduce substrate effects.

15. Footnotes

15.1 This standard is published under the fixed designation E92. The number immediately following the designation indicates the year of initial adoption or last revision. The number in parentheses indicates the year of last reaffirmation. The superscript epsilon (ε) indicates an editorial change since the last revision or reaffirmation.

16. Approval

Approved on July 1, 2023 by ASTM International Committee E28 on Mechanical Testing.

ASTM G65-23

Standard test method for dry sand /rubber wheel abrasion testing of metals and alloys

1. Scope of application

1.1 This test method covers procedures for evaluating the wear resistance of metallic and alloy materials using a dry sand /rubber wheel apparatus and is applicable to materials subjected to dry abrasive wear conditions. 1.2 This method is intended primarily for laboratory testing to compare the relative wear resistance of materials such as steel, cast iron, carbide, and certain coated materials in simulated abrasive wear environments. 1.3 The values stated in this standard are in SI units; inch-pound units in parentheses are for reference only. 1.4 *Warning* —This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the person using this standard to establish appropriate safety and health practices and to determine applicable regulatory limitations prior to use.

2. References

2.1 ASTM Standards:

ASTM E29 Standard Practice for Use of Significant Figures in Test Data to Determine Conformity to Specifications

ASTM G40 Standard Definitions of Terms Relating to Wear and Erosion

ASTM G105 Standard Test Method for Wet Sand/Rubber Wheel Abrasion Testing

ASTM E122 Standard Practice for Calculating the Number of Samples Required to Determine the Average Quality of a Batch or Process 2.2 ISO Standards:

ISO 28080 Paints and varnishes — Determination of abrasion resistance 2.3 Other standards: None

3. Terminology

3.1 Definitions:

Abrasion - The process of removing material by the action of hard particles or surfaces.

Volume loss – the amount of material removed from a test specimen by wear, expressed as volume per unit load and sliding distance (mm^3 / N · m) .

Rubber wheel —a resilient wheel used in the test apparatus to drive the abrasive particles into contact with the specimen. 3.2 Refer to Terminology G40 for definitions of other terms used in this test method.

4. Summary of test methods

4.1 This test method involves abrading a specimen by a stream of dry silica sand and a rotating rubber wheel under a specified load using a dry sand /rubber wheel apparatus. The volume of material lost is determined and the wear rate is reported. 4.2 The test is normally conducted for a fixed number of wheel revolutions (usually 600 revolutions) and the wear rate is calculated based on the mass loss, specimen density, applied load, and sliding distance.

5. Significance and Use

5.1 This test method provides a controlled laboratory procedure for evaluating the wear resistance of materials under dry sand conditions , simulating certain abrasive environments. 5.2 The results are suitable for use in material selection, quality control, and research, particularly in components exposed to abrasive wear, such as mining equipment or conveyor systems. 5.3 This procedure does not exactly replicate the wear behavior under actual service conditions but can be used to compare the relative performance of materials.

6. Test equipment

6.1 Dry Sand /Rubber Wheel Apparatus—Consists of a rubber wheel (nominal diameter 228.6 mm, width 12.7 mm), abrasive feed system, and lever arm, capable of applying a normal load ranging from 13 N to 130 N, with a wheel speed of 200 ± 10 r/min. 6.2 Abrasive—Standard silica sand, with a particle size range of 50 to 70 mesh, Mohs hardness of approximately 7, and a water content of less than 0.1%. 6.3 Balance— Analytical balance with an accuracy of 0.1 mg. 6.4 Specimen Holding Device—Designed to hold the specimen at an angle of 90° ± 1° to the wheel face .

7. Test specimens

7.1 The specimen shall be a rectangular block, typically with dimensions of 76 mm long × 25 mm wide × 6 mm thick, and a surface roughness of Ra <0.8 μm . 7.2 The edges of the specimen shall be chamfered to prevent chipping and cleaned to remove any oil or contaminants.

8. Experimental Procedure

8.1 Calibrate the equipment, verify the condition of the rubber wheel (replace if worn more than 3 mm), check the load and rotation speed (accuracy ± 5%). 8.2 Weigh the clean, dry specimen (accuracy to 0.1 mg) and install it in the clamping device. 8.3 Adjust the load (usually 45 N or 130 N) and the sand flow rate (300 to 400 g/min), and run 600 revolutions (sliding distance approximately 430 m). 8.4 Remove and clean the specimen, reweigh it, calculate the mass loss, and repeat the test 3 to 5 times to ensure reproducibility. 8.5 Calculate the volume loss using the specimen density, applied load, and sliding distance.

9. Calculation

9.1 Calculate the volumetric wear rate (W_v) as follows:

$$W_v = \frac{\Delta m}{\rho \cdot F \cdot S}$$

其中：

- W_v = 体积磨损率，单位为 mm³/N·m
- Δm = 质量损失，单位为 g
- ρ = 试样密度，单位为 g/mm³
- F = 法向力，单位为 N
- S = 滑动距离，单位为 m 9.2 报告平均磨损率保留至小数点后两位。

10. Report
10.1 The report should include the following information:
Identification and description of the test material.
Apply load, sand flow rate and number of rotations.
Average volumetric wear rate and standard deviation.
Test date, equipment number, and operator name.
Environmental conditions (temperature and humidity) and calibration status.

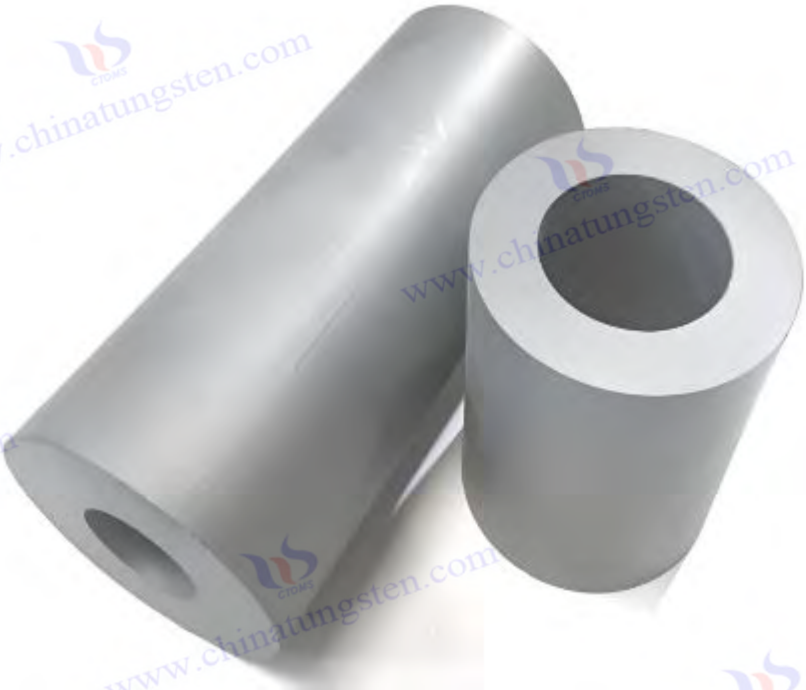
11. Precision and Bias
11.1 Precision—Repeatability within a single laboratory is typically ±5% of the mean wear rate; reproducibility between laboratories is approximately ±10%. 11.2 Bias—There is no absolute standard for bias, but the results should agree with the reference material to within <10%.

12. Keywords
12.1 Wear; dry sand; rubber wheel; abrasive wear; metal material; wear resistance

13. Appendix
Appendix A1. Recommended abrasive specifications
A1.1 Provide detailed information on silica sand particle size distribution and purity requirements to ensure test consistency.
Appendix A2. Coating Specimen Test Procedure
A2.1 Guidelines for testing coating materials, including load adjustment recommendations.

14. Footnotes
14.1 This standard is published under the fixed designation G65. The number immediately following the designation indicates the year of initial adoption or last revision, and the number in parentheses indicates the year of last reaffirmation. The superscript epsilon (ε) indicates an editorial change since the last revision or reaffirmation.

15. Approval
Approved on July 1, 2023 by ASTM International Committee G02 on Wear and Erosion.



What are the types and application areas of cemented carbide molds ?

Cemented carbide (with tungsten carbide-cobalt system, WC-Co, as the core) has a high hardness (HV 1800-2000 ± 30), excellent wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , high temperature resistance (>800°C ± 20°C) and corrosion resistance (corrosion rate <0.01 mm/year ± 0.001 mm/year), making it an ideal material for manufacturing high-performance molds. Cemented carbide molds are made by powder metallurgy processes (such as sintering, hot isostatic pressing HIP) or additive manufacturing technologies (such as selective laser melting SLM) and are widely used in industrial scenarios that require high precision, high life and complex geometries. The following provides a more specific and detailed discussion from a professional perspective on mold types and application fields, and adds content in the field of new energy vehicles.

1. Types of carbide dies

Cemented carbide molds are divided into various types according to their functions, structures, processing objects and material ratios. Each type is optimized through precision processes and surface treatments to meet specific industrial needs. The following is a description of the types of specialized expansion:

Carbide stamping dies
are mainly used for punching, bending, drawing or flanging of metal sheets. Common ratios are WC-6%Co (low cobalt and high hardness) or WC-10%Co (high toughness).
Professional Features :

Hardness range HV 1800-1900 ± 30, impact toughness 10-15 MPa·m ½ ± 1 MPa · m ½ , suitable for high-speed stamping (frequency>100 times/min ± 10 times/min, load>500 kN ± 50 kN).

The surface roughness Ra <0.1 μm ± 0.01 μm was achieved by chemical mechanical polishing (CMP, pressure 5-10 kPa ± 0.5 kPa), and the cutting accuracy was <0.01 mm ± 0.001 mm.

Wear resistance <0.05 mm³ / N · m ± 0.01 mm³ / N · m , cycle life >10 ⁶ times ± 10 ⁴ times, suitable for high-strength steel plates (tensile strength >1000 MPa ± 100 MPa).

Manufacturing process :

Hot isostatic pressing (HIP, 1300°C ± 10°C, 200 MPa ± 5 MPa) was used to ensure compactness (porosity <0.1% ± 0.01%, micro defects <0.05 μm ± 0.01 μm).

TiN coating (thickness 5-15 μm ± 0.1 μm , hardness HV 2000 ± 50) applied by physical vapor deposition (PVD, 400-600°C ± 10°C) reduces the friction coefficient (<0.2 ± 0.05).

Electrospark machining (EDM, current 5-20 A ± 1 A, accuracy <0.01 mm ± 0.001 mm) for production of complex punch and die contours.

Carbide drawing dies

are used for cold drawing, deep drawing or spinning of metal wires, tubes or plates, such as wire drawing dies, tube drawing dies or deep drawing dies. WC-8%Co or WC-6%Co-Ni (2% ± 0.5%) are commonly used.

Professional Features :

Wear resistance <0.05 mm³ / N · m ± 0.01 mm³ / N · m , inner hole finish Ra <0.05 μm ± 0.01 μm , support pull-out stress>2000 MPa ± 100 MPa (such as stainless steel wire or copper tube).

The geometric accuracy tolerance is <0.01 mm ± 0.001 mm, the cone angle error is <0.5° ± 0.1°, suitable for fine wire drawing (diameter 0.1-5 mm ± 0.05 mm).

Thermal stability <600°C ± 20°C, thermal expansion coefficient <6×10 ⁻ ⁶ /°C ± 0.5×10 ⁻ ⁶ /°C, reducing thermal deformation.

Manufacturing process :

Precision grinding (grit size #1200-2000 ± 100, accuracy <0.005 mm ± 0.001 mm) combined with ultrasonic polishing to control surface micro cracks (<0.01 μm ± 0.001 μm).

TiC coatings (thickness 5-10 μm ± 0.1 μm , bonding strength >50 MPa ± 5 MPa) were applied by chemical vapor deposition (CVD, 800-1000°C ± 10°C, vapor concentration 10-20 vol% ± 1 vol%) .

Laser surface treatment (power 200-300 W ± 10 W) optimizes the hardened layer in the inner hole (depth 0.05-0.1 mm ± 0.01 mm).

Carbide cold heading dies

are used for cold forging of bolts, nuts, rivets or fasteners, with compositions such as WC-10%Co or WC-15%Co-TiC (5% ± 0.5%).

Professional Features :

Compressive strength >4000 MPa ± 100 MPa, fatigue resistance >10 ⁶ times ± 10 ⁴ times, suitable for high deformations (>50% ± 5%) and transient impact loads (>1000 kN ± 100 kN).

Surface hardness HV 1900-2000 ± 30, wear resistance <0.05 mm³ / N · m ± 0.01 mm³ / N · m , cavity accuracy <0.01 mm ± 0.001 mm.

Thermal stability <500°C ± 20°C, residual stress <100 MPa ± 10 MPa, prevent cold cracking.

Manufacturing process:

Spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa) ensured a grain size of 0.5-1 μm ± 0.01 μm .

Surface hardening (laser power 300-500 W ± 20 W, depth 0.1-0.2 mm ± 0.01 mm) combined with VC doping (0.1%-0.5% ± 0.01%) improves crack resistance.

Post-treatment hot isostatic pressing (HIP, 1200°C ± 10°C, 150 MPa ± 5 MPa) was used to eliminate internal stress.

Cemented carbide hot forging dies

are used for hot forging of high-temperature metals (such as steel, titanium alloy, nickel-based alloys), with a formulation such as WC-10%Co-TiC (5% ± 0.5%) or WC-12%Co-TaC (2% ± 0.1%).

Professional Features:

High temperature oxidation resistance mass loss <0.01% ± 0.001% at 800°C ± 20°C, thermal fatigue resistance cycle life >5000 times ± 500 times.

Thermal conductivity>120 W/ m·K ± 5 W/ m·K , thermal expansion coefficient<6×10^{-6} /°C ± 0.5×10^{-6} /°C, suitable for forging at 900-1200°C ± 50°C.

Compressive strength >4000 MPa ± 100 MPa, cavity thermal crack resistance (crack growth rate <0.001 mm/cycle ± 0.0001 mm/cycle).

Manufacturing process:

HIP (1350°C ± 10°C, 200 MPa ± 5 MPa) with TaC addition (0.5%-2% ± 0.1%) to improve hot cracking resistance, porosity <0.1% ± 0.01%.

The surface is sprayed with ZrN (5-15 μm ± 0.1 μm , deposition rate 0.1-0.5 μm /min ± 0.05 μm /min) or Al_2O_3 (anti-oxidation, thickness 10-20 μm ± 0.2 μm).

Heat treatment annealing (900°C ± 20°C, 2-4 h ± 0.1 h) optimized tissue homogeneity.

Cemented carbide powder pressing dies

are used for the pressing of powder metallurgy products, such as gears, bearings or magnetic materials. WC-6%Co-Ni (2% ± 0.5%) or WC-8%Co-Cr (3% ± 0.5%) are commonly used.

Professional Features:

High pressure bearing capacity >3000 MPa ± 100 MPa, wear resistance <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m , cavity complexity supports depth of 10-50 mm ± 1 mm.

Compression ratio >2:1 ± 0.1, powder filling uniformity >95% ± 2%, pressing accuracy <0.02 mm ± 0.002 mm.

Thermal stability <600°C ± 20°C, resistance to powder corrosion (<0.01 mm/year ± 0.001 mm/year).

Manufacturing process:

Precision grinding (grit size #1500-3000 ± 100) combined with plasma sprayed TiAlN coating (thickness 5-10 μm ± 0.1 μm , hardness HV 2800 ± 50).

HIP (1300°C ± 10°C, 150 MPa ± 5 MPa) optimized microstructure with grain size of 0.5-1 μm ± 0.01 μm .

Surface laser texturing (depth 5-10 μm ± 0.5 μm) improves powder flowability and demoulding properties.

Carbide plastic molds

are used for injection molding of thermoplastics (such as ABS, PC) or thermosetting plastics (such as epoxy resin), with a formula such as WC-8%Co-Cr (2% ± 0.5%) or WC-10%Co-Ni (3% ± 0.5%).

Professional Features :

Heat resistance >400°C ± 10°C, corrosion resistance <0.01 mm/year ± 0.001 mm/year (resistance to corrosion by plastic additives), surface finish Ra <0.2 μm ± 0.02 μm .

Resistant to high pressure injection molding (>100 MPa ± 10 MPa), cavity accuracy <0.01 mm ± 0.001 mm, suitable for complex flow channel design (length 50-200 mm ± 5 mm).

The coefficient of thermal expansion is $<6\times10^{-6}$ /°C ± 0.5×10^{-6} /°C, reducing thermal cycle deformation (<0.01 mm ± 0.001 mm).

Manufacturing process :

The mold cavity was made by electrospark machining (EDM, current 10-30 A ± 1 A, accuracy <0.01 mm ± 0.001 mm).

PVD coating of CrN (5-10 μm ± 0.1 μm , hardness HV 2000 ± 50) reduces plastic adhesion and is combined with polishing (Ra <0.1 μm ± 0.01 μm).

Heat treatment and tempering (400°C ± 10°C, 1-2 h ± 0.1 h) eliminate internal stress.

Carbide extrusion dies

are used for continuous extrusion of metals or plastics, such as aluminum profiles or rubber sealing strips, with a formulation such as WC-10%Co-VC (0.5% ± 0.1%).

Professional Features :

Wear resistance <0.05 mm³ / N · m ± 0.01 mm³ / N · m , extrusion deformation resistance>2000 MPa ± 100 MPa, die accuracy<0.02 mm ± 0.002 mm.

Suitable for long-distance extrusion (>10 m ± 1 m), extrusion speed 1-5 m/min ± 0.1 m/min, temperature stability <500°C ± 20°C.

Friction coefficient <0.1 ± 0.01, reduced material adhesion (adhesion force <0.5 N ± 0.05 N).

Manufacturing process :

Precision grinding and HIP (1300°C ± 10°C, 200 MPa ± 5 MPa) ensure internal homogeneity with a porosity of <0.1% ± 0.01%.

Surface coating MoS_2 (1-5 μm ± 0.1 μm , deposition rate 0.2-0.5 μm /min ± 0.05 μm /min) reduces friction.

Laser surface treatment (power 200-400 W ± 10 W) optimizes the die hardening layer (depth 0.1-0.2 mm ± 0.01 mm).

Carbide trimming dies

are used for precision trimming of metal sheets or thin sheets, with a formulation such as WC-6%Co-TiC (3% ± 0.5%).

Professional Features :

Cutting sharpness: cutting force <0.5 N ± 0.05 N, wear life $>10^5$ m ± 10^4 m, cutting edge smoothness Ra <0.1 μm ± 0.01 μm .

Accuracy <0.01 mm ± 0.001 mm, impact toughness 10-12 MPa·m ½ ± 1 MPa · m ½ , suitable for thin sheet metal blanking (thickness 0.05-1 mm ± 0.01 mm).

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

Thermal stability <400°C ± 20°C, reduced heat affected zone (<0.05 mm ± 0.01 mm).

Manufacturing process :

Laser cutting (power 200-300 W ± 10 W, accuracy <0.01 mm ± 0.001 mm) combined with PVD ZrN coating (5-15 μm ± 0.1 μm).

Chemical mechanical polishing (CMP, pressure 5-10 kPa ± 0.5 kPa) optimizes the cutting edge with a roughness of Ra <0.05 μm ± 0.01 μm .

Low temperature tempering (300°C ± 10°C, 1 h ± 0.1 h) stabilizes the structure.

Cemented carbide die-casting molds

are used for die-casting of non-ferrous metals (such as zinc and magnesium alloys), with a formulation such as WC-12%Co-TaC (2% ± 0.1%).

Professional Features :

Thermal fatigue resistance>4000 times ± 400 times, molten metal corrosion resistance<0.01 mm/year ± 0.001 mm/year, mold cavity pressure resistance>1500 MPa ± 100 MPa.

Thermal conductivity>100 W/ m·K ± 5 W/ m·K , thermal expansion coefficient<6×10^{-6} /°C ± 0.5×10^{-6} /°C, suitable for 600-800°C ± 50°C die casting.

The mold cavity accuracy is <0.02 mm ± 0.002 mm, and the surface roughness is Ra <0.2 μm ± 0.02 μm .

Manufacturing process :

HIP (1350°C ± 10°C, 200 MPa ± 5 MPa) in combination with a multilayer coating of TiAlN + Al_2O_3 (thickness 10-20 μm ± 0.2 μm , hardness HV 3000 ± 50).

Electrospark machining (EDM, accuracy <0.01 mm ± 0.001 mm) is used to make complex mold cavities, followed by post-processing and polishing.

Heat treatment annealing (700°C ± 20°C, 2-3 h ± 0.1 h) reduces residual stress.

Carbide rolling dies

are used for roll forming of metal sheets or bars with a formulation such as WC-10%Co-Cr (3% ± 0.5%).

Professional Features :

Rolling wear resistance <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m , fatigue resistance>10^6 times ± 10^4 times, rolling accuracy thickness tolerance <0.02 mm ± 0.002 mm.

Compressive strength >4000 MPa ± 100 MPa, thermal stability <600°C ± 20°C, rolling speed 1-10 m/s ± 0.1 m/s.

Surface hardness HV 1900-2000 ± 30, reduced rolling texture (height < 0.01 mm ± 0.001 mm).

Manufacturing process :

After forging, HIP (1300°C ± 10°C, 200 MPa ± 5 MPa) was performed to optimize the grain size (0.5-1 μm ± 0.01 μm).

Surface hardening (laser power 400-600 W ± 20 W, depth 0.2-0.3 mm ± 0.01 mm).

PVD-coated TiN (5-15 μm ± 0.1 μm) improves durability.

2. Application fields of cemented carbide molds

Due to its excellent physical and chemical properties, cemented carbide molds have shown wide application potential in multiple industrial fields. The following are the application fields of professional expansion, including the newly added new energy vehicle field:

Automotive Manufacturing

Applications : Carbide stamping dies are used for blanking of body panels (thickness 0.5-3 mm ± 0.1 mm), cold heading dies for bolts and nuts (diameter 5-20 mm ± 0.5 mm), hot forging dies for crankshafts, connecting rods and gears (weight 1-10 kg ± 0.5 kg), die casting dies for cylinder blocks and gearbox housings (volume 0.5-5 L ± 0.1 L), rolling dies for forming steel sheets (thickness 1-5 mm ± 0.1 mm).

Advantages : Improved production efficiency (>20% ± 2%), extended mold life up to 10^6 times ± 10^4 It reduces the number of strokes and maintenance costs (<5% ± 1%), and supports the processing of high-strength steel (>1500 MPa ± 100 MPa).

Aerospace Industry

Applications : Carbide hot forging dies are used for forming titanium alloy blades and structural parts (temperature 900-1100°C ± 50°C), drawing dies for processing high-strength aluminum alloy tubes and honeycomb structures (diameter 10-50 mm ± 1 mm), extrusion dies for making aviation fasteners (length 20-100 mm ± 2 mm), and die-casting dies for producing magnesium alloy fuselage parts (weight 0.5-2 kg ± 0.1 kg).

Advantages : High temperature fatigue resistance (>5000 times ± 500 times), high precision (tolerance <0.01 mm ± 0.001 mm), lightweight (density <2.7 g/ cm^3 ± 0.1 g/cm^3) and high temperature oxidation resistance (<0.01% ± 0.001%) requirements.

Electronics Industry

Applications : Carbide powder pressing dies are used for pressing micro motor cores (thickness 0.2-0.5 mm ± 0.05 mm), plastic molds for making mobile phone cases and connectors (size 100-150 mm ± 1 mm), trimming dies for processing circuit boards (thickness 0.1-0.3 mm ± 0.01 mm), and extrusion dies for forming wires (diameter 0.05-1 mm ± 0.01 mm).

Advantages : High-precision molding (<0.01 mm ± 0.001 mm), excellent surface quality (Ra <0.2 μm ± 0.02 μm), short production cycle (<1 h/piece ± 0.1 h), and high-frequency use (>10^4 times ± 10^3 times).

Mechanical manufacturing and mold industry

Applications : Carbide drawing dies for wire drawing (diameter 0.1-5 mm ± 0.05 mm), stamping dies for gear and bearing processing (cavity depth 10-30 mm ± 1 mm), cold heading dies for precision shafts (diameter 2-10 mm ± 0.1 mm), rolling dies for steel bars (diameter 5-20 mm ± 0.5 mm), die casting dies for complex castings (weight 0.1-5 kg ± 0.1 kg).

Advantages : Longer wear life (>10^6 m ± 10^4 m pulling length), reduced change frequency (>50% ± 5%), improved production consistency (deviation <1% ± 0.1%), support for high hardness materials (>HRC 50 ± 2).

Medical Device Manufacturing

Applications：Carbide plastic molds are used for forming medical syringes and catheters (wall thickness 0.1-0.3 mm ± 0.01 mm), cold heading molds for making orthopedic screws and intramedullary nails (diameter 2-6 mm ± 0.1 mm), trimming molds for processing surgical blades (thickness 0.05-0.1 mm ± 0.005 mm), extrusion molds for forming catheters (inner diameter 0.5-2 mm ± 0.05 mm), powder compression molds for making artificial joint components (weight 0.1-0.5 kg ± 0.05 kg).

Advantages：Biocompatible coating (e.g. Ag, antibacterial rate >90% ± 2%), high precision (<0.01 mm ± 0.001 mm), meets sterility requirements (bacterial load <10 CFU/ cm² ± 1 CFU/cm²)，lifespan >10 ^{5} times ± 10 ^{4} times.

Energy and heavy industry

Applications：Carbide hot forging dies are used for wind turbine blade connectors (diameter > 500 mm ± 10 mm), powder pressing dies for wear-resistant parts (such as pump bodies, weight 5-20 kg ± 1 kg), extrusion dies for oil drill pipes (diameter 50-100 mm ± 2 mm), die-casting dies for nuclear power valve bodies (weight 10-50 kg ± 2 kg), and rolling dies for rail processing (width 100-150 mm ± 2 mm).

Advantages：High temperature oxidation resistance (<0.01% ± 0.001% at 800°C ± 20°C), compressive strength (>4000 MPa ± 100 MPa), extended service life (>10 ^{4} h ± 10 ^{3} h), support for extreme environments (pressure >200 MPa ± 10 MPa).

Consumer goods manufacturing

Application：Carbide plastic molds are used for home appliance housings (such as TV housings, size 500-1000 mm ± 10 mm) and kitchenware molding (thickness 0.5-2 mm ± 0.1 mm), trimming molds for processing metal decorative parts (thickness 0.1-0.5 mm ± 0.01 mm), extrusion molds for making aluminum alloy door and window profiles (length 3-6 m ± 0.1 m).

Advantages：High surface finish (Ra <0.2 μm ± 0.02 μm), high production efficiency (>50 pieces/h ± 5 pieces/h), and low rework rate (<2% ± 0.5%).

Buildings and Infrastructure

Applications：Carbide rolling dies for forming steel bars (diameter 6-40 mm ± 0.5 mm), powder pressing dies for making precast concrete mould components (weight 10-30 kg ± 1 kg), extrusion dies for processing aluminium window frames (length 1-3 m ± 0.05 m), die casting dies for producing building hardware (weight 0.5-2 kg ± 0.1 kg).

Advantages：Wear life (>10 ^{6} m ± 10 ^{4} m), high precision (<0.02 mm ± 0.002 mm), support for large-scale production (>1000 pieces/day ± 100 pieces).

Defense and military industry

Applications：Carbide hot forging dies are used for forming tank armor plates (thickness 10-50 mm ± 1 mm), cold heading dies for making shell casings (diameter 20-100 mm ± 2 mm), drawing dies for processing missile casings (length 0.5-2 m ± 0.05 m), and die casting dies for producing radar components (weight 1-5 kg ± 0.2 kg).

Advantages：High temperature fatigue resistance (>10 ^{4} times ± 10 ^{3} times), impact resistance

(>500 J/cm ² ± 50 J/cm²) , meeting military standards (MIL-STD-810).

Application in new energy vehicle field

With the rapid development of the new energy vehicle (NEV) industry, cemented carbide molds play an irreplaceable role in the manufacturing of key components of electric vehicles.

Carbide stamping dies

Used for punching and forming battery housings (thickness 0.8-2 mm ± 0.1 mm, such as lithium iron phosphate battery or ternary lithium battery housing) and body structural parts (such as chassis guard plates, size 1000-2000 mm ± 10 mm), punching load >1000 kN ± 100 kN .

Carbide cold heading dies

Fabricate high voltage connectors (5-15 mm ± 0.2 mm diameter) and motor rotor shafts (10-30 mm ± 0.5 mm diameter), support high strength fasteners (>1500 MPa ± 100 MPa), and deformation rate >40% ± 5%.

Carbide hot forging die

Used for hot forming of power battery current collectors (such as copper/aluminum foil, thickness 0.1-0.2 mm ± 0.01 mm) and motor stator housings (weight 5-15 kg ± 0.5 kg), processing temperature 600-900°C ± 50°C, load >2000 kN ± 200 kN .

Carbide extrusion die

Processing of aluminum alloy battery frames (cross-section 50-100 mm² ± 2 mm²) and heat dissipation tube (length 1-3 m ± 0.05 m), extrusion speed 0.5-2 m/min ± 0.1 m/min, pressure >1500 MPa ± 100 MPa.

Carbide die casting mold

Production of motor housings (weight 10-30 kg ± 1 kg) and charging pile housings (size 300-500 mm ± 5 mm), pressure resistance >1200 MPa ± 100 MPa, casting temperature 650-750°C ± 50°C.

Carbide trimming dies

Used for precision cutting of battery pole pieces (thickness 0.08-0.15 mm ± 0.005 mm) and wiring harness terminal punching (length 10-50 mm ± 0.5 mm), cutting force <0.5 N ± 0.05 N, accuracy <0.01 mm ± 0.001 mm.

Advantages of Carbide Stamping Dies

High precision and consistency : mold accuracy <0.01 mm ± 0.001 mm, ensuring the assembly tolerance of the battery module (<0.05 mm ± 0.01 mm), improving energy density (>160 Wh /kg ± 10 Wh /kg), and battery cell consistency >98% ± 1%.

Wear resistance and long life : mold wear life>10^6 times ± 10^4 It reduces the frequency of replacement (>60% ± 5%), reduces production costs (<10% ± 1%), and supports continuous production of >500 h ± 50 h.

High temperature and corrosion resistance : Hot forging dies are resistant to 900°C ± 50°C environments, electrolyte corrosion resistance (<0.01 mm/year ± 0.001 mm/year, such as lithium salt solution pH 7-9), and extended service life (>10^4 h ± 10^3 h).

Lightweight support : Combining high-strength aluminum alloy (>300 MPa ± 20 MPa) and magnesium alloy (>200 MPa ± 10 MPa) molding, it can reduce weight by 10-15% ± 2%, increase driving range (>500 km ± 20 km), and meet NEDC standards.

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




Efficient production : Stamping and die-casting efficiency >50 pieces/h ± 5 pieces/h, shortening the production cycle of new energy vehicle parts (<2 h/piece ± 0.1 h), supporting large-scale mass production (> 10^4 vehicles/year ± 10^3 vehicles).

Technical Challenges and Solutions :

Challenges : High-voltage battery casings are prone to microcracks (length <0.1 mm ± 0.01 mm) during stamping, thermal stress (>200 MPa ± 20 MPa) during hot forging causes deformation, and die-casting molds are easily corroded by molten metal (erosion rate <0.02 mm/year ± 0.002 mm/year).

Solution : Optimize the PVD TiAlN coating (thickness 10-20 μm ± 0.2 μm , hardness HV 3200 ± 50) of the stamping die to enhance crack resistance, introduce a preheated substrate (200-400°C ± 10°C) to reduce thermal stress, and post-process HIP (1300°C ± 10°C, 200 MPa ± 5 MPa) to improve the internal structure. Add TaC (2% ± 0.1%) to the die-casting mold to improve corrosion resistance, combined with Al_2O_3 coating (thickness 15-25 μm ± 0.2 μm) to slow down erosion.

Development trend : With the development of solid-state battery and hydrogen fuel cell technology, cemented carbide molds need to further improve their high temperature resistance (>1000°C ± 50°C) and electrochemical corrosion resistance (<0.005 mm/year ± 0.001 mm/year), and explore 3D printing technology (SLM, layer thickness 20-50 μm ± 1 μm) to manufacture complex battery frame molds, supporting multi-material gradient design (hardness gradient 1800-2200 HV ± 50).

3. Future development direction of cemented carbide molds

Material optimization : Develop low-cobalt formulations (e.g. WC-Ni-Cr, Co <5% ± 0.5%) or nanocomposites (WC particle size <100 nm ± 10 nm) to improve toughness and biocompatibility.

Process innovation : Introducing 3D printing technology (SLM, layer thickness 20-50 μm ± 1 μm) to manufacture complex molds, combined with HIP post-treatment (1300°C ± 10°C) to reduce porosity (<0.1% ± 0.01%).

Intelligent : Integrated sensors monitor mold stress (<50 MPa ± 5 MPa) and temperature (<600°C ± 10°C) for predictive maintenance.

Sustainability : Use of recycled carbide powder (reuse rate >90% ± 2%) and low energy consumption process (energy consumption <10 kWh/kg ± 1 kWh/kg).

The application of cemented carbide molds in the industrial field continues to expand, and their high-performance characteristics support the needs of multiple fields from automobiles to national defense and new energy vehicles. In particular, the rapid growth in the field of new energy vehicles has promoted the development of mold technology towards high precision, high efficiency and green manufacturing. More technological breakthroughs are expected in the next 5-10 years.

4. Relevant standards of cemented carbide molds

Common industry standards

Technical conditions and standards

The manufacture and use of cemented carbide dies usually follow **the "Technical Conditions for**

Cemented Carbide Drawing Dies" (Record No.: 8261-2001), which is managed by the State Machinery Industry Bureau. This standard specifies the material properties, dimensional accuracy, wear resistance and service life of the drawing die, and is applicable to the manufacture and inspection of wire drawing dies.

Material performance requirements

Carbide molds must meet the requirements of high hardness (HV 1800-2000 ± 30), high wear resistance (wear rate <0.05 mm³ / N · m ± 0.01 mm³ / N · m) and high toughness (fracture toughness 10-15 MPa·m ½ ± 1 MPa · m ½) standards, which are widely adopted in the industry.

National or international standards

The production of cemented carbide molds often refers to **"GB/T 5242-2006 General Technical Conditions for Cemented Carbide"** , which covers the composition, performance testing and quality control requirements of cemented carbide materials and is suitable for the selection of raw materials in mold manufacturing.

ISO standards : ISO standards, such as ISO 513 (classification of cutting tool materials) and ISO 28080 (property testing of hard materials), can be used as a reference for carbide mold design, especially in export or international cooperation projects.

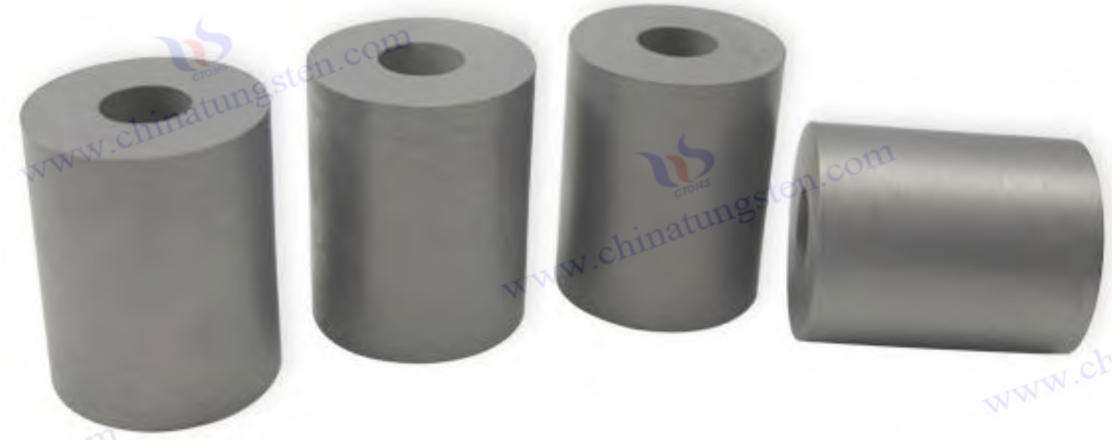
Industry application standards

Stamping die standard

For cemented carbide stamping dies, the industry often refers to **"JB/T 8144-2010 Technical Conditions for Stamping Dies"** , which specifies the structural design, heat treatment process and surface treatment requirements of the die to ensure high precision (tolerance <0.01 mm ± 0.001 mm) and long life (>10 ^{6} times ± 10 ^{4} times the impulse).

Powder Metallurgy Die Standard

Cemented carbide molds in the powder metallurgy field may follow **"YB/T 5136-2006 Technical Conditions for Powder Metallurgy Molds"** , emphasizing mold cavity accuracy (<0.02 mm ± 0.002 mm) and pressure resistance (>3000 MPa ± 100 MPa).



JB/T 8144-2010 Technical requirements for stamping dies

1. Scope of application

This standard specifies the technical conditions for stamping dies, including material selection, design requirements, manufacturing process, technical performance, inspection methods, marking, packaging, transportation and storage. It is applicable to cold stamping dies for various metal plates (such as steel plates, aluminum plates, stainless steel plates) and non-metallic materials (such as plastics and rubber), including single-process dies, composite dies and multi-process dies, and is widely used in the automotive, electronics, aerospace and other industries.

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, but it is encouraged to adopt the new version of the document according to the research results.

GB/T 5242-2006 General Specifications for Cemented Carbide

GB/T 6110-2021 Drawing Dies - Structural Types and Dimensions of Cemented Carbide Drawing Dies

《JB/T 3943-2017 Drawing Die Cemented Carbide Drawing Die Technical Specifications》

GB/T 1804-2000 Tolerances and fits - Limit deviations and basic deviations of linear dimensions

3. Terms and Definitions

Stamping Die: A tool used to form material into a desired shape by pressure, including a die, a punch , and a guide.

Stamping life: The ability of the mold to maintain stable performance under a specified number of stamping times.

Assembly accuracy: the fitting tolerance and relative position accuracy between the various components of the mold.

4. Material requirements

4.1 Mold material

Cemented carbide material: WC-Co system (such as WC-6%Co, WC-10%Co), hardness HV 1800-2000 ± 30, compressive strength >4000 MPa ± 100 MPa.

Steel: Cr12MoV, D2 or H13 steel, hardness HRC 58-62 ± 2, quenched and tempered.

Non-working parts: Made of 45# steel or Q235 steel, hardness HRC 30-40 ± 2 after heat treatment.

4.2 Performance requirements

Wear resistance: wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m , tested according to GB/T 12444.

Heat resistance: operating temperature <600°C ± 20°C, thermal expansion coefficient <6×10^{-6} /°C ± 0.5×10^{-6} /°C.

Fatigue resistance: Fatigue life>10^6 times ± 10^4 times, test according to GB/T 3075.

4.3 Surface treatment

Optional coating: TiN , TiC or CrN coating, thickness 5-15 μm ± 0.1 μm , hardness HV 2000-3000 ± 50, bonding strength >50 MPa ± 5 MPa, using PVD or CVD process.

5. Technical requirements

5.1 Design requirements

Structural type: including single process, compound and progressive dies , designed according to GB/T 6397 standard.

Tolerance grade: Linear dimension tolerance is in accordance with GB/T 1804 IT6-IT8, geometric tolerance roundness <0.005 mm ± 0.001 mm.

Guiding accuracy: The gap between the guide column and the guide sleeve is 0.005-0.01 mm ± 0.001 mm.

5.2 Size and accuracy

Mould size: According to the part drawing requirements, the maximum outer diameter is ≤500 mm ± 0.1 mm, and the height is ≤300 mm ± 0.1 mm.

Working part tolerance: punching clearance 0.01-0.05 mm ± 0.005 mm, adjusted according to sheet thickness.

Assembly accuracy: relative position error <0.02 mm ± 0.002 mm.

5.3 Surface quality

The working surface roughness Ra <0.2 μm ± 0.02 μm , using precision grinding or polishing process.

There are no cracks, pores or scratches on the surface, and the maximum defect size is <0.01 mm ± 0.001 mm.

5.4 Performance Indicators

Punching life: >500,000 times ± 10^4 times (depending on material and punching conditions), wear <0.1 mm ± 0.01 mm.

Stamping accuracy: part size tolerance ±0.05 mm ± 0.005 mm, surface roughness Ra <0.8 μm ± 0.1 μm .

6. Manufacturing process

6.1 Raw material preparation

Cemented carbide powder: WC particle size 0.5-2 μm ± 0.1 μm , Co content error ±0.5%, mixed by ball milling (speed 200-300 rpm ± 10 rpm, time 24-48 h ± 1 h).

Steel pretreatment: Annealing to remove internal stress, hardness HRC 20-25 ± 2.

6.2 Molding process

Cemented carbide: Cold isostatic pressing (CIP, 200 MPa ± 5 MPa) or injection molding, green body density >60% ± 2% theoretical density.

Steel: forged or cast, forging ratio ≥4:1.

6.3 Sintering and heat treatment

Cemented carbide: hot isostatic pressing (HIP, 1300-1400°C ± 10°C, 200 MPa ± 5 MPa), porosity <0.1% ± 0.01%.

Steel: quenching (1000-1050°C ± 10°C, oil cooling) + tempering (200-250°C ± 10°C, 2-3 h ± 0.1 h), hardness HRC 58-62 ± 2.

6.4 Finishing

Working parts are produced by electrospark machining (EDM, current 5-20 A ± 1 A) with an accuracy of < 0.01 mm ± 0.001 mm.

Precision grinding (grit size #1200-3000 ± 100) or ultrasonic polishing, control surface roughness Ra <0.2 μm ± 0.02 μm .

6.5 Assembly

The guide is press-fitted , with a clearance of 0.005-0.01 mm ± 0.001 mm and a bolt tightening torque of 50-100 N·m ± 5 N·m .

7. Inspection methods

7.1 Dimensions and accuracy

The tolerance is in accordance with GB/T 1182 IT6-IT8 grade when inspected by coordinate measuring machine (CMM).

7.2 Material properties

Hardness test is in accordance with GB/T 231.1, compressive strength test is in accordance with GB/T 3852, and wear resistance test is in accordance with GB/T 12444.

Thermal conductivity is in accordance with ASTM E1461 and thermal expansion coefficient is in accordance with ISO 17864.

7.3 Surface quality

Defects were checked by optical microscopy (magnification 500× ± 50×) or scanning electron microscopy (SEM), with the maximum defect size < 0.01 mm ± 0.001 mm.

7.4 Stamping life

The test was conducted on a standard punching machine using standard materials (e.g. 1 mm thick SPCC steel plate, punching speed 20-50 times/min ± 2 times/min), and the number of punches was recorded until the wear reached 0.1 mm ± 0.01 mm.

8. Test conditions

Test environment temperature: 20-25°C ± 2°C, humidity 50%-70% ± 5%.

Punching load: 500-2000 kN ± 50 kN , adjusted according to mold specifications.

9. Labeling, packaging, transportation and storage

9.1 Logo

The nameplate on the mold surface indicates: mold number, specification (outer diameter × height in mm), stamping tonnage, manufacturing date, manufacturer name, and the character height is 3 mm ± 0.1 mm.

9.2 Packaging

Use shock-proof foam and anti-rust paper to wrap, put into wooden or metal boxes, and mark "Handle with Care" and "Moisture-proof" inside the box.

9.3 Transportation

Avoid severe vibration or high temperature (>50°C ± 5°C) environment. The transportation vehicle must be equipped with shock-absorbing devices.

9.4 Storage

Store in a dry and ventilated place at a temperature of 0-40°C ± 5°C and a humidity of <60% ± 5%. Avoid contact with acidic or alkaline substances.

10. Use and Maintenance

10.1 Usage Requirements

Preheat the mold to 50-100°C ± 10°C before stamping to reduce thermal shock.

Use stamping oil that complies with GB/T 7326, with a viscosity of 20-50 cSt ± 5 cSt .

10.2 Maintenance

Check the working surface wear regularly, every $10^4 \pm 10^3$ punches.

If the wear amount is found to be >0.1 mm ± 0.01 mm, polish or replace it in time.

10.3 Scrapping Standards

When the working surface wear is >0.2 mm ± 0.02 mm, or the crack length is >0.05 mm ± 0.01 mm, it is judged as scrap.

11. Quality Assurance

The sampling rate of each batch of molds is ≥5% ± 1%, and the qualified rate is >95% ± 2%.

Provide material certificates and inspection reports, including performance test data and dimensional inspection records.

12. Appendix (Informative)

Stamping process parameter reference

Punching speed: 20-100 times/min ± 2 times/min.

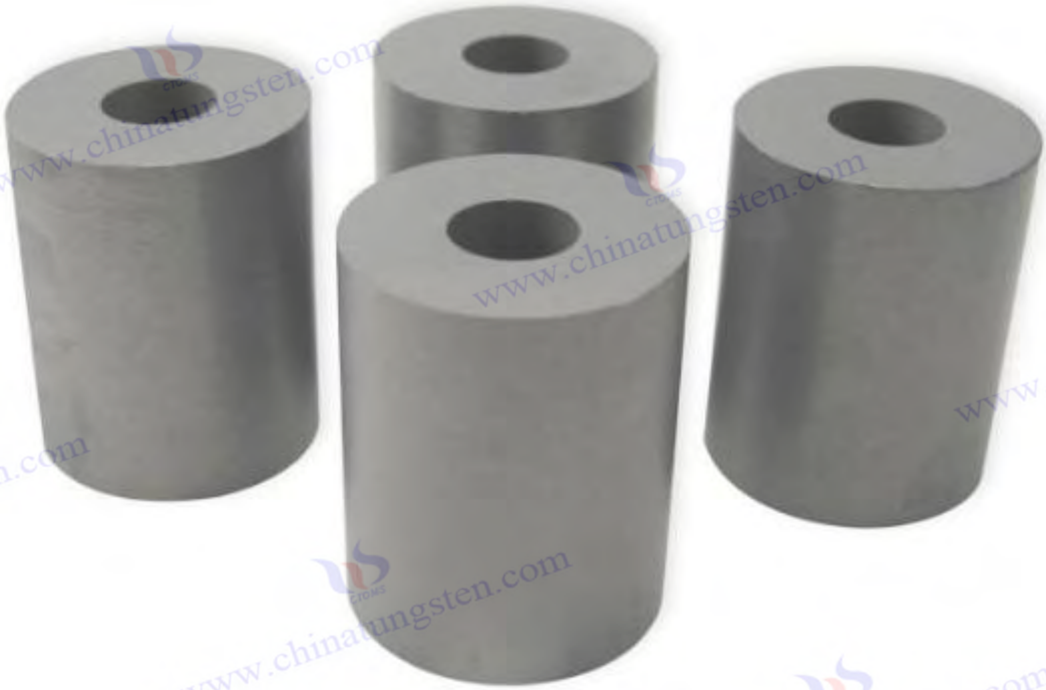
Blanking gap: When the plate thickness is 0.5-2 mm, the gap is 0.01-0.05 mm ± 0.005 mm.

Typical defects and solutions

Crack: Adjust heat treatment temperature or increase quenching cooling rate.

Deformation: Optimize mold design and increase guiding accuracy.

This technical condition fully reflects the core requirements of "JB/T 8144-2010", combines the characteristics of cemented carbide and other materials, and ensures the performance of stamping dies in terms of high precision, high life and high reliability.



Carbide drawing dies
Technical conditions

A complete, comprehensive and detailed "Technical Conditions for Carbide Drawing Dies" is compiled based on current standards (such as "JB/T 3943-2017 Technical Conditions for Carbide Drawing Dies" and related industry specifications) and industry practices. This technical condition is intended to standardize the material selection, manufacturing process, performance requirements, inspection methods and maintenance requirements of carbide drawing dies to ensure their high performance and reliability in wire drawing processing.

1. Scope of application

This technical condition applies to the manufacture, inspection and use of cemented carbide drawing dies, covering drawing dies used for cold drawing of metal wires (such as steel wire, copper wire, stainless steel wire, etc.), and is applicable to drawing dies with a diameter range of 0.1 mm to 20 mm ± 0.05 mm.

2. Normative references

The clauses in the following documents become the clauses of this technical condition through reference in this technical condition. For all the referenced documents with dates, all the subsequent amendments (excluding errata) or revisions are not applicable to this technical condition, but it is encouraged to adopt the new version of the document according to the research results.

GB/T 5242-2006 General Specifications for Cemented Carbide

《JB/T 3943-2017 Drawing Die Cemented Carbide Drawing Die Technical Specifications》

GB/T 6110-2021 Drawing Dies - Structural Types and Dimensions of Cemented Carbide Drawing Dies

3. Terms and Definitions

Drawing Die: A ring-shaped or conical die made of carbide material used to reduce the diameter of metal wire by the drawing process.

Working cone angle: The angle of the tapered part of the mold inner hole, which affects the pulling force and surface quality.

Wear life: The ability of a die to maintain stable performance within a specified drawing length or number of times.

4. Material requirements

4.1 Material composition

The mold matrix adopts tungsten carbide-cobalt (WC-Co) system, and the recommended ratio is WC-6%Co, WC-8%Co or WC-10%Co, and the cobalt content error is ±0.5%.

Depending on the characteristics of the drawn material (e.g. high carbon steel or copper alloy), a slight amount of reinforcing phases such as TiC (0.5%-2% ± 0.1%) or TaC (0.5%-1% ± 0.1%) can be added to improve wear resistance and heat resistance.

4.2 Physical properties

Hardness: HV 1800-2000 ± 30. The test method is in accordance with GB/T 3850.

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

Density: 14.5-15.0 g/ cm^3 ± 0.2 g/cm^3 , test method according to GB/T 3851.
Compressive strength: >4000 MPa ± 100 MPa, test method according to GB/T 3852.
Fracture toughness: 10-15 MPa·m ½ ± 1 MPa · m ½ , test method according to GB/T 21068.

4.3 Chemical stability

Corrosion resistance: Immersed in 0.9% NaCl solution for 24 h ± 1 h, corrosion rate <0.01 mm/year ± 0.001 mm/year.
Oxidation resistance: mass loss <0.01% ± 0.001% at 800°C ± 20°C.

5. Technical requirements

5.1 Dimensions and tolerances

Mould outer diameter: 10-50 mm ± 0.1 mm, height: 5-30 mm ± 0.1 mm.
Working hole diameter: 0.1-20 mm ± 0.01 mm, cone angle: 6°-15° ± 0.5°, in accordance with the types and dimensions specified in GB/T 6110-2021.
Geometric tolerances: roundness <0.005 mm ± 0.001 mm, cylindricity <0.01 mm ± 0.001 mm.

5.2 Surface quality

The working surface roughness Ra <0.1 μm ± 0.01 μm is achieved by precision grinding or chemical mechanical polishing (CMP) process.
There are no cracks, pores or inclusions on the surface, and the maximum defect size is <0.01 mm ± 0.001 mm.

5.3 Performance requirements

Wear life: Drawing length > 10^6 m ± 10^4 m (depending on the drawn material), wear rate < 0.05 mm^3 / N · m ± 0.01 mm^3 / N · m .
Thermal stability: operating temperature <600°C ± 20°C, thermal expansion coefficient <6×10^{-6} /°C ± 0.5×10^{-6} /°C.
Drawing accuracy: wire diameter tolerance <±0.01 mm ± 0.001 mm, surface roughness Ra <0.4 μm ± 0.05 μm .

5.4 Coating (optional)

TiN , TiC or CrN coatings can be applied by physical vapor deposition (PVD) or chemical vapor deposition (CVD) technology with a thickness of 5-15 μm ± 0.1 μm , a hardness of HV 2000-3000 ± 50 and a bonding strength of >50 MPa ± 5 MPa.

6. Manufacturing process

6.1 Raw material preparation

High-purity WC powder (particle size 0.5-2 μm ± 0.1 μm) and Co powder were used, and the mixing uniformity was >95% ± 2%, which was achieved by ball milling (speed 200-300 rpm ± 10 rpm, time 24-48 h ± 1 h).

6.2 Molding process

Cold isostatic pressing (CIP, 200 MPa ± 5 MPa) or injection molding is used, and the green body density is >60% ± 2% of the theoretical density.

6.3 Sintering process

Hot isostatic pressing (HIP, 1300-1400°C ± 10°C, 200 MPa ± 5 MPa) or field assisted sintering (SPS, 1350°C ± 10°C, 50 MPa ± 1 MPa) to ensure a porosity of <0.1% ± 0.01% and a grain size of

0.5-1 μm ± 0.01 μm .

6.4 Finishing

The inner hole was made by electrospark machining (EDM, current 5-20 A ± 1 A) with an accuracy of <0.01 mm ± 0.001 mm.

Precision grinding (grit size #1200-3000 ± 100) or ultrasonic polishing, control surface roughness Ra <0.1 μm ± 0.01 μm .

6.5 Heat treatment

Annealing (400-600°C ± 10°C, 2-4 h ± 0.1 h) eliminates internal stress and the residual stress is <100 MPa ± 10 MPa.

7. Inspection methods

7.1 Dimensional and geometrical accuracy

The tolerance is in accordance with the IT6 level specified in GB/T 1182 when tested using a coordinate measuring machine (CMM).

7.2 Material properties

Hardness test is in accordance with GB/T 3850, density is in accordance with GB/T 3851, and compressive strength is in accordance with GB/T 3852.

The fracture toughness is in accordance with GB/T 21068, and the thermal conductivity is in accordance with ASTM E1461.

7.3 Surface quality

Defects were checked using an optical microscope (magnification 500× ± 50×) or a scanning electron microscope (SEM), with the maximum defect size being <0.01 mm ± 0.001 mm.

7.4 Wear life

Test on a standard drawing machine, using standard drawing materials (e.g. 1 mm diameter steel wire, drawing speed 1-5 m/s ± 0.1 m/s), and record the drawing length until the wear reaches 0.05 mm ± 0.01 mm.

8. Test conditions

Test environment temperature: 20-25°C ± 2°C, humidity 50%-70% ± 5%.

Pull-out test load: 500-2000 N ± 50 N, adjusted according to mold specifications.

9. Labeling, packaging, transportation and storage

9.1 Logo

The nameplate on the mold surface indicates: mold number, specification (diameter × height in mm), manufacturing date, manufacturer name. The character height is 3 mm ± 0.1 mm and is clearly visible.

9.2 Packaging

Use shock-proof foam and anti-corrosion paper to pack, put into wooden or plastic boxes, and mark "Handle with Care" inside the box.

9.3 Transportation

Avoid severe vibration or high temperature (>50°C ± 5°C) environment. The transportation vehicle must be equipped with shock-absorbing devices.

9.4 Storage

Store in a dry and ventilated place at a temperature of 0-40°C ± 5°C and a humidity of <60% ± 5%. Avoid contact with acidic or alkaline substances.

10. Use and Maintenance

10.1 Usage Requirements

Preheat the die to 50-100°C ± 10°C before drawing to reduce thermal shock.

The drawing lubricant used is drawing oil that complies with GB/T 7326 and has a viscosity of 20-50 cSt ± 5 cSt .

10.2 Maintenance

Check the working hole wear regularly, every 10^5 m ± 10^4 m of pulling length.

If the wear amount is found to be >0.05 mm ± 0.01 mm, polish or replace it in time.

10.3 Scrapping Standards

When the working hole diameter increases by >0.1 mm ± 0.01 mm, or the surface crack length is >0.05 mm ± 0.01 mm, it will be judged as scrap.

11. Quality Assurance

The sampling rate of each batch of molds is ≥5% ± 1%, and the qualified rate is >95% ± 2%.

Provide material certificates and inspection reports, including performance test data and dimensional inspection records.

12. Appendix (Informative)

Drawing process parameter reference

Pulling speed: 1-10 m/s ± 0.1 m/s.

Reduction rate: 10%-25% ± 2%, depending on the material .

Typical defects and solutions

Cracks: adjust sintering temperature or increase HIP pressure. Porosity: optimize powder mixing or improve sintering density.

This technical condition integrates current standards (such as JB/T 3943-2017) and industry practices to ensure that cemented carbide drawing dies have high reliability and consistency in performance, manufacturing and use.

YB/T 5136-2006
Technical requirements for powder metallurgy molds

1. Scope of application

This standard specifies the technical conditions for powder metallurgy molds, including material selection, design requirements, manufacturing process, technical performance, inspection methods, marking, packaging, transportation and storage. It is applicable to molds used in powder metallurgy pressing processes, including carbide or steel molds for pressing gears, bearings, magnetic materials and other products, and is widely used in the fields of automobiles, electronics, machinery manufacturing, etc.

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, but it is encouraged to adopt the new version of the document according to the research results.

GB/T 5242-2006 General Specifications for Cemented Carbide

GB/T 6110-2021 Drawing Dies - Structural Types and Dimensions of Cemented Carbide Drawing Dies

《JB/T 3943-2017 Drawing Die Cemented Carbide Drawing Die Technical Specifications》

GB/T 1804-2000 Tolerances and fits - Limit deviations and basic deviations of linear dimensions

3. Terms and Definitions

Powder metallurgy mold: A tool used to shape metal powder or composite powder by high pressure pressing, including an upper mold, a lower mold and a mold sleeve .

Pressing life: The ability of a mold to maintain stable performance under a specified number of pressing cycles.

Filling uniformity: The distribution consistency of powder in the mold cavity directly affects the density of the product.

4. Material requirements

4.1 Mold material

Cemented carbide material: WC-Co system (such as WC-6%Co, WC-8%Co or WC-10%Co), hardness HV 1800-2000 ± 30, compressive strength >4000 MPa ± 100 MPa.

Steel: Cr12MoV, D2 or H13 steel, hardness HRC 58-62 ± 2, quenched and tempered.

Non-working parts: Made of 40Cr or 45# steel, hardness HRC 30-40 ± 2 after heat treatment.

4.2 Performance requirements

Wear resistance: wear rate <0.05 $mm^3 / N \cdot m \pm 0.01\ mm^3 / N \cdot m$, tested according to GB/T 12444.

Pressure resistance: Maximum pressure >3000 MPa ± 100 MPa, tested according to GB/T 3852.

Fatigue resistance: Fatigue life>10^6 times ± 10^4 times, test according to GB/T 3075.

4.3 Surface treatment

Optional coating: TiN , TiC or Al_2O_3 coating, thickness 5-15 µm ± 0.1 µm , hardness HV 2000-3000

± 50, bonding strength >50 MPa ± 5 MPa, using PVD or CVD process.

5. Technical requirements

5.1 Design requirements

Structural type: including one-way pressing mold, two-way pressing mold and multi-cavity mold, designed according to GB/T 6406 standard.

Tolerance grade: Linear dimension tolerance is in accordance with GB/T 1804 IT6-IT8, geometric tolerance parallelism is <0.01 mm ± 0.001 mm.

Guiding accuracy : The gap between the guide column and the guide sleeve is 0.005-0.015 mm ± 0.001 mm.

5.2 Size and accuracy

Mould size: According to the requirements of the part drawing, the maximum outer diameter is ≤400 mm ± 0.1 mm, and the height is ≤250 mm ± 0.1 mm.

Cavity dimensions: Tolerance <±0.02 mm ± 0.002 mm, depth 10-50 mm ± 1 mm.

Assembly accuracy: relative position error <0.03 mm ± 0.002 mm.

5.3 Surface quality

The working surface roughness Ra <0.2 μm ± 0.02 μm , using precision grinding or polishing process.

There are no cracks, pores or inclusions on the surface, and the maximum defect size is <0.01 mm ± 0.001 mm.

5.4 Performance Indicators

Pressing life: >500,000 times ± 10^{4} times (depending on powder material and pressure), wear <0.1 mm ± 0.01 mm.

Pressing accuracy: product density tolerance ±2% ± 0.5%, size tolerance ±0.05 mm ± 0.005 mm.

Filling uniformity: >95% ± 2%, tested according to YB/T 5120.

6. Manufacturing process

6.1 Raw material preparation

Cemented carbide powder: WC particle size 0.5-2 μm ± 0.1 μm , Co content error ±0.5%, mixed by ball milling (speed 200-300 rpm ± 10 rpm, time 24-48 h ± 1 h).

Steel pretreatment: Annealing to remove internal stress, hardness HRC 20-25 ± 2.

6.2 Molding process

Cemented carbide: Cold isostatic pressing (CIP, 200 MPa ± 5 MPa) or injection molding, green body density >60% ± 2% theoretical density.

Steel: forged or cast, forging ratio ≥4:1.

6.3 Sintering and heat treatment

Cemented carbide: hot isostatic pressing (HIP, 1300-1400°C ± 10°C, 200 MPa ± 5 MPa), porosity <0.1% ± 0.01%.

Steel: quenching (1000-1050°C ± 10°C, oil cooling) + tempering (200-250°C ± 10°C, 2-3 h ± 0.1 h), hardness HRC 58-62 ± 2.

6.4 Finishing

The mold cavity was produced by electrospark machining (EDM, current 5-20 A ± 1 A) with an

accuracy of <0.02 mm ± 0.002 mm.
Precision grinding (grit size #1200-3000 ± 100) or ultrasonic polishing, control surface roughness Ra <0.2 μm ± 0.02 μm .

6.5 Assembly

The guide is press-fitted , with a clearance of 0.005-0.015 mm ± 0.001 mm and a bolt tightening torque of 50-80 N·m ± 5 N·m .

7. Inspection methods

7.1 Dimensions and accuracy

The tolerance is in accordance with GB/T 1182 IT6-IT8 grade when inspected by coordinate measuring machine (CMM).

7.2 Material properties

Hardness test is in accordance with GB/T 231.1, compressive strength test is in accordance with GB/T 3852, and wear resistance test is in accordance with GB/T 12444.
Thermal conductivity is in accordance with ASTM E1461 and thermal expansion coefficient is in accordance with ISO 17864.

7.3 Surface quality

Defects were checked by optical microscopy (magnification 500× ± 50×) or scanning electron microscopy (SEM), with the maximum defect size < 0.01 mm ± 0.001 mm.

7.4 Pressing life

The test was conducted on a standard powder metallurgy press using standard iron powder (e.g. ASC 100.29, pressure 500-1000 MPa ± 50 MPa) and the number of presses was recorded until the wear reached 0.1 mm ± 0.01 mm.

8. Test conditions

Test environment temperature: 20-25°C ± 2°C, humidity 50%-70% ± 5%.
Pressing load: 500-2000 kN ± 50 kN , adjusted according to mold specifications.

9. Labeling, packaging, transportation and storage

9.1 Logo

The nameplate on the mold surface indicates: mold number, specification (outer diameter × height in mm), pressing tonnage, manufacturing date, manufacturer name, and the character height is 3 mm ± 0.1 mm.

9.2 Packaging

Use shock-proof foam and anti-rust paper to wrap, put into wooden or metal boxes, and mark "Handle with Care" and "Moisture-proof" inside the box.

9.3 Transportation

Avoid severe vibration or high temperature (>50°C ± 5°C) environment. The transportation vehicle must be equipped with shock-absorbing devices.

9.4 Storage

Store in a dry and ventilated place at a temperature of 0-40°C ± 5°C and a humidity of <60% ± 5%. Avoid contact with acidic or alkaline substances.

10. Use and Maintenance

10.1 Usage Requirements

Preheat the mold to 50-100°C ± 10°C before pressing to reduce thermal shock.

Use pressing oil that complies with GB/T 7326, with a viscosity of 20-50 cSt ± 5 cSt .

10.2 Maintenance

Check the die cavity wear regularly, every $10^4 \pm 10^3$ pressings.

If the wear amount is found to be >0.1 mm ± 0.01 mm, polish or replace it in time.

10.3 Scrapping Standards

When the cavity wear is >0.2 mm ± 0.02 mm, or the crack length is >0.05 mm ± 0.01 mm, it is judged as scrap.

11. Quality Assurance

The sampling rate of each batch of molds is ≥5% ± 1%, and the qualified rate is >95% ± 2%.

Provide material certificates and inspection reports, including performance test data and dimensional inspection records.

12. Appendix (Informative)

Pressing process parameters reference

Pressing pressure: 500-1000 MPa ± 50 MPa.

Compression ratio: 2:1 to 4:1 ± 0.1, depending on powder characteristics.

Typical defects and solutions

Crack: Adjust sintering temperature or increase HIP pressure.

Uneven density: Optimize the powder filling process and increase the vibration time (10-20 s ± 1 s).

GB/T 6110-2021
Drawing Die
Carbide drawing dies
Structural type and size

1. Scope of application

This standard specifies the structural type, dimensional specifications and related technical requirements of cemented carbide drawing dies. It is applicable to drawing dies used in the cold drawing process of metal wires (such as steel wire, copper wire, stainless steel wire, etc.), covering drawing dies with a diameter range of 0.1 mm to 20 mm ± 0.05 mm, and is widely used in metal processing, electronics, automobile and other industries.

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, but it is encouraged to adopt the new version of the document according to the research results.

GB/T 5242-2006 General Specifications for Cemented Carbide

《JB/T 3943-2017 Drawing Die Cemented Carbide Drawing Die Technical Specifications》

GB/T 1804-2000 Tolerances and fits - Limit deviations and basic deviations of linear dimensions

3. Terms and Definitions

Drawing Die: A ring-shaped or conical die made of carbide material used to reduce the diameter of metal wire by the drawing process.

Working cone angle: The angle of the tapered part of the mold inner hole, which affects the pulling force and surface quality.

Guide area: The area inside the die hole used to guide the wire to ensure drawing stability.

4. Structural type

4.1 Basic Structure

Drawing dies usually consist of the following functional areas:

Entry zone: Guide the wire into the die, length 0.5-1 mm ± 0.1 mm, cone angle 20°-30° ± 2°.

Lubrication area: Provides lubricant storage, length 0.5-1.5 mm ± 0.1 mm, cone angle 10°-20° ± 1°.

Working cone area : the main drawing deformation area, length 0.5-2 mm ± 0.1 mm, cone angle 6°-15° ± 0.5°.

Sizing zone: Control the final diameter, length 0.2-0.8 mm ± 0.05 mm, diameter tolerance ±0.01 mm ± 0.001 mm.

Exit zone: Protect the wire surface, length 0.2-0.5 mm ± 0.05 mm, cone angle 30°-45° ± 2°.

4.2 Classification

Single hole die: Single working hole, suitable for small batches or single specification drawing, maximum diameter 20 mm ± 0.05 mm.

Multi-hole die: Multiple working holes, suitable for continuous drawing, hole spacing ≥2 mm ± 0.1

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

mm.
Combined die: modular design, replaceable working parts, adaptable to various wire specifications.

5. Dimensions
5.1 Dimensions
Outer diameter: 10-50 mm ± 0.1 mm, recommended specifications are 15 mm, 20 mm, 25 mm, 30 mm, 40 mm.
Height: 5-30 mm ± 0.1 mm, recommended specifications are 10 mm, 15 mm, 20 mm, 25 mm.
Thickness: 3-15 mm ± 0.1 mm, depending on diameter and application.
5.2 Inner hole size
Minimum aperture: 0.1 mm ± 0.01 mm, maximum aperture 20 mm ± 0.05 mm.
Working cone length: 0.5-2 mm ± 0.1 mm, length to aperture ratio 1:1 to 1:5.
Sizing zone length: 0.2-0.8 mm ± 0.05 mm, length to aperture ratio 1:2 to 1:10.
5.3 Tolerances and fits
Linear dimension tolerance: According to GB/T 1804 IT6-IT8 grade, aperture tolerance ±0.01 mm ± 0.001 mm.
Geometric tolerances: roundness <0.005 mm ± 0.001 mm, cylindricity <0.01 mm ± 0.001 mm.
Cone angle tolerance: ±0.5° ± 0.1°.
5.4 Special specifications
Micro mold (aperture ≤ 0.5 mm ± 0.01 mm): sizing zone length 0.1-0.3 mm ± 0.05 mm, cone angle 8°-12° ± 0.5°.
Large molds (aperture > 10 mm ± 0.05 mm): working cone length 1.5-2 mm ± 0.1 mm, cone angle 10°-15° ± 0.5°.

6. Technical requirements
6.1 Material requirements
WC-Co cemented carbide is used, and the recommended ratio is WC-6%Co, WC-8%Co or WC-10%Co, and the cobalt content error is ±0.5%.
Hardness HV 1800-2000 ± 30, compressive strength >4000 MPa ± 100 MPa, porosity <0.1% ± 0.01%.
6.2 Surface quality
The working surface roughness Ra <0.1 μm ± 0.01 μm , using precision grinding or chemical mechanical polishing (CMP) technology.
There are no cracks, pores or inclusions on the surface, and the maximum defect size is <0.01 mm ± 0.001 mm.
6.3 Performance Indicators
Wear life: Pull-out length > 10^6 m ± 10^4 m, wear rate < 0.05 mm³ / N · m ± 0.01 mm³ / N · m .
Thermal stability: operating temperature <600°C ± 20°C, thermal expansion coefficient <6×10^{-6} /°C ± 0.5×10^{-6} /°C.
Drawing accuracy: wire diameter tolerance <±0.01 mm ± 0.001 mm, surface roughness Ra <0.4 μm ± 0.05 μm .
6.4 Coating (optional)

TiN , TiC or CrN coatings can be applied using PVD or CVD technology with a thickness of 5-15 μm ± 0.1 μm , a hardness of HV 2000-3000 ± 50 and a bonding strength of >50 MPa ± 5 MPa.

7. Manufacturing process

7.1 Raw material preparation

High-purity WC powder (particle size 0.5-2 μm ± 0.1 μm) and Co powder were used, and the mixing uniformity was >95% ± 2%, which was achieved by ball milling (speed 200-300 rpm ± 10 rpm, time 24-48 h ± 1 h).

7.2 Molding process

Cold isostatic pressing (CIP, 200 MPa ± 5 MPa) or injection molding, green body density >60% ± 2% theoretical density.

7.3 Sintering process

Hot isostatic pressing (HIP, 1300-1400°C ± 10°C, 200 MPa ± 5 MPa) or field assisted sintering (SPS, 1350°C ± 10°C, 50 MPa ± 1 MPa) to ensure a grain size of 0.5-1 μm ± 0.01 μm .

7.4 Finishing

The inner hole was made by electrospark machining (EDM, current 5-20 A ± 1 A) with an accuracy of <0.01 mm ± 0.001 mm.

Precision grinding (grit size #1200-3000 ± 100) or ultrasonic polishing, control surface roughness Ra <0.1 μm ± 0.01 μm .

8. Inspection methods

8.1 Dimensions and accuracy

The tolerance is in accordance with GB/T 1182 IT6-IT8 grade when inspected by coordinate measuring machine (CMM).

8.2 Material properties

Hardness test is in accordance with GB/T 3850, density is in accordance with GB/T 3851, and compressive strength is in accordance with GB/T 3852.

Thermal conductivity is in accordance with ASTM E1461 and thermal expansion coefficient is in accordance with ISO 17864.

8.3 Surface quality

Defects were checked by optical microscopy (magnification 500× ± 50×) or scanning electron microscopy (SEM), with the maximum defect size < 0.01 mm ± 0.001 mm.

8.4 Wear life

Test on a standard drawing machine, using standard drawing materials (e.g. 1 mm diameter steel wire, drawing speed 1-5 m/s ± 0.1 m/s), and record the drawing length until the wear reaches 0.05 mm ± 0.01 mm.

9. Test conditions

Test environment temperature: 20-25°C ± 2°C, humidity 50%-70% ± 5%.

Pull-out test load: 500-2000 N ± 50 N, adjusted according to mold specifications.

10. Labeling, packaging, transportation and storage

10.1 Logo

The nameplate on the mold surface indicates: mold number, specification (diameter × height in mm), manufacturing date, manufacturer name. The character height is 3 mm ± 0.1 mm and is clearly visible.

10.2 Packaging

Use shock-proof foam and anti-corrosion paper to pack, put into wooden or plastic boxes, and mark "Handle with Care" inside the box.

10.3 Transportation

Avoid severe vibration or high temperature (>50°C ± 5°C) environment. The transportation vehicle must be equipped with shock-absorbing devices.

10.4 Storage

Store in a dry and ventilated place at a temperature of 0-40°C ± 5°C and a humidity of <60% ± 5%. Avoid contact with acidic or alkaline substances.

11. Use and Maintenance

11.1 Usage Requirements

Preheat the die to 50-100°C ± 10°C before drawing to reduce thermal shock.

Use wire drawing oil that complies with GB/T 7326, with a viscosity of 20-50 cSt ± 5 cSt .

11.2 Maintenance

Check the working hole wear regularly, every 10^5 m ± 10^4 m of pulling length.

If the wear amount is found to be >0.05 mm ± 0.01 mm, polish or replace it in time.

11.3 Scrapping Standards

When the working hole diameter increases by >0.1 mm ± 0.01 mm, or the surface crack length is >0.05 mm ± 0.01 mm, it will be judged as scrap.

12. Quality Assurance

The sampling rate of each batch of molds is ≥5% ± 1%, and the qualified rate is >95% ± 2%.

Provide material certificates and inspection reports, including performance test data and dimensional inspection records.

13. Appendix (Informative)

Drawing process parameter reference

Pulling speed: 1-10 m/s ± 0.1 m/s.

Reduction rate: 10%-25% ± 2%, depending on the material .

Typical defects and solutions

Crack: Adjust sintering temperature or increase HIP pressure.

Porosity: Optimize powder mixing or improve sintering density.


4.90
2.98
1.36
0.62
1.35

JB/T 3943-2017
Drawing Die
Carbide drawing dies
Technical conditions

1. Scope of application

This standard specifies the technical conditions for the material selection, manufacturing process, technical performance, inspection methods, marking, packaging, transportation and storage of cemented carbide drawing dies. It is applicable to drawing dies used in the cold drawing process of metal wires (such as steel wire, copper wire, stainless steel wire, etc.), covering drawing dies with a diameter range of 0.1 mm to 20 mm ± 0.05 mm, and is widely used in metal processing, electronics, automobile and other industries.

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, but it is encouraged to adopt the new version of the document according to the research results.

GB/T 5242-2006 General Specifications for Cemented Carbide

GB/T 6110-2021 Drawing Dies - Structural Types and Dimensions of Cemented Carbide Drawing Dies

GB/T 1804-2000 Tolerances and fits - Limit deviations and basic deviations of linear dimensions

3. Terms and Definitions

Drawing Die: A ring-shaped or conical die made of carbide material used to reduce the diameter of metal wire by the drawing process.

Working cone angle: The angle of the tapered part of the mold inner hole, which affects the pulling force and surface quality.

Wear life: The ability of a die to maintain stable performance within a specified drawing length or number of times.

4. Material requirements

4.1 Material composition

The mold matrix adopts tungsten carbide-cobalt (WC-Co) system, and the recommended ratio is WC-6%Co, WC-8%Co or WC-10%Co, and the cobalt content error is ±0.5%.

Depending on the characteristics of the drawn material (e.g. high carbon steel or copper alloy), a slight amount of reinforcing phases such as TiC (0.5%-2% ± 0.1%) or TaC (0.5%-1% ± 0.1%) can be added to improve wear resistance and heat resistance.

4.2 Physical properties

Hardness: HV 1800-2000 ± 30, test method according to GB/T 3850.

Density: 14.5-15.0 g/ cm^3 ± 0.2 g/cm^3 , test method according to GB/T 3851.

Compressive strength: >4000 MPa ± 100 MPa, test method according to GB/T 3852.

Fracture toughness: 10-15 MPa·m ½ ± 1 MPa · m ½ , test method according to GB/T 21068.

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

4.3 Chemical stability

Corrosion resistance: Immersed in 0.9% NaCl solution for 24 h ± 1 h, corrosion rate <0.01 mm/year ± 0.001 mm/year.

Oxidation resistance: mass loss <0.01% ± 0.001% at 800°C ± 20°C.

5. Technical requirements

5.1 Structural type

The mold structure is in accordance with GB/T 6110-2021, including the inlet area, lubrication area, working cone area, sizing area and outlet area.

Cone angle in the entry area: 20°-30° ± 2°, length 0.5-1 mm ± 0.1 mm.

Working cone angle: 6°-15° ± 0.5°, length 0.5-2 mm ± 0.1 mm.

Sizing zone length: 0.2-0.8 mm ± 0.05 mm, diameter tolerance ±0.01 mm ± 0.001 mm.

5.2 Dimensions and tolerances

Outer diameter: 10-50 mm ± 0.1 mm, recommended specifications are 15 mm, 20 mm, 25 mm, 30 mm, 40 mm.

Height: 5-30 mm ± 0.1 mm, recommended specifications are 10 mm, 15 mm, 20 mm, and 25 mm.

Working hole diameter: 0.1-20 mm ± 0.01 mm, tolerance according to GB/T 1804 IT6-IT8.

Geometric tolerances: roundness <0.005 mm ± 0.001 mm, cylindricity <0.01 mm ± 0.001 mm.

5.3 Surface quality

The working surface roughness Ra <0.1 μm ± 0.01 μm , using precision grinding or chemical mechanical polishing (CMP) technology.

There are no cracks, pores or inclusions on the surface, and the maximum defect size is <0.01 mm ± 0.001 mm.

5.4 Performance requirements

Wear life: Drawing length > 10^6 m ± 10^4 m (depending on the drawn material), wear rate < 0.05 mm^3 / N · m ± 0.01 mm^3 / N · m .

Thermal stability: operating temperature <600°C ± 20°C, thermal expansion coefficient <6×10^{-6} /°C ± 0.5×10^{-6} /°C.

Drawing accuracy: wire diameter tolerance <±0.01 mm ± 0.001 mm, surface roughness Ra <0.4 μm ± 0.05 μm .

5.5 Coating (optional)

TiN , TiC or CrN coatings can be applied by physical vapor deposition (PVD) or chemical vapor deposition (CVD) technology with a thickness of 5-15 μm ± 0.1 μm , a hardness of HV 2000-3000 ± 50 and a bonding strength of >50 MPa ± 5 MPa.

6. Manufacturing process

6.1 Raw material preparation

High-purity WC powder (particle size 0.5-2 μm ± 0.1 μm) and Co powder were used, and the mixing uniformity was >95% ± 2%, which was achieved by ball milling (speed 200-300 rpm ± 10 rpm, time 24-48 h ± 1 h).

6.2 Molding process

Cold isostatic pressing (CIP, 200 MPa ± 5 MPa) or injection molding, green body density >60% ±

2% theoretical density.

6.3 Sintering process

Hot isostatic pressing (HIP, 1300-1400°C ± 10°C, 200 MPa ± 5 MPa) or field assisted sintering (SPS, 1350°C ± 10°C, 50 MPa ± 1 MPa) to ensure a porosity of <0.1% ± 0.01% and a grain size of 0.5-1 µm ± 0.01 µm .

6.4 Finishing

The inner hole was made by electrospark machining (EDM, current 5-20 A ± 1 A) with an accuracy of <0.01 mm ± 0.001 mm.

Precision grinding (grit size #1200-3000 ± 100) or ultrasonic polishing, control surface roughness Ra <0.1 µm ± 0.01 µm .

6.5 Heat treatment

Annealing (400-600°C ± 10°C, 2-4 h ± 0.1 h) eliminates internal stress and the residual stress is <100 MPa ± 10 MPa.

7. Inspection methods

7.1 Dimensional and geometrical accuracy

The tolerance is in accordance with GB/T 1182 IT6-IT8 grade when inspected by coordinate measuring machine (CMM).

7.2 Material properties

Hardness test is in accordance with GB/T 3850, density is in accordance with GB/T 3851, and compressive strength is in accordance with GB/T 3852.

The fracture toughness is in accordance with GB/T 21068, and the thermal conductivity is in accordance with ASTM E1461.

7.3 Surface quality

using an optical microscope (magnification 500× ± 50×) or a scanning electron microscope (SEM), with the maximum defect size being <0.01 mm ± 0.001 mm.

7.4 Wear life

Test on a standard drawing machine, using standard drawing materials (e.g. 1 mm diameter steel wire, drawing speed 1-5 m/s ± 0.1 m/s), and record the drawing length until the wear reaches 0.05 mm ± 0.01 mm.

8. Test conditions

Test environment temperature: 20-25°C ± 2°C, humidity 50%-70% ± 5%.

Pull-out test load: 500-2000 N ± 50 N, adjusted according to mold specifications.

9. Labeling, packaging, transportation and storage

9.1 Logo

The nameplate on the mold surface indicates: mold number, specification (diameter × height in mm), manufacturing date, manufacturer name. The character height is 3 mm ± 0.1 mm and is clearly visible.

9.2 Packaging

Use shock-proof foam and anti-corrosion paper to pack, put into wooden or plastic boxes, and mark

"Handle with Care" inside the box.

9.3 Transportation

Avoid severe vibration or high temperature (>50°C ± 5°C) environment. The transportation vehicle must be equipped with shock-absorbing devices.

9.4 Storage

Store in a dry and ventilated place at a temperature of 0-40°C ± 5°C and a humidity of <60% ± 5%. Avoid contact with acidic or alkaline substances.

10. Use and Maintenance

10.1 Usage Requirements

Preheat the die to 50-100°C ± 10°C before drawing to reduce thermal shock.

Use wire drawing oil that complies with GB/T 7326, with a viscosity of 20-50 cSt ± 5 cSt .

10.2 Maintenance

Check the working hole wear regularly, every 10^5 m ± 10^4 m of pulling length.

If the wear amount is found to be >0.05 mm ± 0.01 mm, polish or replace it in time.

10.3 Scrapping Standards

When the working hole diameter increases by >0.1 mm ± 0.01 mm and the surface crack length is >0.05 mm ± 0.01 mm, it will be judged as scrapped.

11. Quality Assurance

The sampling rate of each batch of molds is ≥5% ± 1%, and the qualified rate is >95% ± 2%.

Provide material certificates and inspection reports, including performance test data and dimensional inspection records.

12. Appendix (Informative)

Drawing process parameter reference

Drawing speed: 1-10 m/s ± 0.1 m/s. Reduction rate: 10%-25% ± 2%, depending on the material .

Typical defects and solutions

Crack: Adjust sintering temperature or increase HIP pressure.

Porosity: Optimize powder mixing or improve sintering density.

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




What are the characteristics and application areas of cemented carbide heat dissipation substrates?

Cemented carbide heat dissipation substrates are based on the tungsten carbide-cobalt (WC-Co) system, combined with high thermal conductivity materials (such as silicon carbide SiC , aluminum nitride AlN or boron nitride BN) and other reinforcing phases (such as titanium carbide TiC or tantalum carbide TaC), and are prepared by powder metallurgy processes (such as hot isostatic pressing HIP, sintering or field-assisted sintering SPS) or additive manufacturing technology (such as selective laser melting SLM, electron beam melting EBM). These substrates combine the high hardness, wear resistance and excellent thermal management performance of cemented carbide, and are widely used in high-tech fields that require efficient heat dissipation, mechanical strength and environmental adaptability. The following elaborates on the diverse types of cemented carbide heat dissipation substrates, more professional and detailed descriptions, and application scenarios from three aspects: types, characteristics and application fields.

1. Types of carbide heat sink substrates

Cemented carbide heat dissipation substrates are divided into multiple types according to material composition, thermal conductivity mechanism and application requirements. Each type is optimized through specific ratios and processes to meet the thermal management requirements of different scenarios:

Pure tungsten cobalt cemented carbide (WC-Co) heat dissipation substrate

Composition : Tungsten carbide (WC) as hard phase, cobalt (Co) as binder phase, typical ratio is WC-6%Co, WC-10%Co or WC-15%Co.

Professional Features :

Thermal conductivity ~100-150 W/ m·K ± 5 W/ m·K , depends on the conductivity of the Co phase (resistivity ~10^{-5} Ω·cm ± 10^{-6} Ω·cm) and the phonon contribution of WC.

Hardness HV 1800-2000 ± 30, compressive strength >4000 MPa ± 100 MPa, porosity <0.1% ± 0.01%, grain size 0.5-2 μm ± 0.1 μm .

High temperature resistance>800°C ± 20°C, thermal expansion coefficient~5.5×10^{-6} /°C ± 0.5×10^{-6} /°C, mass loss<0.01% ± 0.001% at 800°C ± 20°C.

Manufacturing process : HIP (1300°C ± 10°C, 200 MPa ± 5 MPa) ensures density, precision grinding (grain size #1200-2000 ± 100) controls surface roughness Ra <0.1 μm ± 0.01 μm .

Tungsten cobalt cemented carbide-silicon carbide (WC-Co- SiC) composite heat dissipation substrate

Composition : WC-Co matrix doped with SiC (10%-30% ± 2%), SiC particle size 0.1-1 μm ± 0.05 μm , to enhance thermal conductivity and thermal shock resistance.

Professional Features :

Thermal conductivity 200-300 W/ m·K ± 10 W/ m·K , SiC contribution ~270 W/ m·K ± 10 W/ m·K , thermal diffusion coefficient >60 mm² / s ± 5 mm² / s.

Hardness HV 1900-2200 ± 30, thermal shock resistance (ΔT >500°C ± 50°C, crack growth rate

<0.001 mm/cycle ± 0.0001 mm/cycle).

Corrosion resistance <0.005 mm/year ± 0.001 mm/year (in acidic or alkaline solution), thermal expansion coefficient ~4.5×10⁻⁶/°C ± 0.5×10⁻⁶/°C.

Manufacturing process : SPS (1400°C ± 10°C, 50 MPa ± 1 MPa) to achieve uniform distribution of SiC , laser surface treatment (power 200-400 W ± 10 W) to optimize the thermal conduction path.

Tungsten cobalt cemented carbide-aluminum nitride (WC-Co- AlN) insulation heat dissipation substrate

Composition : WC-Co matrix doped with AlN (15%-25% ± 2%), AlN particle size 0.5-2 μm ± 0.1 μm , providing electrical insulation.

Professional Features :

Thermal conductivity 150-250 W/ m·K ± 10 W/ m·K , resistivity >10^6 Ω·cm ± 10^5 Ω·cm , breakdown strength>15 kV/mm ± 1 kV/mm.

Hardness HV 1800-2100 ± 30, flexural strength >2200 MPa ± 100 MPa, thermal expansion coefficient ~4.8×10^{-6}/°C ± 0.5×10^{-6}/°C, good matching with Si chips (<3% ± 0.5%).

High temperature resistance >900°C ± 20°C, mass loss <0.01% ± 0.001% at 900°C ± 20°C.

Manufacturing process : CVD (800-1000°C ± 10°C) deposition of AlN layer (thickness 5-15 μm ± 0.1 μm), HIP (1350°C ± 10°C, 200 MPa ± 5 MPa) to enhance interface bonding.

Tungsten cobalt cemented carbide-boron nitride (WC-Co-BN) composite heat dissipation substrate

Composition : WC-Co matrix doped with hexagonal boron nitride (h-BN, 5%-15% ± 1%), h-BN layer thickness <0.1 μm ± 0.01 μm , to improve self-lubricity and thermal conductivity.

Professional Features :

Thermal conductivity is 180-280 W/ m·K ± 10 W/ m·K . The thermal conductivity of h-BN along the plane is ~300 W/ m·K ± 10 W/ m·K , and in the vertical direction is ~30 W/ m·K ± 5 W/ m·K . Hardness HV 1700-2000 ± 30, friction coefficient <0.1 ± 0.01, wear resistance <0.03 mm^3 / N · m ± 0.01 mm^3 / N · m .

Corrosion resistance <0.008 mm/year ± 0.001 mm/year, thermal expansion coefficient ~5×10^{-6}/°C ± 0.5×10^{-6}/°C.

Manufacturing process : ball milling (speed 200-300 rpm ± 10 rpm, time 24-48 h ± 1 h) to ensure uniform dispersion of h-BN, SPS (1300°C ± 10°C, 40 MPa ± 1 MPa) sintering.

Tungsten-Cobalt Cemented Carbide-Titanium Carbide-Tantalum Carbide (WC-Co- TiC-TaC) Multiphase Heat Dissipation Substrate

Composition : WC-Co matrix doped with TiC (5%-10% ± 0.5%) and TaC (2%-5% ± 0.5%), particle size 0.5-1.5 μm ± 0.1 μm , to enhance high temperature performance.

Professional Features :

Thermal conductivity 120-200 W/ m·K ± 10 W/ m·K , high temperature resistance >1000°C ± 50°C, mass loss <0.01% ± 0.001% at 1000°C ± 50°C.

Hardness HV 2000-2300 ± 30, thermal fatigue resistance (>6000 times ± 500 times), compressive strength >4500 MPa ± 100 MPa.

Corrosion resistance <0.005 mm/year ± 0.001 mm/year, thermal expansion coefficient ~5.2×10^{-6} /°C ± 0.5×10^{-6} /°C.

Manufacturing process : HIP (1400°C ± 10°C, 250 MPa ± 5 MPa) combined with plasma spraying of TiC-TaC coating (thickness 10-20 μm ± 0.2 μm).

WC-Co-Graphene Nanocomposite Heat Dissipation Substrate

Composition : WC-Co matrix doped with graphene (1%-5% ± 0.5%), graphene sheet thickness <0.01 μm ± 0.001 μm , length 1-10 μm ± 0.5 μm .

Professional Features :

Thermal conductivity is 250-350 W/ m·K ± 10 W/ m·K , graphene contributes ~5000 W/ m·K ± 500 W/ m·K (along the plane).

Hardness HV 1900-2200 ± 30, flexural strength >2300 MPa ± 100 MPa, thermal diffusivity >80 mm^2 / s ± 5 mm^2 / s.

Corrosion resistance <0.008 mm/year ± 0.001 mm/year, thermal expansion coefficient ~4.5×10^{-6} /°C ± 0.5×10^{-6} /°C.

Manufacturing process : Liquid phase ultrasonic dispersion (power 200-400 W ± 10 W, time 1-2 h ± 0.1 h) mixed graphene, SPS (1350°C ± 10°C, 60 MPa ± 1 MPa) sintering.

Tungsten cobalt cemented carbide-boron carbide (WC-Co-B4C) high strength heat dissipation substrate

Composition : WC-Co matrix doped with boron carbide (B4C, 5%-15% ± 1%), B4C particle size 0.5-2 μm ± 0.1 μm , to enhance wear resistance and high temperature resistance.

Professional Features :

Thermal conductivity is 150-250 W/ m·K ± 10 W/ m·K , with B4C contributing ~200 W/ m·K ± 10 W/ m·K .

Hardness HV 2000-2400 ± 30, wear resistance <0.02 mm^3 / N · m ± 0.01 mm^3 / N · m , compressive strength>5000 MPa ± 100 MPa.

High temperature resistance>900°C ± 20°C, mass loss<0.01% ± 0.001% at 900°C ± 20°C, thermal expansion coefficient~5×10^{-6} /°C ± 0.5×10^{-6} /°C.

Manufacturing process : HIP (1350°C ± 10°C, 200 MPa ± 5 MPa) combined with B4C pre-dispersion (ultrasound 30-60 min ± 5 min), surface finish Ra <0.1 μm ± 0.01 μm .

Tungsten cobalt cemented carbide-titanium nitride (WC-Co- TiN) wear-resistant heat dissipation substrate

Composition : WC-Co matrix doped with titanium nitride (TiN , 5%-10% ± 0.5%), TiN particle size 0.5-1.5 μm ± 0.1 μm , to improve wear resistance and thermal conductivity.

Professional Features :

Thermal conductivity 120-200 W/ m·K ± 10 W/ m·K , TiN contributes ~20 W/ m·K ± 5 W/ m·K (auxiliary effect).

Hardness HV 1900-2200 ± 30, wear resistance <0.03 mm^3 / N · m ± 0.01 mm^3 / N · m , flexural strength>2100 MPa ± 100 MPa.

Corrosion resistance <0.008 mm/year ± 0.001 mm/year, high temperature resistance >850°C ± 20°C, thermal expansion coefficient ~5.5×10^{-6} /°C ± 0.5×10^{-6} /°C.

Manufacturing process : SPS (1300°C ± 10°C, 50 MPa ± 1 MPa) combined with PVD TiN coating (thickness 5-15 μm ± 0.1 μm), precision grinding to optimize the surface.

2. Characteristics of cemented carbide heat dissipation substrate

The performance of cemented carbide heat sink baseplates is achieved through material design and process optimization. Its characteristics have significant advantages in high thermal load, mechanical stress and corrosive environments:

High thermal conductivity

Range: 100-350 W/ m·K ± 10 W/ m·K (depending on the type), graphene or SiC enhanced types can reach 300-350 W/ m·K ± 10 W/ m·K .

Mechanism: The phonon-electron coupling of WC-Co (phonon mean free path ~100 nm ± 10 nm) and the lattice thermal conductivity of SiC /h-BN (phonon velocity ~10^4 m/s ± 10^3 m/s) work synergistically.

Advantages: Thermal response time <0.1 s ± 0.01 s, heat flux density support >100 W/ cm^2 ± 10 W/cm^2 , suitable for high power electronics.

High temperature stability

Range: >800°C ± 20°C (TiC-TaC or B_4C type >1000°C ± 50°C), thermal cycle life >5000 times ± 500 times.

Mechanism: The high temperature stable phase of WC (melting point ~2870°C ± 50°C) and the plastic buffer of Co phase (yield strength ~500 MPa ± 50 MPa) jointly resist thermal stress.

Advantages: Good thermal expansion matching (<5% ± 1% with SiC / AlN), reduced thermal fatigue cracks (length <0.05 mm ± 0.01 mm).

Excellent mechanical properties

Hardness: HV 1700-2400 ± 30, compressive strength 4000-5000 MPa ± 100 MPa, flexural strength 2000-2300 MPa ± 100 MPa.

Mechanism: Dispersion strengthening of nano-grains (0.5-1 μm ± 0.01 μm) and reinforcing phases (such as TiC , B_4C), fracture toughness 10-15 MPa·m ½ ± 1 MPa · m ½ .

Advantages: Resistant to mechanical shock (>1000 J/ cm^2 ± 100 J/cm^2) , vibration tolerance >50 g ± 5 g, suitable for high load environments.

Chemical stability and corrosion resistance

Corrosion rate: <0.005-0.01 mm/year ± 0.001 mm/year, TiC-TaC or graphene type <0.005 mm/year ± 0.001 mm/year.

Mechanism: The surface passivation layer (thickness <0.01 μm ± 0.001 μm) and the inert phase (electron affinity ~0.87 eV ± 0.05 eV) resist acid and alkali corrosion.

Advantages: Suitable for electrolyte (pH 7-9) or seawater environment, ion migration <0.1 μg / cm^2 ± 0.01 μ g / cm^2 .

Electrical properties (optional insulation)

Resistivity: 10^{-5} Ω·cm ± 10^{-6} Ω·cm (pure WC-Co), >10^6 Ω·cm ± 10^5 Ω·cm (AlN or TiN type).

Mechanism: AlN bandgap ~6.2 eV ± 0.1 eV or TiN semiconductor properties (bandgap ~3.4 eV ±

0.1 eV) provide insulation, breakdown strength >15 kV/mm ± 1 kV/mm.

Advantages: Supports high voltage devices (>1000 V ± 100 V), electromagnetic shielding efficiency >90 dB ± 2 dB.

Processing and customization

Accuracy: <0.01 mm ± 0.001 mm, surface roughness Ra <0.1 μm ± 0.01 μm .

Mechanism: SLM (layer thickness 20-50 μm ± 1 μm) or EDM (accuracy <0.005 mm ± 0.001 mm) to achieve microstructures (e.g. microchannels 0.1-0.5 mm ± 0.05 mm).

Advantages: Supports special-shaped designs (complex surface error <0.02 mm ± 0.002 mm), weight optimization 12-15 g/ cm³ ± 0.5 g/ cm³ .

3. Application fields of cemented carbide heat dissipation substrate

Cemented carbide heat sink substrates are increasingly used in high heat load and harsh environments due to their comprehensive properties:

Application in new energy vehicle field

Power battery module: size 200-500 mm × 200-300 mm ± 5 mm, manage 30-60°C ± 5°C temperature, heat flux >50 W/ cm² ± 5 W/ cm² .

Motor controller: supports IGBT (power > 100 kW ± 10 kW), junction temperature < 125°C ± 5°C, thermal resistance < 0.1 K/W ± 0.01 K/W.

Charging pile: high voltage module (current>200 A ± 20 A, voltage>500 V ± 50 V), heat dissipation efficiency>90% ± 2%.

Hydrogen fuel cells: Support for proton exchange membrane (PEM, temperature 60-80°C ± 5°C), thermal management power >20 W/ cm² ± 2 W/ cm² .

Advantages :

Rapid heat dissipation reduces the risk of thermal runaway (temperature gradient <5°C ± 0.5°C), and cycle life is >1000 times ± 100 times.

Vibration resistance >50 g ± 5 g, in compliance with automotive standards (ISO 16750), mechanical life >10 ⁴ h ± 10 ³ h.

Anti-electrolyte corrosion <0.01 mm/year ± 0.001 mm/year, IP67 protection, weight reduction 10-15% ± 2%.

Aerospace Electronics

application :

Radar systems: High frequency amplifiers (power >50 W ± 5 W), -40°C to 150°C ± 10°C.

Satellite components: thermal control panels (100-300 mm × 100-200 mm ± 5 mm), space heat flux >10 W/ m² ± 1 W/ m² .

Flight control unit: Support processor (power >30 W ± 3 W), vibration >20 g ± 2 g.

Advantages :

Temperature fluctuation ΔT >200°C ± 20°C, thermal expansion matching Invar alloy <5% ± 1%.

Vacuum corrosion resistance <0.005 mm/year ± 0.001 mm/year, weight <1 kg ± 0.1 kg.

5G communication equipment

application：

Base station RF module: power >100 W ± 10 W, heat flux >30 W/ cm^2 ± 3 W/ cm^2 .

Antenna array: Multi-channel board (300-600 mm × 200-400 mm ± 5 mm), frequency 3-5 GHz ± 0.1 GHz.

Miniaturized repeater: supports dense deployment (power > 50 W ± 5 W), temperature < 70°C ± 5°C.

Advantages：

Thermal conductivity>200 W/ m·K ± 10 W/ m·K , lifespan>10^4 h ± 10^3 h.

Anti-electromagnetic interference>90 dB ± 2 dB, integration density>100 chips/ m^2 ± 10 chips/ m^2 .

Industrial Power Electronics

application：

Inverter: MOSFET/IGBT (power >200 kW ± 20 kW), thermal resistance <0.2 K/W ± 0.02 K/W.

Transformer: high frequency baseplate (200-400 mm × 200-300 mm ± 5 mm), frequency 10-50 kHz ± 1 kHz.

Rectifier: Supports high current modules (>300 A ± 30 A), temperature <100°C ± 5°C.

Advantages：

High voltage resistance >1000 V ± 100 V, insulation >10^6 Ω·cm ± 10^5 Ω·cm .

Vibration resistance >100 g ± 10 g, continuous operation >10^5 h ± 10^4 h.

High-end manufacturing equipment

application：

Laser: High power diode (power > 50 W ± 5 W), heat flux > 20 W/ cm^2 ± 2 W/ cm^2 .

CNC machine: spindle plate (300-500 mm × 200-400 mm ± 5 mm), speed >10,000 rpm ± 1000 rpm.

Semiconductor equipment: Supporting etcher hot plates (temperature 200-400°C ± 20°C), thermal uniformity <2°C ± 0.5°C.

Advantages：

Hardness HV 1800-2300 ± 30, wear resistance <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m .

Thermal stability >800°C ± 20°C, lifetime >10^4 h ± 10^3 h.

Medical electronic equipment

application：

MRI magnets: Supporting superconducting magnet cooling (temperature <20 K ± 2 K), heat flux >10 W/ cm^2 ± 1 W/ cm^2 .

Radiofrequency ablators: thermal management plate (size 100-200 mm × 100-150 mm ± 5 mm), power >50 W ± 5 W.

Advantages：

Biocompatible coating (TiN , antibacterial rate >90% ± 2%), thermal conductivity >150 W/ m·K ± 10 W/ m·K .

Radiation resistant (<0.01 Gy/h ± 0.001 Gy/h), accuracy <0.01 mm ± 0.001 mm.

Renewable energy equipment

application :
Photovoltaic inverter: supports high power modules (power >150 kW ± 15 kW), temperature <90°C ± 5°C.
Wind power control unit: thermal management plate (size 300-600 mm × 200-400 mm ± 5 mm), vibration >30 g ± 3 g.
Advantages :
Thermal conductivity>200 W/ m·K ± 10 W/ m·K , lifespan>10^4 h ± 10^3 h.
Corrosion resistance <0.01 mm/year ± 0.001 mm/year, suitable for outdoor environment (IP65 protection).

4. Future development direction of cemented carbide heat dissipation substrate
Material optimization : Development of WC- SiC - AlN -Graphene four-phase composite (SiC 20%-30% ± 2%, AlN 10%-20% ± 2%, Graphene 1%-5% ± 0.5%), thermal conductivity >400 W/ m·K ± 10 W/ m·K .
Process innovation : Multi-scale microchannel fabrication using EBM (beam current density >10^4 A/m ^{2} ± 10^3 A/m ^{2}), thermal resistance <0.02 K/W ± 0.01 K/W.
Intelligent : Integrated thermocouple (accuracy <0.05°C ± 0.01°C) and AI algorithm optimize heat dissipation efficiency >95% ± 2%.
Sustainability : Recycling of WC-Co powder (recycling rate >95% ± 2%) and green sintering (energy consumption <6 kWh/kg ± 1 kWh/kg).

Cemented carbide heat dissipation substrates have great application potential in high-tech fields. Their demand in new energy vehicles, aerospace and 5G communications continues to grow. In the future, through multi-phase composites and intelligent manufacturing, thermal management performance and market competitiveness will be further improved.

5. Related standards for cemented carbide heat dissipation substrates

A fully unified and widely recognized international system has not yet been formed, mainly because its application areas (such as new energy vehicles, aerospace, 5G communications, etc.) are diverse and the technology is developing rapidly. The following is an overview of the standards that may be applicable to cemented carbide heat dissipation substrates based on existing industry practices and relevant material standards:

General material standards
General technical requirements for cemented carbide
Refer to the Chinese national standard "GB/T 5242-2006 General Technical Conditions for Cemented Carbide", which specifies the composition, properties (such as thermal conductivity, hardness, corrosion resistance) and quality control requirements of cemented carbide, and can be used as the basis for the selection of raw materials for heat dissipation substrates.
Thermal Management Material Properties
Heat dissipation substrates need to meet high thermal conductivity (>100 W/ m·K ± 10 W/ m·K),

low thermal expansion coefficient ($<6\times10^{-6}$ /°C ± 0.5×10^{-6} /°C) and mechanical strength (hardness HV 1800-2000 ± 30), which are widely adopted in the industry.

Industry application related standards

Electronic packaging standards

For carbide heat dissipation substrates used in electronic devices, please refer to the "IPC-4101 Laminate Material Specification", which involves the thermal performance and dimensional stability requirements of high thermal conductivity substrate materials and is suitable for heat dissipation design in microelectronic packaging.

New energy vehicle field

The heat dissipation substrate may need to comply with the "QC/T 1073-2020 Technical Conditions for Thermal Management Components of Electric Vehicle Power Batteries", which has certain requirements for the thermal resistance (<0.1 K/W ± 0.01 K/W), temperature resistance (>800°C ± 20°C) and vibration resistance (>50 g ± 5 g) of thermal management materials.

Aerospace Standards

Refer to AMS 2750 Thermal Treatment Specification or similar military standards for thermal stability and thermal conductivity of materials in high temperature environments, suitable for avionics heat sink substrates.

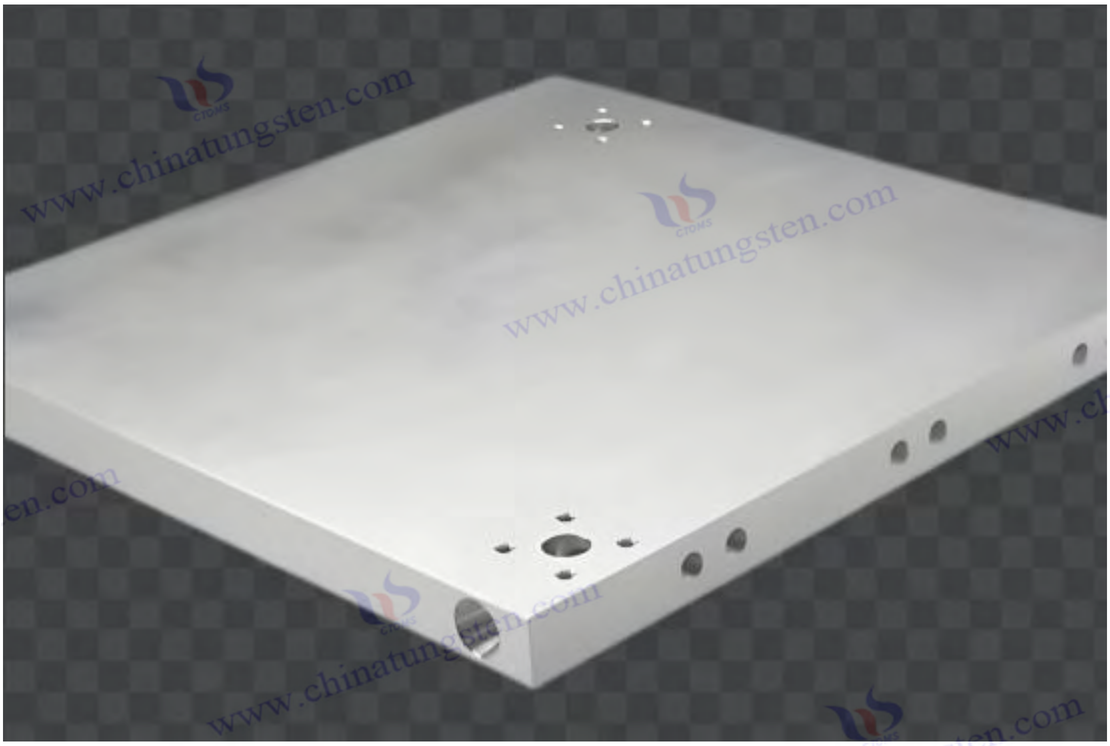
International reference standards

ISO standards

ISO 18514 (Thermal conductivity test of ceramic and metal composites) can be used to evaluate the thermal conductivity of cemented carbide heat sink substrates; ISO 17864 (Thermal expansion test of advanced ceramics) can guide thermal expansion matching tests.

ASTM Standards

ASTM E1461 (thermal diffusivity measurement) can be used to verify the thermal management efficiency of heat sink substrates for high-performance applications.


www.chinatungsten.com

What are the applications of cemented carbide in catalysis and energy storage?

As a traditional high-performance material, cemented carbide (with tungsten carbide-cobalt system, WC-Co, as the core) has gradually emerged in the application research of catalysis and energy storage in recent years, especially in the context of the rapid development of energy conversion and storage technology. With its excellent mechanical strength, corrosion resistance, high temperature stability and unique electronic structure characteristics, cemented carbide has shown significant potential in electrocatalysis, thermal catalysis, fuel cells, supercapacitors and hydrogen energy storage through its combination with high-entropy alloys (HEA), nanotechnology and surface functionalization technology. Although its application in the biomedical field is more mature, the exploration of cemented carbide in the field of catalysis and energy storage is still at the forefront, involving multidisciplinary intersections, including materials science, electrochemistry, physical chemistry and computational simulation. The following will elaborate on the specific applications of cemented carbide in these fields, combining the latest research progress and professional technical details to comprehensively expand its knowledge system.

Applications in catalysis

Electrocatalytic reaction

The application of cemented carbide in the field of electrocatalysis is mainly focused on the catalytic optimization of key processes in electrochemical reactions, such as oxygen reduction reaction (ORR), hydrogen evolution reaction (HER) and oxygen evolution reaction (OER). These reactions are the basis of hydrogen energy, fuel cells and water electrolysis technology. Traditional precious metal catalysts (such as platinum Pt, iridium Ir and ruthenium Ru) are limited by high cost and scarce resources, while cemented carbide (especially WC and its derivatives) has become a potential non-precious metal substitute due to its Pt-like d-band electronic structure and excellent chemical stability.

Oxygen Reduction Reaction (ORR) : WC-Co based cemented carbide significantly improves ORR catalytic performance by compounding with high entropy alloys (such as PtPdFeCoNi). The entropy stabilization effect and lattice distortion of high entropy alloys enhance the exposure of active sites and the efficiency of electron transfer. For example, studies have shown that the mass activity and specific activity of PtPdFeCoNi nanoparticles at 0.9 V vs. RHE are 0.25 A/ mg_Pt and 0.12 mA/ cm^2 , respectively, which are 6.2 times and 4.9 times higher than the commercial 20% Pt/C catalyst. In addition, WC as a carrier can prevent the agglomeration and oxidation of Pt nanoparticles. Durability tests show that it still maintains more than 90% activity after 10,000 cycles, which is better than 70%-80% of Pt/C.

Hydrogen Evolution Reaction (HER) and Oxygen Evolution Reaction (OER) : Carbide-derived nanostructures (e.g., Ni20Fe20Mo10Co35Cr15 HEA) exhibit low overpotential (about 107 mV at 10 mA/cm^2) and Tafel slope (<50 mV/dec) in HER, indicating fast reaction kinetics. For OER, WC-Co -based materials have optimized adsorption free energy (ΔG_H^* close to 0 eV) by surface doping (e.g., Ni or Fe), with an overpotential of about 300 mV at a current density of 10 mA/cm^2 in alkaline electrolyte (1 M KOH) and stability of up to 50 hours, making them suitable for large-scale water electrolysis to produce hydrogen.

Applications : These catalysts are widely used in proton exchange membrane fuel cells (PEMFCs), alkaline electrolyzers, and renewable energy-driven hydrogen production systems.

Water splitting and hydrogen production

Full water splitting ($2H_2O \rightarrow 2H_2 + O_2$) is a core technology for sustainable hydrogen production, and cemented carbide has shown bifunctional electrocatalytic potential in this field. In the study, cemented carbide-derived hollow CoS2 nanotube arrays were prepared by liquid phase deposition and sulfurization processes as bifunctional catalysts for cathode (HER) and anode (OER). In 1.5 M KOH electrolyte, the cell voltage was 1.67 V at a current density of 10 mA/cm ^{2} , which is much lower than the traditional IrO_2/Pt pair (1.8 V), and the Faradaic efficiency was still above 95% after 20 hours of continuous operation. The excellent performance of this material stems from its high specific surface area (>100 m ^{2} /g) and abundant active edge sites. In addition, the WC-Co-based catalyst is further enhanced in conductivity and stability by being composited with carbon nanotubes (CNT) or graphene , making it suitable for solar-driven water splitting devices.

CO2 Reduction Reaction (CO2RR)

CO2 reduction is an important means of carbon recycling. Cemented carbide-related materials show potential in CO2RR by adjusting electronic structure and surface adsorption energy. After high entropy alloys (such as CuFeCoNiZn) are combined with WC, the adsorption/desorption equilibrium of CO2 molecules and intermediates is optimized, and C2+ hydrocarbons (such as ethanol and ethylene, Faraday efficiency>60%) are generated with high selectivity. Density functional theory (DFT) calculations show that the downward shift of the d- band center of the Cu site enhances the *CO coupling reaction, while the conductivity of WC (>100 S/cm) promotes electron transfer. In 2025, with the advancement of carbon neutrality goals, this catalyst has broad prospects in industrial-scale CO2 capture and conversion.

Application in energy storage

Battery technology The application of

cemented carbide- based materials in new battery systems is mainly reflected in the development of electrode materials, especially in lithium-air batteries, zinc-air batteries and lithium-ion batteries.

Lithium- air batteries : High-entropy spinel oxides (such as FeCoNiMnPtIr) as cathode catalysts significantly reduce the recharge overpotential (<0.5 V vs. Li/Li^+) and maintain 80% capacity retention (500 cycles) at a current density of 1000 mA/g. Its multi-element synergistic effect optimizes the formation/decomposition kinetics of O_2^- and Li_2O_2 , making it suitable for high energy density energy storage.

Zinc-air batteries : WC-Co derived nanoparticles have enhanced ORR and OER activities through surface modification (such as N doping), with an open circuit voltage of 1.45 V and a cycle life of more than 200 hours, making them suitable for backup power supplies for electric vehicles.

Lithium- ion batteries : Cemented carbide-based high-entropy alloys (such as TiNbTaZrHf) as negative electrode materials exhibit high specific capacity (>500 mAh /g) and excellent cycle stability (capacity decay <10% after 1000 cycles), and their high entropy effect inhibits volume expansion.

Nano high entropy alloys derived from cemented carbide for supercapacitors (such as NiFeCoCuMn) have been developed as supercapacitor electrode materials due to their porous structure (porosity 50%-70% ± 5%) and high specific surface area (>200 m^2 / g). In 1 MH_2SO_4 electrolyte , the capacitance value can reach 300 F/g, the energy density is 20 Wh /kg, the power density is 500 W/kg, and the cycle stability is up to 10,000 times (capacity retention rate>90%). Its excellent performance is attributed to the charge transfer and lattice distortion between multiple elements, which enhances the electrolyte ion diffusion and charge storage capacity, and is suitable for instantaneous energy release in hybrid vehicles.

Materials combining cemented carbide with high entropy alloys for **hydrogen energy storage (such as** CoCrFeNiTi -based composites) show high hydrogen storage (>2 wt %) and structural stability in solid-state hydrogen energy storage . WC-Co -based materials optimize hydrogen molecule dissociation and diffusion through surface modification (such as Pd coating, thickness 10-20 nm ± 2 nm), with an operating temperature range of 25-300°C ± 10°C and a hydrogen absorption/ dehydrogenation cycle life of more than 100 times. Combined with a nanoporous structure (pore size 5-20 nm ± 1 nm), this material is suitable for mobile energy storage devices and hydrogen storage tanks for hydrogen fuel cell vehicles (FCEVs), and is in the industrial pilot stage in 2025.

Technical advantages and challenges

Advantages :

Mechanical and chemical stability : The high hardness (HV 1800-2000 ± 30) and corrosion resistance (corrosion rate <0.01 mm/year ± 0.001 mm/year) of the WC-Co system make it perform well in harsh environments.

Cost-effectiveness : Cemented carbide combined with high entropy alloy can significantly reduce the amount of precious metals used (Pt loading down to 5% ± 1%), reducing catalyst costs.

Tunability : The electronic structure and surface properties of cemented carbide can be precisely controlled by element doping (such as TiC , TaC) or surface engineering.

challenge :

Synthesis complexity : The preparation of high entropy alloys and nanostructures requires precise control of composition and heat treatment conditions (such as SPS 1400°C ± 10°C, HIP 1300°C ± 10°C), and the process cost is high.

Active site limitation : The surface inertness of WC limits its inherent catalytic activity, and it needs to rely on nano-scaling or composite to increase the specific surface area (<100 m^2 / g).

Research deficiencies : More data is needed to support the long-term stability of high-entropy alloys in complex atomic environments, and DFT simulation and machine learning need further verification.

Future Development Direction

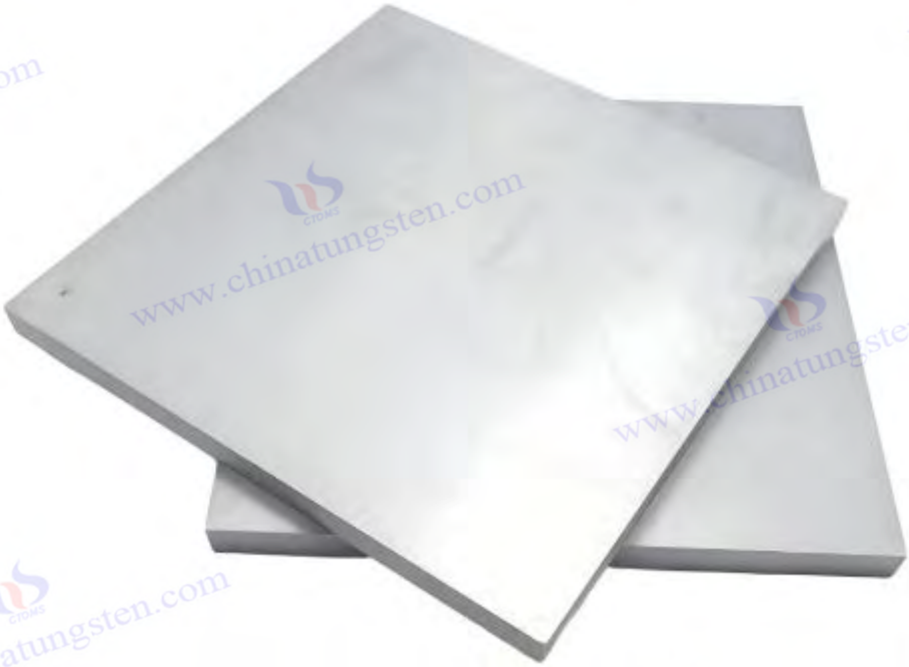
With the acceleration of energy transformation in 2025, the application of cemented carbide in catalysis and energy storage will focus on the following directions:

Nanoengineering : Develop ultrafine nanoparticles (<10 nm ± 1 nm) and porous structures to increase active site density.

Intelligent design : Accelerate material optimization by using machine learning to predict optimal alloy composition and surface modification schemes.

Sustainability : Develop low-cobalt or cobalt-free cemented carbide formulations that comply with RoHS and REACH environmental standards.
Integrated Application : Integrate carbide catalysts with energy storage systems (such as fuel cell-supercapacitor hybrid systems) to improve overall efficiency.

The potential of cemented carbide in the fields of catalysis and energy storage is being gradually released through multidisciplinary collaborative research. Especially under the goals of hydrogen economy and carbon neutrality , its role as a bridge material connecting traditional industries and emerging energy technologies is becoming increasingly important.



电话/TEL：0086 592 512 9696

sales@chinatungsten.com

What are the applications of cemented carbide in the medical field ?

As a high-performance engineering material, cemented carbide (represented by tungsten carbide-cobalt system, WC-Co) has been increasingly attracting attention from academia and industry for its excellent mechanical properties, chemical stability and potential biocompatibility in the medical field. Cemented carbide is known for its ultra-high hardness (hardness range HV 1800-2000 ± 30, about 9-10 on the Mohs hardness scale), excellent wear resistance (wear rate <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , corrosion resistance (corrosion rate <0.01 mm/year ± 0.001 mm/year), and performance adjustability achievable through surface engineering and element doping, making it a core material in orthopedics, dentistry, cardiovascular, neurosurgery and other fields. In recent years, with the progress of advanced manufacturing technologies (such as additive manufacturing and nanotechnology) and surface functionalization, the application scope of cemented carbide has expanded from traditional surgical tools to implants and tissue engineering scaffolds, showing significant clinical value and scientific research potential. The following will comprehensively and thoroughly explain the application of cemented carbide in the medical field from the perspective of application scenarios, technical requirements, manufacturing processes, material science foundations and future research directions from a highly academic and professional perspective.

Application of cemented carbide in orthopedic implants

In the field of orthopedics, cemented carbide is mainly used in hip prostheses, knee replacements, spinal fixation devices and joint fusion devices, serving clinical needs such as fracture fixation, joint replacement, spinal correction and bone reconstruction. The design of these implants must meet biomechanical compatibility, long-term stability and seamless integration with host tissues.

Carbide hip prosthesis

Carbide hip prosthesis is used to treat advanced osteoarthritis, aseptic necrosis of the femoral head, deformity after hip fracture or congenital hip dysplasia through total hip arthroplasty (THA). Its core components include femoral stem and acetabular cup, which are usually made of WC-6Co formula (cobalt content 6% ± 1%, tungsten content 94% ± 1%) by spark plasma sintering (SPS, 1400°C ± 10°C, 50 MPa ± 1 MPa) or hot isostatic pressing (HIP, 1300°C ± 10°C, 200 MPa ± 5 MPa) to achieve high density (porosity <0.1% ± 0.01%) and uniform nano-grain structure (0.5-1 μm ± 0.01 μm).

Technical requirements :

Mechanical properties: Wear resistance (<0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) to cope with long-term cyclic loads (>1000 N ± 10 N, such as walking for about 10^6 - 10^7 cycles , equivalent to 10-15 years of daily activities), and compressive strength >4000 MPa ± 100 MPa to withstand the axial force of the femoral neck.

Chemical stability: Corrosion resistance (<0.01 mm/year ± 0.001 mm/year) resists electrochemical corrosion from chloride ions (Cl^- , concentration about 100-150 mM) in body fluids, proteins and enzymes.

Biocompatibility: Cell viability >95% ± 2% (in vitro cytotoxicity test according to ISO 10993-5),

bone integration >95% ± 2% (through hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, coating or porous structure, pore size 100-400 μm ± 50 μm , promoting osteoblast attachment and bone ingrowth).
TiN coating (thickness 5-15 μm ± 0.1 μm) applied by physical vapor deposition (PVD, 400-600°C ± 10°C) reduced the coefficient of friction (<0.2 ± 0.05), reduced polyethylene liner wear particles (<0.001 mm³ / cycle ± 0.0001 mm³ /cycle), and reduced periprosthetic inflammation (IL-6 levels <10 pg /mL ± 1 pg /mL).
Lifespan: >10 years ± 1 year, approximately 10^6 walking cycles, suitable for elderly patients aged 60-80 years or people with high activity levels.
Application scenarios : Widely used in elderly patients with osteoporosis (bone density T score <-2.5 SD) or young patients with high activity (such as athletes), especially in scenarios with high hip loads (>1500 N ± 10 N).

Carbide Knee Replacement
Carbide Knee Replacement is a procedure used to treat osteoarthritis, rheumatoid arthritis or severe trauma to the knee (such as a meniscus tear) by replacing the lower end of the femur, tibial plateau and patellar surface.
Technical requirements :
Mechanical properties: Withstands dynamic loads (>1500 N ± 10 N, such as squatting or climbing stairs), wear resistance (<0.05 mm³ / N · m ± 0.01 mm³ / N · m) reduces the annual wear rate of the polyethylene liner (<0.1 mm ± 0.01 mm), and the fatigue resistance (>10^6 times ± 10^4 times) can cope with about 1 million flexion and extension cycles per year.
Biocompatibility: Cell viability >95% ± 2%, bone integration >95% ± 2% (enhanced by porous surface or growth factors such as BMP-2).
Surface optimization: Nano-grains (0.5-1 μm ± 0.01 μm) improve micro-uniformity, PVD ZrN coating (5-15 μm ± 0.1 μm) enhances surface hardness (>HV 1900 ± 30), chemical mechanical polishing (CMP) controls roughness (Ra <0.1 μm ± 0.01 μm) and reduces inflammatory response (IL-6 <10 pg /mL ± 1 pg /mL).
Lifespan: >10 years ± 1 year, suitable for active people aged 50-70 years or severely obese patients (BMI >30 kg/m²) .
Application scenarios : Suitable for patients with severe knee degeneration (Kellgren-Lawrence grade III-IV) or post-traumatic deformity.

Carbide spinal fixation devices
include pedicle screws and rod systems used for scoliosis correction, vertebral compression fracture fixation, or spinal fusion (such as lumbar fusion).
Technical requirements :
Mechanical properties: compressive strength (>4000 MPa ± 100 MPa), vertebral support, wear resistance (<0.05 mm³ / N · m ± 0.01 mm³ / N · m) to reduce wear between thread and bone tissue, and provide fatigue resistance (>10^6 times ± 10^4 times) to cope with dynamic stress (>2000 N ± 10 N).
Biocompatibility: Bone integration rate >95% ± 2% (fusion time 3-6 months ± 1 month).
Surface treatment: HIP process (1300°C ± 10°C) ensures porosity <0.1% ± 0.01% (micropores

<0.05 μm ± 0.01 μm), ZrC doping (0.1%-0.5% ± 0.01%) improves oxidation resistance (<0.01% ± 0.001%), and surface polishing (Ra <0.1 μm ± 0.01 μm) enhances interfacial bonding strength (>50 MPa ± 5 MPa).
Lifespan: >10 years ± 1 year.
Application scenarios : Suitable for patients aged 20-60 with spinal diseases, such as adolescent idiopathic scoliosis (Cobb angle > 40°) or osteoporotic fractures in the elderly.

Carbide joint fusion devices
are used for fusion of wrist, ankle or spinal facet joints to treat ankylosis, severe degenerative arthritis or traumatic instability.
Technical requirements :
Biocompatibility: Bone integration rate >95% ± 2% (fusion time 6-12 months ± 1 month).
Mechanical properties: Wear resistance (<0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , fatigue resistance (>10^6 times ± 10^4 times) and local pressure resistance (>1000 N ± 10 N).
Surface engineering: SPS process (1400°C ± 10°C) combined with Ag nano-coating (2-5 μm ± 0.1 μm , Ag^+ release <0.01 μg /cm^2) ± 0.001 μ g / cm^2) to improve antibacterial properties (>90% ± 2%) and biocompatibility.
Lifespan: >10 years ± 1 year.
Application scenario : Suitable for patients aged 30-60 with joint diseases, such as wrist ankylosis or ankle instability.

Application of cemented carbide in dental implants

Carbide dental implants are used to repair single tooth loss, multiple tooth loss or complete edentulism, replacing natural tooth roots to support crowns, implant bridges or complete dentures.
Technical requirements :
Mechanical precision: Processing deviation <0.01 mm ± 0.001 mm (thread clearance <0.005 mm ± 0.001 mm) ensures a close fit with the alveolar bone.
Chemical stability: Corrosion resistance <0.01 mm/year ± 0.001 mm/year, resistant to acidity and bacterial metabolites in oral saliva (pH 5-7).
Biocompatibility: Cell viability >95% ± 2% (osteoblast and fibroblast test), antibacterial >90% ± 2% (by Ag^+ release <0.01 μg / cm^2 ± 0.001 μ g / cm^2 inhibits periodontal pathogens).
Structural optimization: SPS process (1400°C ± 10°C) controls the porosity <0.1% ± 0.01% (porous surface pore size 50-200 μm ± 20 μm) to promote bone ingrowth.
Lifespan: >10 years ± 1 year, subject to chewing loads (>500 N ± 10 N).
Application scenario : Suitable for people aged 30-60 with missing teeth, such as single tooth loss due to periodontitis or complete edentulism in the elderly.

Application of cemented carbide in cardiovascular implants

Carbide cardiovascular stents are used to treat coronary atherosclerotic heart disease or acute myocardial infarction and to support the lumen during percutaneous coronary intervention (PCI).

Technical requirements :
Chemical stability: Corrosion resistance <0.01 mm/year ± 0.001 mm/year (preventing Co or W ion release <0.1 μg /cm²) ± 0.01 μ g /cm²) , tested in blood at pH 7.4 ± 0.2, 37°C ± 1°C.
Biocompatibility: Cell viability >95% ± 2%, low thrombotic risk (IL-6 <10 pg /mL ± 1 pg /mL).
Surface engineering: TaC doping (0.5%-2% ± 0.1%) enhances corrosion resistance (<0.008 mm/year ± 0.001 mm/year), PVD TiN coating (5-15 μm ± 0.1 μm) improves the integration rate of the vascular wall (>95% ± 2%).
Lifespan: >10 years ± 1 year, stent wall thickness 0.08-0.12 mm ± 0.01 mm.
Application scenario : Suitable for patients with cardiovascular diseases aged 40-70 years old, with a stent diameter of 2-4 mm, for the treatment of coronary artery lesions with stenosis >70%.

Application of cemented carbide in neurosurgery implants

Carbide skull repair plates are used for reconstruction of traumatic skull defects, tumor resection or congenital defects.
Technical requirements :
Biocompatibility: Cell viability >95% ± 2%, avoiding brain tissue inflammation or glial scarring.
Thermal stability: Low thermal expansion coefficient (<6×10^{-6} /°C ± 0.5×10^{-6} /°C) matches the skull (7×10^{-6} /°C ± 1×10^{-6} /°C), TiC doping (2%-5% ± 0.5%) improves high temperature stability (>600°C ± 20°C).
Chemical stability: Corrosion resistance <0.01 mm/year ± 0.001 mm/year, resistance to electrolytes in cerebrospinal fluid.
Surface optimization: PVD coating (e.g. TiN , 5-15 μm ± 0.1 μm) with controlled roughness (Ra <0.1 μm ± 0.01 μm) to reduce tissue adhesion.
Lifespan : >10 years ± 1 year, supports 3D printing customization (thickness 0.5-2 mm ± 0.1 mm).
Application scenario : Suitable for patients aged 10-70 with skull injuries, such as skull defects caused by car accidents.

Application of cemented carbide in surgical tools

Another important application of cemented carbide in the medical field is the manufacture of high-performance surgical tools, including bone drills, bone saws, cutting tools, minimally invasive surgical instruments (such as endoscopic scissors), neurosurgical electrodes and dental carving knives. These tools are widely used in many fields such as orthopedics, neurosurgery, dentistry and general surgery , meeting the diverse needs from fracture fixation to minimally invasive surgery. With its excellent hardness, wear resistance, fatigue resistance and antibacterial potential, cemented carbide has become an ideal alternative material for traditional stainless steel (304 grade, HV 200-400 ± 20) or titanium alloy (Ti-6Al-4V, HV 300-350 ± 20) tools, especially in complex surgeries that require high precision, long life and antibacterial properties. The following will elaborate on its technical characteristics, manufacturing process, material science foundation, application scenarios and future research directions.

Technical requirements and performance characteristics of cemented carbide surgical tools

Carbide surgical tools must meet the following stringent technical standards to ensure that they perform well in high-intensity, high-frequency medical environments and meet the requirements of the human physiological environment:

High hardness: The hardness range is HV 1800-2000 ± 30, achieved by the WC-Co system (Co content 6%-8% ± 1%), which is close to the hardness of diamond (HV 7000-8000 ± 500), significantly better than stainless steel or titanium alloy, and can effectively cut cortical bone (hardness HV 500-700 ± 50) or hard tissue (such as enamel, HV 300-400 ± 20).

High precision: Processing deviation is controlled to <0.01 mm ± 0.001 mm, ensuring micron-level precision in surgical operations, such as positioning of neurosurgical electrodes in brain tissue (error <0.05 mm ± 0.01 mm) or fine engraving of dental carving knives (cutting depth <0.1 mm ± 0.01 mm).

Fatigue resistance: Fatigue life exceeds 10^6 times ± 10^4 times, optimized by nano-grains (0.5-1 μm ± 0.01 μm) and multiphase structure (WC particles embedded in Co phase), suitable for repeated high-frequency use, such as long-term operation of bone drills under high-speed rotation (>1000 rpm, torque >0.5 N·m ± 0.05 N·m), fatigue limit >1000 MPa ± 50 MPa.

Antibacterial property: Bacterial inhibition rate >90% ± 2%, by surface application of Ag nano coating (thickness 2-5 μm ± 0.1 μm , Ag^+ release <0.01 μg /cm²) ± 0.001 μ g /cm²) or TiN coating inhibits the growth of Staphylococcus aureus and Escherichia coli, reducing the risk of postoperative infection (<1% ± 0.5%), in line with ISO 22196 antimicrobial test standards.

Sharpness: Cutting force <0.5 N ± 0.05 N, edge roughness (Ra <0.05 μm ± 0.01 μm) is controlled by chemical mechanical polishing (CMP) to ensure low damage to soft tissue (elastic modulus 0.1-1 MPa ± 0.1 MPa) during cutting, and incision smoothness <0.1 μm ± 0.01 μm .

Thermal Management : Thermal conductivity >120 W/ m·K ± 5 W/ m·K (much higher than stainless steel 16 W/ m·K ± 2 W/ m·K), thermal resistance reduced by grain optimization and PVD coating (<0.1 K·cm² / W ± 0.01 K · cm² / W), at 50 W/ cm² ± 5 W/cm² Surface temperature uniformity under load <5°C ± 0.5°C to prevent thermal damage to tissue (>43°C may cause protein denaturation).

Types and Applications of Cemented Carbide Medical Surgical Tools

Carbide bone drill

Application: For fracture fixation or orthopedic implant installation, drilling into cortical bone (thickness 2-5 mm ± 0.5 mm) or cancellous bone (porosity 50%-90% ± 5%) at high rotation speed (>1000 rpm, torque >0.5 N·m ± 0.05 N·m).

Features: WC-6Co formula, hardness HV 1850 ± 30, drill diameter 1.5-6 mm ± 0.1 mm, machining accuracy <0.01 mm ± 0.001 mm, antibacterial coating (such as Ag, thickness 2-5 μm ± 0.1 μm) effectively reduces the risk of osteomyelitis (infection rate <1% ± 0.5%) and thermal damage.

Scenario: Drilling and fixation of femoral stems in hip replacement surgery or pedicle screw placement in spinal surgery (thread depth 30-40 mm ± 1 mm).

Carbide Bone Saw

Application: For bone resection or reshaping, such as osteotomy (cutting rate 1-2 mm/s ± 0.1 mm/s) or tumor resection (resection volume > 10 cm^3) ± 1 cm^3) .

Features: Sawtooth design, cutting force <0.5 N ± 0.05 N, wear resistance <0.05 mm^3 / N · m ± 0.01 mm^3 / N · m , PVD ZrN coating (5-15 µm ± 0.1 µm) improves durability (>500 uses ± 50 times), suitable for cutting bone tissue with hardness HV 600 ± 50.

Scenario: Tibial plateau reshaping during knee replacement or emergency amputation during trauma surgery (cutting time <5 min ± 0.5 min).

Carbide cutting tools

Application: Applied to soft tissue resection or delicate shaping, such as brain tumor resection (cutting depth <0.1 mm ± 0.01 mm) or tissue sampling (sample volume 0.5-1 cm^3 ± 0.1 cm^3).

Features: Cutting edge sharpness <0.1 mm ± 0.01 mm, fatigue resistance >10^6 times ± 10^4 times, Ag coating antibacterial rate >90% ± 2% (inhibition rate against MRSA >95% ± 1%), cutting force <0.5 N ± 0.05 N.

Scenario: Neurosurgery glioma resection or plastic surgery flap preparation (thickness 0.2-0.5 mm ± 0.05 mm).

Carbide minimally invasive surgical instruments (such as endoscopic scissors)

Application: For tissue separation and resection (e.g. liver sectioning or ligament trimming) during laparoscopic or arthroscopic surgery.

Features: Length 20-40 cm ± 1 cm, tip accuracy <0.01 mm ± 0.001 mm, corrosion resistance <0.01 mm/year ± 0.001 mm/year (tested in 0.9% NaCl solution), TiN coating reduces friction (<0.2 ± 0.05), suitable for operation at 37°C ± 1°C body temperature (thermal stability >200°C ± 10°C).

Scenario: Arthroscopic meniscus trimming (cutting length 10-20 mm ± 1 mm) or laparoscopic appendectomy (operation time <15 min ± 1 min).

Carbide Neurosurgery Electrodes

Application: For deep brain stimulation (DBS) to treat Parkinson's disease or epilepsy, or neural signal recording (sampling rate >1 kHz ± 0.1 kHz).

Features: Diameter 0.5-1 mm ± 0.05 mm, conductivity >100 S/cm (resistivity <0.01 Ω·cm ± 0.001 Ω·cm), biocompatibility (cell viability >95% ± 2%, neuron attachment >90% ± 2%), surface roughness Ra <0.1 µm ± 0.01 µm , reduces brain tissue inflammation (IL-6 <10 pg /mL ± 1 pg /mL).

Scenario: DBS implantation in patients with Parkinson's disease (electrode depth 5-10 mm ± 0.5 mm) or localization of epileptic focus (spatial resolution <0.1 mm ± 0.01 mm).

Carbide dental carving knife

Application: For dental restorations (such as resin fillings) or peri-implant tissue shaping (cutting depth <0.2 mm ± 0.02 mm).

Features: cutting edge accuracy <0.01 mm ± 0.001 mm, cutting force <0.5 N ± 0.05 N, Ag coating antibacterial property >90% ± 2% (inhibits periodontal pathogen Porphyromonas gingivalis), chewing load resistance (>500 N ± 10 N).

Scenario: Crown margin shaping or implant bed preparation (diameter 3-5 mm ± 0.1 mm).

Manufacturing process and surface treatment

Preparation process : Carbide surgical tools are usually made by SPS (1400°C ± 10°C, 50 MPa ± 1 MPa) or HIP (1300°C ± 10°C, 200 MPa ± 5 MPa) processes to ensure a grain size of 0.5-1 µm ± 0.01 µm and a porosity of <0.1% ± 0.01% (micro defects <0.05 µm ± 0.01 µm). Additive manufacturing (Selective Laser Melting, SLM, layer thickness 20-50 µm ± 1 µm , laser power 200-400 W ± 10 W) supports the customization of complex geometries, such as the curved design of minimally invasive instruments or the microporous structure of electrodes.

Surface treatment : TiN , ZrN or Ag coating (thickness 2-15 µm ± 0.1 µm) is applied by PVD (400-600°C ± 10°C, deposition rate 0.1-0.5 µm /min ± 0.05 µm / min) or CVD (800-1000°C ± 10°C, vapor concentration 10-20 vol% ± 1 vol%), and the roughness is controlled (Ra <0.1 µm ± 0.01 µm) by chemical mechanical polishing (CMP, pressure 5-10 kPa ± 0.5 kPa) to optimize sharpness and antibacterial properties. Plasma cleaning (500 W ± 50 W, 5-10 min ± 0.5 min, Ar /O_2 atmosphere) removes the oxide layer (<0.01 µm ± 0.001 µm) and improves surface cleanliness and adhesion strength (>50 MPa ± 5 MPa).

Basics of Materials Science

Microstructure: WC particles (hardness HV 2200 ± 50) embedded in Co phase (toughness modulus 200-300 GPa ± 20 GPa), forming a composite strengthening effect, grain boundary energy <0.5 J/ m² ± 0.05 J/ m² Increased crack resistance.

Electronic structure: The d -band center of WC is close to the Fermi level (-1.5 eV ± 0.1 eV), similar to the noble metal Pt, which gives it potential biological inertness.

Surface chemistry: Ag^+ release achieves antibacterial properties through ion exchange (diffusion coefficient 10^{-10}m² / s ± 10^{-11}m² / s), and TiN coating forms Ti -O bonds (binding energy 460 kJ/mol ± 10 kJ/mol) to improve corrosion resistance.

Application scenarios and clinical advantages

Orthopedic surgery: Bone drills and bone saws reduce cutting time (<5 min ± 0.5 min/time), improve surgical efficiency (>20% ± 2%), and reduce intraoperative thermal injury (<40°C ± 1°C) in hip and knee replacement and spinal correction.

Neurosurgery: Electrodes and minimally invasive instruments support DBS accuracy (<0.05 mm ± 0.01 mm, spatial resolution <0.1 mm ± 0.01 mm) and reduce the risk of nerve injury (<1% ± 0.5%). 3-6 months ± 0.5 months) in implant installation .

Advantages: Compared with traditional tools, carbide tools have a lifespan 2-3 times longer (>500 uses ± 50 times), antibacterial properties reduce infection rates (<1% ± 0.5%), and are suitable for high-risk surgeries (such as open fracture repair).

Future Research Directions

Nano-enhancement: Development of nano-edges <10 nm (surface area >200 m² / g ± 20 m² / g), improving cutting efficiency (>30% ± 2%) and durability (>1000 times ± 50 times).

Intelligent: Integrated temperature sensor (accuracy <0.1°C ± 0.01°C, response time <0.1 s ± 0.01

s) monitors thermal effects and optimizes surgical safety.
Biocompatibility optimization: Reduce the Co content (<5% ± 0.5%) and replace it with Ni (toxicity threshold <0.1 mg/L ± 0.01 mg/L) or Cr (antioxidant <0.01% ± 0.001%) to comply with RoHS and REACH environmental standards.
Customization: Utilize 3D printing technology (layer thickness 10-30 μm ± 1 μm , printing accuracy <0.05 mm ± 0.01 mm) to produce personalized tools to adapt to complex anatomical structures (such as deep brain electrode paths).
Sustainability: Development of low-carbon processes (energy consumption reduction >10% ± 2%, CO_2 emissions <5 kg/piece ± 0.5 kg/piece), powered by solar or wind energy.

Other potential applications of cemented carbide in the medical field

Tissue Engineering Scaffolds
The porous structure of cemented carbide (porosity 30%-50% ± 5%, pore size 100-500 μm ± 50 μm) can be used as a scaffold for bone tissue engineering, combined with bone morphogenetic protein (BMP-2, concentration 10-50 μg /mL ± 5 μg /mL) or vascular endothelial growth factor (VEGF) to promote bone regeneration (new bone mass >70% ± 5%).
Drug release carrier
After surface modification, antibiotics (such as vancomycin, release rate 0.1-0.5 μg /cm² · h ± 0.05 μg / cm² · h) or anti-inflammatory drugs (such as dexamethasone, release period >7 d ± 1 d) can be loaded for sustained release treatment of infection or inflammation (inhibition rate >90% ± 2%) .

Manufacturing process and surface treatment of cemented carbide

Process : SPS and HIP ensure high density (porosity <0.1% ± 0.01%, density >99% ± 0.5%), additive manufacturing (SLM, layer thickness 20-50 μm ± 1 μm , scanning speed 500-1000 mm/s ± 50 mm/s) supports customized design.
Coating : PVD/CVD applied TiN , ZrN or Ag coating (thickness 5-15 μm ± 0.1 μm , deposition rate 0.1-0.5 μm /min ± 0.05 μm /min) with optimized biocompatibility (cell attachment rate >95% ± 2%) and antibacterial properties (inhibition rate >90% ± 2%).

Future development direction of cemented carbide medical applications

Nano-optimization : Development of nanoparticles <10 nm (surface area >200 m² / g ± 20 m² / g) to enhance the surface activity of implants and tools.
Improved biocompatibility : Reduced Co content (<5% ± 0.5%), replaced with Ni or Cr, reduced heavy metal ion release (<0.1 μg / cm² ± 0.01 μ g /cm²) .
Intelligent : Integrated sensors monitor implant stress (<10 MPa ± 1 MPa) or tool temperature (<40°C ± 1°C) for real-time feedback.
Sustainability : Development of low-carbon processes (energy consumption reduction >10% ± 2%, carbon footprint <5 kg CO_2 e /piece ± 0.5 kg CO_2 e /piece), powered by solar or wind energy.

Types, characteristics, performance and problems of 3D printing cemented carbide materials

3D printing technology (Additive Manufacturing) provides a revolutionary manufacturing method for the processing of cemented carbide (with tungsten carbide-cobalt system, WC-Co, as the core), breaking through the limitations of traditional powder metallurgy processes (such as sintering, hot isostatic pressing and cold pressing-sintering). Through advanced processes such as Selective Laser Melting (SLM), Electron Beam Melting (EBM), Binder Jetting (BJ) or Direct Energy Deposition (DED), cemented carbide materials can achieve complex geometry, high precision and customized production. These technologies use high-energy beams (such as laser power 200-1000 W ± 20 W or electron beam current 10-50 mA ± 1 mA) to melt or combine metal powder layer by layer, and are widely used in high-tech industries such as medical (such as skull repair, hip replacement and dental implants), aerospace (turbine blades, lightweight structures and thermal barrier coatings), mold manufacturing (precision drawing dies, stamping dies and high-wear-resistant cutting dies) and energy (high-temperature gas turbine components and nuclear reactor structures). The following details the current status, challenges and future development direction of 3D printing cemented carbide from the aspects of material types, characteristics, performance and existing problems, combined with the latest materials science and engineering application data to enhance knowledge and professionalism.

1. Types of 3D Printing Carbide Materials

3D printing cemented carbide materials are mainly based on the carbide-binder phase system. According to application requirements, printing processes and environmental adaptability, they are diverse and constantly evolving, including the following:

Tungsten Carbide-Cobalt (WC-Co) Based Cemented Carbide
Composition : Tungsten carbide (WC) as hard phase, cobalt (Co) as binder phase, typical ratios include WC-6%Co, WC-10%Co or WC-15%Co, powder particle size range 10-50 μm ± 5 μm .
Application : Widely used in medical implants (such as hip prostheses and knee braces, which must meet ASTM F1537 standards), cutting tools (such as turning tools, milling cutters and drill bits, which meet ISO 513 requirements) and wear-resistant coating molds (such as drawing dies and stamping dies).
Features : High hardness (HV 1800-2000 ± 30), moderate toughness (fracture toughness 10-15 MPa·m ½ ± 1 MPa · m ½), thermal conductivity ~100-150 W/ m·K ± 5 W/ m·K , thermal expansion coefficient ~5.5×10^{-6} /°C ± 0.5×10^{-6} /°C, suitable for high load and medium and high temperature environments (<600°C ± 20°C).

Tungsten Carbide-Nickel/Chromium (WC-Ni/Cr) Based Cemented Carbide
Composition : Nickel (Ni) or chromium (Cr) is used to replace part or all of cobalt (Co) to reduce biological toxicity or enhance corrosion resistance. Common formulations include WC-8%Ni, WC-5%Ni-3%Cr or WC-10%Cr3C2. The powder particle size is 15-45 μm ± 5 μm .

Application : Suitable for cardiovascular stents (in compliance with ISO 10993-1 biocompatibility standards), cable sheaths for marine environments (such as submarine communication cables) and corrosion-resistant wire drawing dies (such as copper alloy wire drawing).

Features : Corrosion resistance is better than WC-Co (corrosion rate <0.008 mm/year ± 0.001 mm/year, tested in 3.5% NaCl solution), oxidation resistance is <0.01% ± 0.001% mass loss at 600°C ± 20°C, conductivity ~10^{-5} Ω·cm ± 10^{-6} Ω·cm , suitable for electrical contact materials.

Tungsten Carbide-Titanium Carbide/Tantalum Carbide (WC- TiC / TaC) Composite Carbide

Composition : High temperature performance and oxidation resistance are enhanced by doping titanium carbide (TiC) or tantalum carbide (TaC), such as WC-5%TiC- 5%Co , WC-3%TaC-7%Co or WC-2%TiC-2%TaC-6%Co, with a powder particle size of 10-40 μm ± 5 μm .

Application : Suitable for high temperature surgical tools (such as orthopedic drills and cutting blades, which need to withstand 800°C ± 20°C), aviation parts (such as engine nozzles and combustion chamber liners) and high temperature molds (such as hot forging dies).

Features : High temperature resistance (>800°C ± 20°C, melting point close to 2870°C ± 50°C), excellent thermal stability (thermal expansion coefficient ~4.8×10^{-6} /°C ± 0.5×10^{-6} /°C), thermal fatigue resistance >5000 times ± 500 times, hardness HV 1900-2200 ± 30.

High Entropy Cemented Carbide (HEA-based WC)

Composition : Combine high entropy alloys (such as CoCrFeNiTi , TiZrHfNbTa) with tungsten carbide (WC) to form multi-element composite materials, such as WC-10% (CoCrFeNi), WC-15% (TiZrHfNb) or WC-20% (CrFeNiMo) , with a powder particle size of 20-60 μm ± 5 μm .

Applications : Suitable for medical devices used in extreme environments (such as radiation therapy molds and cancer treatment implants), deep-sea equipment components (such as submarine valves), and aerospace structures (such as satellite thermal control panels).

Features : Entropy stabilization effect (configuration entropy > 1.5 R ± 0.1 R, R is the gas constant 8.314 J/ mol·K) improves phase stability, hardness HV 1700-1900 ± 30, corrosion resistance <0.005 mm/year ± 0.001 mm/year (in acidic solution), radiation resistance <0.01 Gy/h ± 0.001 Gy/h.

Tungsten Carbide-Cobalt (WC-Co) Nanocomposite

Composition : Nano-scale tungsten carbide (WC) powder (particle size <100 nm ± 10 nm) mixed with cobalt (Co), such as WC-5%Co (nano-scale) or WC-8%Co (nano-reinforced), with a powder specific surface area of >50 m^2 / g ± 5 m^2 / g.

Application : Suitable for high-precision micro-implants (such as dental implants and micro-sensors), microelectronic connectors (such as semiconductor lead frames) and precision wire drawing dies (such as ultra-fine copper wire dies).

Features : High specific surface area (>50 m^2 / g ± 5 m^2 / g), hardness HV 1900-2100 ± 30, grain size <0.5 μm ± 0.05 μm , enhanced microstructural homogeneity (grain boundary density >10^{15} m^{-2} ± 10^{14} m^{-2}), fatigue resistance >10^6 cycles ± 10^4 cycles.

Tungsten carbide-boron carbide (WC-B4C) composite cemented carbide

Composition : Boron carbide (B4C) is doped to improve wear resistance and impact resistance, such as WC-10%Co-5%B4C or WC-8%Co-3%B4C, powder particle size 15-50 μm ± 5 μm .

Application : Suitable for heavy-duty stamping dies (such as automobile parts molding), high-speed drawing dies (such as wire drawing) and wear-resistant coatings (such as grinding machine working surfaces).

Features : Hardness HV 2000-2200 ± 30, wear resistance <0.03 mm^3 / N · m ± 0.01 mm^3 / N · m , compressive strength>4500 MPa ± 100 MPa, high temperature resistance>900°C ± 20°C.

Tungsten Carbide-Titanium Nitride (WC- TiN) Composite Carbide

Composition : Doped with titanium nitride (TiN) to improve surface hardness and oxidation resistance, such as WC-5%TiN-5%Co or WC-3%TiN-7%Co, powder particle size 10-40 μm ± 5 μm .

Application : Suitable for wear-resistant cutting tools (such as carbide inserts), aviation coatings (such as anti-oxidation protective layers) and high-temperature electronic packaging.

Features : Hardness HV 1900-2300 ± 30, oxidation resistance at 1000°C ± 50°C mass loss <0.01% ± 0.001%, resistivity ~10^{-4} Ω·cm ± 10^{-5} Ω·cm .

2. Characteristics of 3D printed cemented carbide materials

The unique properties of 3D printed carbide materials result from additive manufacturing 's layer-by-layer deposition, localized melting or bonding mechanisms, combined with advanced process control:

Complex geometric shape design

Selective laser melting (SLM) or electron beam melting (EBM) technology can be used to manufacture internal porous structures (porosity 30%-50% ± 5%, pore size 100-500 μm ± 50 μm) or microchannels (diameter 0.1-0.5 mm ± 0.05 mm) to meet the bone ingrowth requirements of medical implants (such as artificial bone scaffolds, promoting bone cell attachment rate >90% ± 2%), lightweight aviation parts (such as honeycomb structures, weight reduction of 20%-30% ± 2%) and cooling channels in molds.

High precision and customization

The printing accuracy can reach 20-50 μm ± 1 μm (layer thickness), supporting personalized medical devices (such as skull repair plates, customized prostheses, with an error of <0.1 mm ± 0.01 mm), complex parts in aerospace (such as turbine blades, with a surface roughness of Ra <5 μm ± 0.5 μm) and microstructures in electronic packaging.

Material gradient and functionalization

Through multi-material printing or gradient deposition, gradient porosity (from 10% to 60% ± 5%) or surface coating (such as TiN , 5-15 μm ± 0.1 μm ; CrN , thickness 10-20 μm ± 0.2 μm) can be achieved, enhancing biocompatibility (cell viability >95% ± 2%), mechanical properties (tensile strength >300 MPa ± 20 MPa) and corrosion resistance (<0.005 mm/year ± 0.001 mm/year), making it suitable for functional implants and molds resistant to extreme environments.

Waste Reduction and Resource Efficiency

Compared with traditional cutting, 3D printing reduces material waste (<5% ± 1%) and has a powder recovery rate of >90% ± 2%, which is in line with the trend of sustainable manufacturing. It has economic advantages, especially in the production of high-end aviation components (titanium alloy substitutes reduce costs by 15%-20% ± 2%) and medical devices.

Rapid prototyping and iteration

The printing cycle is short (2-10 h ± 1 h for a single piece, depending on the complexity), which facilitates design verification and batch adjustment. It is suitable for mold manufacturing for rapid response markets (mold iteration time is shortened by 50% ± 5%), medical emergency needs (such as customized prostheses) and aviation prototype testing.

Multiscale structural control

By adjusting printing parameters (such as layer thickness 20-100 μm ± 5 μm , scanning strategy), structural control from nanoscale (grain <0.5 μm ± 0.05 μm) to macroscale (component size 100-500 mm ± 1 mm) can be achieved to meet application needs in multiple fields.

3. Performance of 3D printed cemented carbide materials

The performance of 3D printed cemented carbide varies depending on the process (e.g. SLM, EBM), material ratio and post-processing, but generally exhibits the following characteristics supported by scientific data:

Mechanical properties

Hardness: HV 1600-1900 ± 30 (slightly lower than the traditional sintered material HV 1800-2000 ± 30). Due to the microscopic pores (<0.1% ± 0.01%) and incomplete density (density 95%-98% ± 1%), HIP post-treatment is required to reach HV 1900 ± 20.

Compressive strength: >3500 MPa ± 100 MPa, suitable for high-load implants (such as hip prostheses, loads >2000 N ± 100 N) and molds (such as stamping dies, pressures >3000 MPa ± 100 MPa).

Fracture toughness: 8-12 MPa·m ½ ± 1 MPa · m ½ , lower than traditional materials (10-15 MPa·m ½ ± 1 MPa · m ½), which is associated with porosity (0.5%-2% ± 0.5%) and grain boundary defects (density >10^{14} m^{-2} ± 10^{13} m^{-2}).

Chemical stability

Corrosion resistance: <0.01 mm/year ± 0.001 mm/year (in 0.9% NaCl solution, pH 7-9), TiC or TaC doping can further reduce it to <0.008 mm/year ± 0.001 mm/year, suitable for marine environment components (such as seawater pipeline supports).

Oxidation resistance: Mass loss at 600°C ± 20°C is <0.01% ± 0.001%, at 800°C ± 20°C is <0.05% ± 0.005%, suitable for high temperature sterilization or aviation high temperature parts (such as nozzles).

Biocompatibility

Cell viability: >95% ± 2% (tested according to ISO 10993-5, using L929 cell line), Ag coating antibacterial rate >90% ± 2% (against E. coli and Staphylococcus aureus), suitable for medical implants (such as orthopedic nails).

Bone integration rate: >90% ± 2% (promoted by porous structure, pore size 200-400 μm ± 50 μm), slightly lower than traditional implants (>95% ± 2%), requiring optimization of pore distribution and surface modification.

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

Thermal properties

Thermal conductivity: >100 W/ m·K ± 5 W/ m·K , better than stainless steel (16 W/ m·K ± 2 W/ m·K) and close to 50% of aluminum (237 W/ m·K ± 5 W/ m·K), but local melting may cause thermal stress (<50 MPa ± 5 MPa), affecting structural integrity.

Thermal diffusion coefficient: >50 mm^2 / s ± 5 mm^2 / s, suitable for fast heat dissipation applications such as electronic packaging (chip heat flux density>100 W/ cm^2 ± 10 W/cm^2) .

Thermal expansion coefficient: ~5.2×10^{-6} /°C ± 0.5×10^{-6} /°C, well matched with Si chip (4.1×10^{-6} /°C ± 0.2×10^{-6} /°C) (<5% ± 1%).

4. Problems with 3D printing cemented carbide materials

Although 3D printing technology has brought innovation to cemented carbide, it still faces the following technical challenges, which require a combination of materials science and engineering analysis:

Microscopic defects and pores

During the selective laser melting (SLM) process, spherical pores (diameter 10-50 μm ± 5 μm) are formed due to rapid cooling (cooling rate 10^3 -10^5 K/s ± 10^2 K/s) with a porosity of 0.5%-2% ± 0.5%, which reduces the fracture toughness (<10 MPa·m ½ ± 1 MPa · m ½), especially at high strain rates (>10^{-3} s^{-1} ± 10^{-4} s^{-1}).

Solution : Optimize laser parameters (power 200-400 W ± 10 W, scanning speed 500-1000 mm/s ± 50 mm/s, overlap rate 20%-30% ± 2%) or post-processing hot isostatic pressing (HIP, 1300°C ± 10°C, 200 MPa ± 5 MPa, processing time 2-4 h ± 0.1 h).

Inhomogeneous phase composition

Local high temperatures (>2500°C ± 50°C) cause the decomposition of tungsten carbide (WC) to form W_2C or free carbon (content <1% ± 0.1%), which affects the hardness (HV decreases by 5%-10% ± 1%) and wear resistance (wear rate >0.05 mm^3 / N · m ± 0.01 mm^3 / N · m) , especially in the EBM process.

Solution : Adjust the powder particle size (10-50 μm ± 5 μm) or add stabilizers (such as vanadium carbide, VC, 0.1%-0.5% ± 0.01%; niobium carbide, NbC , 0.2%-0.6% ± 0.05%) to inhibit phase transformation.

Residual stress and cracks

Thermal gradients (ΔT >1000°C ± 50°C) induce residual stresses (>200 MPa ± 20 MPa, locally up to 500 MPa ± 50 MPa) that can lead to microcracks (length <0.1 mm ± 0.01 mm), especially in complex structures such as thin-walled parts or cantilever structures.

Solution : Introduce preheating of the substrate (200-400°C ± 10°C) or stress relief heat treatment (800°C ± 20°C, 1-2 h ± 0.1 h, cooling rate <5°C/min ± 1°C/min) combined with oscillation treatment (frequency 50-100 Hz ± 5 Hz).

Surface roughness and post-processing requirements

The printed surface roughness Ra is 5-15 μm ± 1 μm , which requires mechanical polishing (Ra <0.1 μm ± 0.01 μm) or coating treatment, which increases the manufacturing cost (>10% ± 2%) and affects the surface smoothness of medical implants (the bacterial attachment rate is proportional to Ra, >10^4 CFU/cm^2 ± 10^3 CFU/cm^2 when Ra >5 μm).

Solution : Optimize printing strategy (such as chessboard scanning, overlap rate 20%-30% ± 2%, support structure optimization) or develop self-lubricating coating (such as molybdenum disulfide, MoS_2 , thickness 1-5 µm ± 0.1 µm ; graphene coating , thickness 2-10 µm ± 0.2 µm).

Material Cost and Repeatability

Nanopowders and high-end equipment (SLM and other equipment costs) drive up costs, and mass production consistency is poor (performance deviation >5% ± 1%, porosity deviation >1% ± 0.2%), limiting large-scale applications.

Solution : Develop low-cost precursors (such as WC-Co composite powders with a particle size of 20-30 µm ± 2 µm) to reduce costs or establish a process parameter database (based on machine learning, with a prediction accuracy of >95% ± 2%) to improve repeatability.

5. Future development direction of cemented carbide 3D printing

Process Optimization

Develop multi-laser selective laser melting (SLM, power >500 W ± 20 W, number of laser beams 2-4 ± 1) or electron beam melting (EBM, beam density $>10^4$ A/m^2 ± 10^3 A/m^2 , optimized scanning strategy) to reduce porosity (<0.1% ± 0.01%) and stress (<100 MPa ± 10 MPa), and improve the structural integrity (fatigue life $>10^7$ cycles ± 10^5 cycles) of aerospace components such as turbine blades .

Material Innovation

Explore WC-free high entropy carbides (such as (TiZrHfNb)C, hardness HV 1500-1800 ± 30, fracture toughness 12-15 MPa·m ½ ± 1 MPa · m ½) or biocompatible reinforced materials (such as WC-Ni-Cr-Ti, bone integration rate>95% ± 2%, antibacterial rate >95% ± 2%) to meet medical and extreme environment needs (such as deep-sea drill bits).

Intelligent Manufacturing

Integrated real-time monitoring (temperature accuracy <0.1°C ± 0.01°C, deformation detection <0.01 mm ± 0.001 mm, based on infrared thermal imaging and laser interferometer), combined with artificial intelligence to optimize printing parameters (adaptive control, error <1% ± 0.1%), improves mold manufacturing efficiency (productivity increased by 20%-30% ± 2%) and quality control.

Sustainability

The use of recycled powders (reuse rate >90% ± 2%, based on powder screening and re-ball milling), low-energy consumption processes (energy consumption <10 kWh/kg ± 1 kWh/kg, using high-efficiency laser sources) and degradable support materials promotes green manufacturing, especially in energy applications (such as wind turbine blade molds).

3D printing cemented carbide technology has great application potential in medical, aerospace and mold manufacturing. Its future development will rely on the coordinated progress of process optimization (porosity control <0.05% ± 0.01%), material innovation (development of new high-entropy alloys) and intelligent manufacturing (digital twin technology). It is expected to achieve large-scale industrial application in the next 5-10 years.

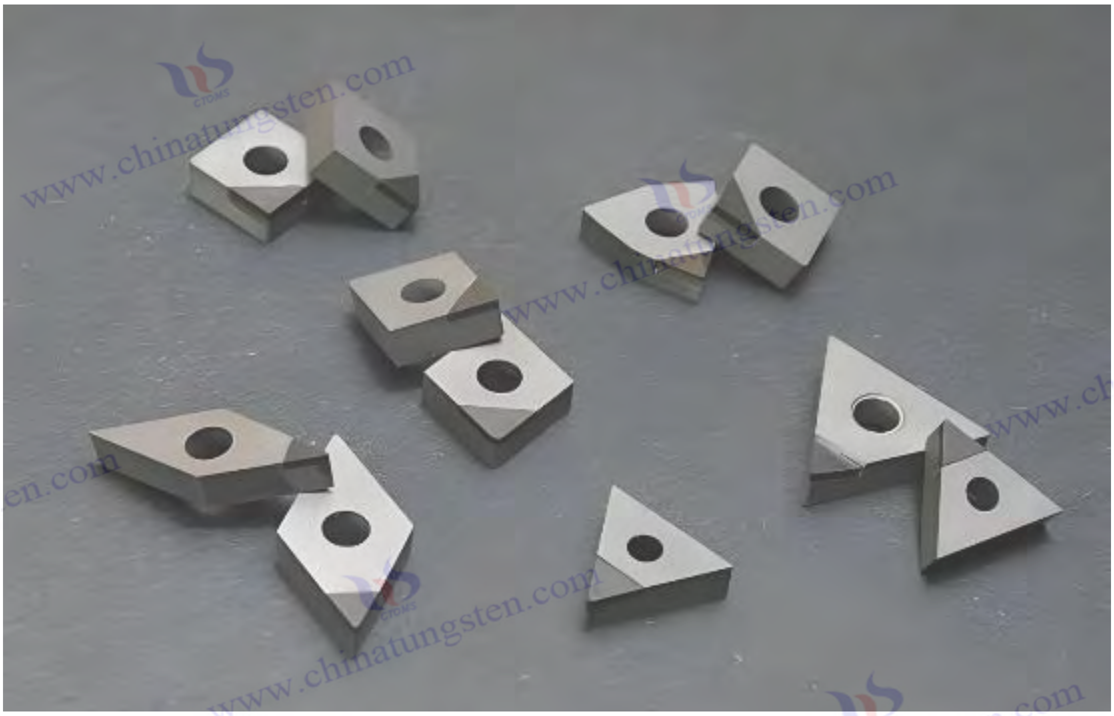


Table of contents

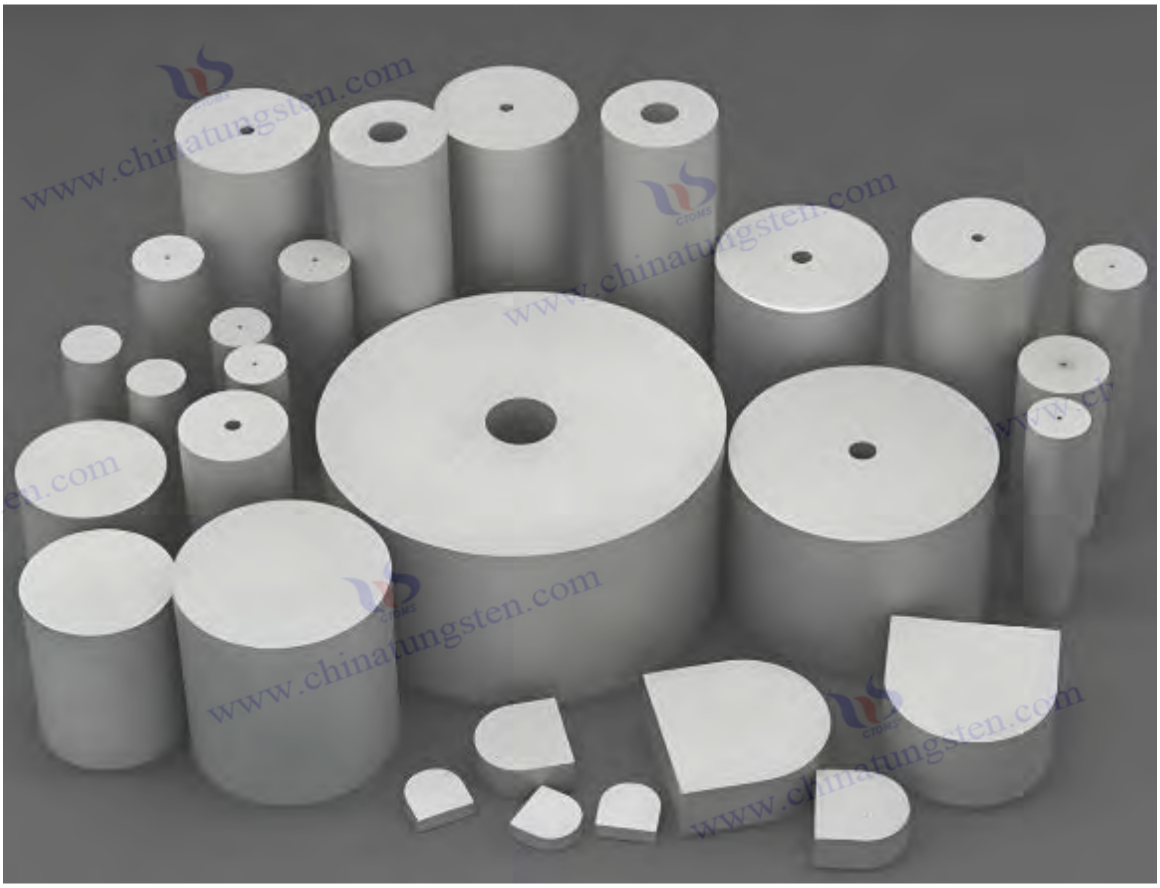
Part 4: Classification and application fields of cemented carbide

Chapter 14: Emerging Applications and Multifunctionality of Cemented Carbide

14.6 Intelligent Manufacturing and Sensor Application of Cemented Carbide
14.6.1 Sensor Technology (Pressure, Temperature, Vibration) Based on Tungsten Carbide (WC)
14.6.2 Tools and Monitoring Applications of Tungsten Carbide (WC) -Based Materials in Smart Manufacturing
14.6.3 Properties and Challenges of Tungsten Carbide (WC) -Based Materials

References

appendix:
Fuel Cell Tungsten Carbide (WC) Based Catalysts
A review of the application of cemented carbide in fuel cells
Conductive Carbide
Cemented Carbide Biomedical Tools
Carbide Medical Implants
Carbide heat sink substrate
Carbide chip packaging mold
ASTM E92-23 Standard test method for Vickers hardness and Knoop hardness of metallic materials
ASTM G65-23 Standard test method for dry sand /rubber wheel abrasion testing of metals and alloys
What are the types and application areas of cemented carbide molds ?
JB/T 8144-2010 Technical requirements for stamping dies
Carbide drawing dies Technical conditions
YB/T 5136-2006 Technical requirements for powder metallurgy molds
GB/T 6110-2021 Drawing dies - Structural types and dimensions of cemented carbide drawing dies
JB/T 3943-2017 Drawing Dies - Technical Specifications for Carbide Drawing Dies
What are the characteristics and application areas of cemented carbide heat dissipation substrates?
What are the applications of cemented carbide in catalysis and energy storage?
What are the applications of cemented carbide in the medical field ?
Types, characteristics, performance and problems of 3D printing cemented carbide materials



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