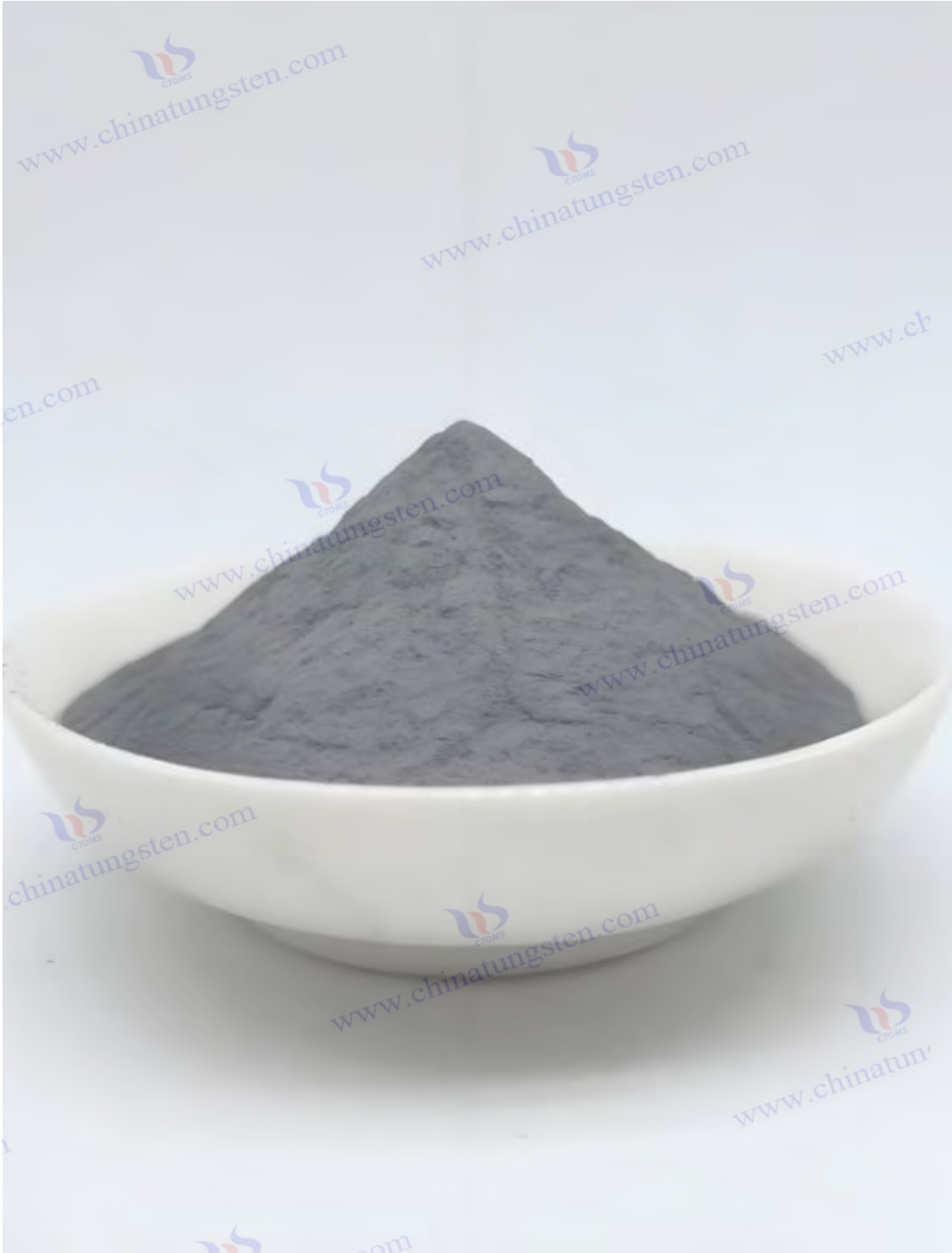


电话/TEL：0086 592 512 9696

sales@chinatungsten.com

Tungsten Carbide Powder (TCP)

Physical & Chemical Properties, Preparation, & Applications

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

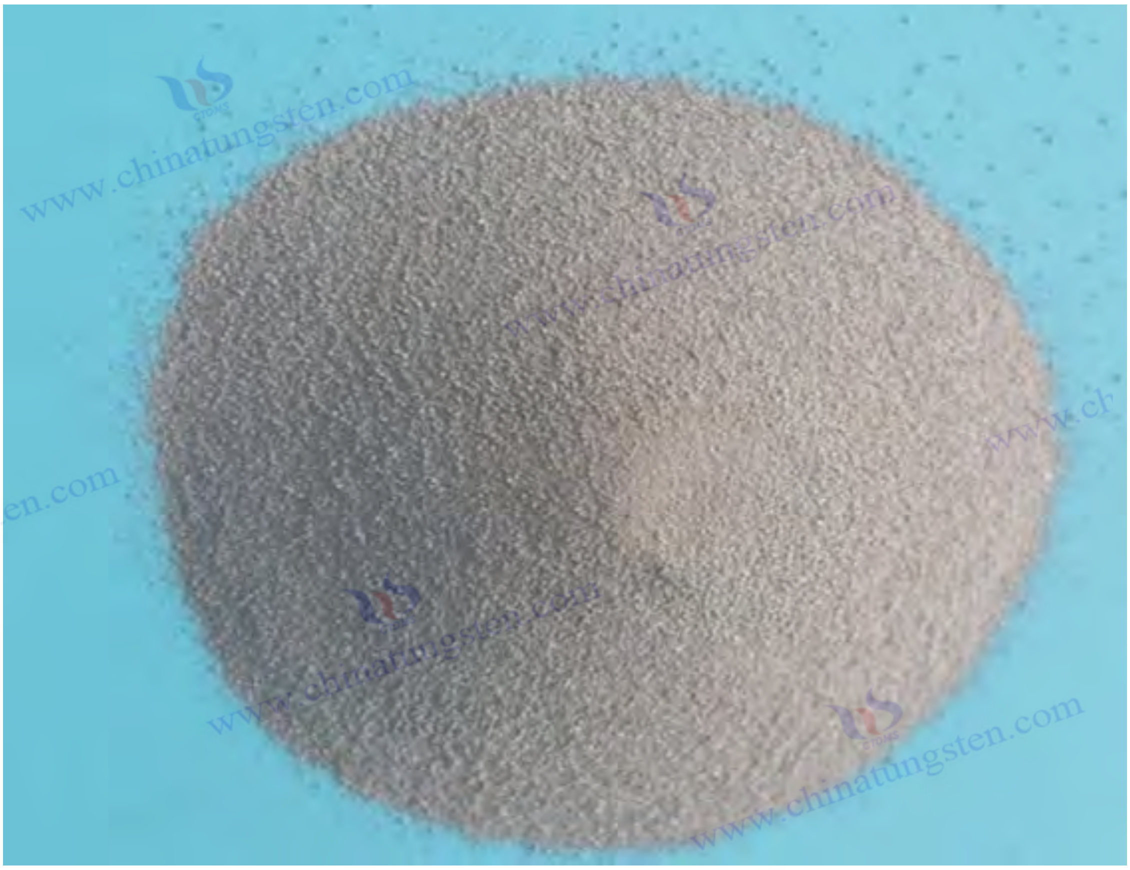


Table of Contents

Chapter 3: Microstructure and Characterization Technology of Tungsten Carbide Powder

3.1 Microstructure characteristics

3.2 Characterization methods

3.3 Chemical composition analysis

3.4 Physical properties test

Chapter 4: Application fields of tungsten carbide powder (key chapters)

Overview

The versatility and application value of tungsten carbide powder

Chapter Structure and Research Methods

Data Source and Case Analysis

4.1 Cemented Carbide Manufacturing

4.1.1 Cutting tools

4.1.1.1 Turning tools and milling cutters

WC-Co formula (cobalt content 6%-12%) and cutting performance Data: Cutting speed increased by 50% (compared to high-speed steel, >200 m/min) Case: Automobile engine cylinder block processing (lifespan > 100,000 pieces)

4.1.1.2 Drill bits and boring tools

micron-grade WC powder (1-3 μm) in deep hole processing Performance: Hardness HV 1600, chipping resistance >12 MPa·m1/2Technology: Multi-layer WC-TiC coated drill (wear resistance increased by 3 times)

4.1.1.3 Special cutting tools

PCB micro drill (diameter < 0.1 mm) and superhard material processing tools Sintering process (1450°C, HIP) of nano WC powder (<100 nm) Case: Aviation composite material processing (accuracy ±0.005 mm)

4.1.2 Wear-resistant parts

4.1.2.1 Stamping Dies

Application of WC-based dies in cold stamping steel plates Data: Lifespan > 500,000 times (5 times higher than Cr12MoV) Technology: WC-Co sintering (1500°C, 30 MPa)

4.1.2.2 Wire drawing die and extrusion die

fine WC powder (0.5-1 μm) in copper wire drawing Performance: Surface roughness Ra <0.02 μm, wear rate <0.001 mm³/N·m Case: Wire drawing die in cable industry (continuous operation > 6 months)

4.1.2.3 Wear-resistant bearings and seals

Application of WC-Ni composite materials in high-speed bearings Data: Friction coefficient <0.1, temperature resistance >800°C Technology: Hot Isostatic Pressing (HIP) Process Optimization

4.1.3 Precision machining tools

4.1.3.1 Dental and medical tools

Micromachining of WC powder on dental drill bits (diameter 0.3-1 mm) Properties: Hardness HV 1800, biocompatibility (ISO 10993-5) Case: Dental surgery drill (durability > 1000 times)

4.1.3.2 Optical mold

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

Application of Ultrafine WC Powder in Glass Lens Moulds Data: Surface accuracy <10 nm, lifespan >100,000 times of die pressing Technology: Mirror polishing combined with WC coating

4.2 Surface Coating Technology

4.2.1 Thermal spray coating

4.2.1.1 HVOF spraying

Application of WC-Co powder (10%-12% Co) in wear-resistant coating Data: coating hardness HV 1200-1400, wear rate <0.01 $mm^3/N\cdot m$ Case: Aircraft engine blades (lifespan > 3000 hours)

4.2.1.2 Flame spraying

Application of WC-Ni powder in low-cost wear-resistant coating Performance: Bonding strength >50 MPa, thickness 100-300 μm Case: Agricultural machinery blades (wear resistance increased by 4 times)

4.2.2 Plasma spraying and laser cladding

4.2.2.1 Plasma spraying

WC-Cr3C2 composite coating in high temperature corrosion resistance Data: Oxidation resistance >1000°C, porosity <2% Case: Gas turbine blades (operating > 5000 hours)

4.2.2.2 Laser cladding

Strengthening of the Surface of Oil Drilling Tools with WC Powder Performance: coating thickness 0.5-2 mm, hardness HV 1300 Case: Deep-sea drill pipe (corrosion resistance life > 2 years)

4.2.3 High temperature resistance and special coating

4.2.3.1 Thermal shock resistant coating

Application of WC-based coatings in high-temperature molds Data: Thermal expansion coefficient <5×10-6/°C, temperature resistance >1200°C Technology: WC-TiC-Ni composite coating

4.2.3.2 Chemical resistant coating

Corrosion resistance of WC-CoCr coating in chemical pipelines Case: Valves in acidic environments (lifespan > 3 years)

4.3 Mining and Construction Tools

4.3.1 Rock drilling tools

4.3.1.1 Hard rock drill bits

Application of WC inlaid drill bits in granite mining Data: Impact toughness >25 J/cm^2, drilling speed >12 m/h Case: Mine blasting drilling (lifespan > 1000 m)

4.3.1.2 Coal seam drilling tools

WC-Co cutter head in coal mine excavation Performance: Hardness HV 1500, wear resistance <0.002 $mm^3/N\cdot m$ Technology: WC-TiC composite strengthening

4.3.2 Shield cutters and tunneling equipment

4.3.2.1 Metro shield cutterhead

Application of WC-based cutting tools in sandstone formations Data: Cutting life > 6000 m, wear resistance increased by 2 times Case: Urban tunnel project (replacement cycle > 1 year)

4.3.2.2 Hard ground tunneling cutter

WC-TiC tools in basalt Performance: Fracture toughness >15 MPa·m1/2Technology: Sintering optimization of superhard WC powder

4.3.3 Wear-resistant lining and crushing equipment

4.3.3.1 Ball mill lining

Application of WC reinforced liner in ore grinding Data: Wear rate <0.05 g/t, life span >2 years Case: Iron ore processing (30% efficiency improvement)

4.3.3.2 Crusher hammer

Wear resistance of WC-Co hammer in limestone crushing Performance: Impact life > 100,000 times

4.4 Electronics and Energy Field

4.4.1 Conductive coating and electrode materials

4.4.1.1 Fuel cell electrodes

Electrical conductivity of WC powder in PEM fuel cells Data: Resistivity <10-5 Ω·cm, cycle stability >10,000 times Technology: PVD deposition of WC thin film

4.4.1.2 Lithium battery current collector

Durability of WC coating on aluminum foil Performance: Adhesion >20 N/cm, corrosion resistance increased by 2 times Case: Electric vehicle battery (capacity retention rate > 90%)

4.4.2 Catalyst carrier

4.4.2.1 Hydrogen fuel catalysis

Application of Nano-WC Powder (<50 nm) in Water Electrolysis Data: Catalytic activity >95% (compared to Pt/C) Technology: WC-Pt composite catalyst

4.4.2.2 Chemical Catalysis

Stability of WC-based supports in ammonia synthesis Performance: Temperature resistance >600°C, lifespan >5000 hours

4.4.3 Energy Storage and Thermal Management

4.4.3.1 Supercapacitor

Specific capacity of WC-based electrode materials (>250 F/g) Data: Cycle life > 8000 times Case: New energy storage system

4.4.3.2 Thermal Management Coating

Application of WC heat dissipation coating in LED Performance: Thermal conductivity >120 W/m·K

4.5 Aerospace and Military Applications

4.5.1 Turbine blades and nozzles

4.5.1.1 Aircraft engine blades

Application of WC-Co coating in high temperature wear resistance Data: Temperature resistance >1300°C, lifespan >4000 hours Case: Turbofan engine (thrust efficiency increased by 5%)

4.5.1.2 Rocket Nozzle

Application of WC-based heat-resistant coating in solid rockets Performance: Ablation resistance <0.01 mm/s

4.5.2 Armor materials

4.5.2.1 Tank Armor

Anti-ballistic performance of WC ceramic composite armor Data: Hardness >2200 HV, penetration resistance >1200 m/s Case: Main battle tank protection (thickness <50 mm)

4.5.2.2 Bulletproof vest plug-in

Application of lightweight WC substrate Performance: Weight <2 kg/m², protection level NIJ IV

4.5.3 Spacecraft wear-resistant parts

4.5.3.1 Onboard machinery

Wear resistance of WC coatings in satellite joints Data: Friction coefficient <0.05, life span >10 years Technology: Vacuum PVD process

4.6 Other Emerging Applications

4.6.1 3D Printing and Additive Manufacturing

4.6.1.1 Metal Parts Printing

Application of WC-Co powder in SLM (Selective Laser Melting) Data: Density >99%, accuracy ±0.02 mm Case: Rapid prototyping of aviation parts

4.6.1.2 Mould manufacturing

Advantages of Nano WC Powder in 3D Printing Molds Performance: Surface hardness HV 2000

4.6.2 Biomedical Materials

4.6.2.1 Orthopedic implants

Wear resistance of WC coating in hip joint Data: Wear rate <0.001 mm³/N·m, cell survival rate >98% Technology: WC-Ti composite coating

4.6.2.2 Dental restorations

WC-based materials in dental crowns Performance: Fracture strength >1000 MPa

4.6.3 Intelligent Manufacturing and Sensors

4.6.3.1 High temperature sensor

Stability of WC powder in industrial sensors Data: Temperature resistance > 1000°C, response time < 1 ms Case: Steelmaking furnace monitoring

4.7 Application Cases and Data Analysis

4.7.1 Industry Application Summary Table

Data comparison in the fields of cemented carbide, coating, mining, electronics, etc.

4.7.2 Performance Comparison Analysis

Key indicators such as hardness, wear resistance, life span, etc. (compared with traditional materials)

4.7.3 Successful Case Studies

Global enterprise application examples (such as Sandvik, Kennametal)

4.8 Future Application Prospects

4.8.1 Potential in emerging fields

Quantum computing cooling components Flexible electronic conductive layer

4.8.2 Technical Challenges and Solutions

Improvement of the Dispersion of Nano-WC Powder Improved stability of high temperature coatings

4.8.3 Market Forecast

Demand growth rate in 2030 >6%, analysis of key areas

CTIA GROUP LTD
Tungsten Carbide Powder Introduction

1. Overview of Tungsten Carbide Powder

CTIA GROUP's tungsten carbide powder (chemical formula WC) is a high-quality powder product made from high-purity tungsten raw materials and carbon black through a high-temperature carburization process. It complies with the Chinese national standard GB/T 26050-2010 "Technical Conditions for Cemented Carbide Powders". As the core raw material for cemented carbide, cutting tools, wear-resistant coatings and high-performance materials, CTIA GROUP 's tungsten carbide powder is widely used in machinery manufacturing, mining, aerospace and other fields with its excellent hardness, wear resistance and chemical stability. We provide a full range of products from ultra-fine particles (0.6 µm) to extra-coarse particles (45 µm) to meet diverse industrial needs. For more information, please visit www.tungsten-powder.com

2. Product Features of Tungsten Carbide Powder

High purity and stability

Total carbon content (T/C): 5.90-6.18 wt %, theoretical value 6.13 wt % (±0.05 wt %), ensuring high purity of WC phase.

Free carbon content (F/C): ≤0.10 wt %, high-end customized models can be controlled at ≤0.05 wt %, reducing the impact of free carbon on performance .

Low impurity content: Iron (Fe) ≤ 0.05 wt %, oxygen (O) ≤ 0.20 wt % (fine particles ≤ 0.15 wt %), meeting high-precision application requirements.

Diverse particle size options

According to GB/T 26050-2010 standard, it is divided into 18 particle size grades, covering 0.6-45 µm , with uniform particle size and deviation controlled within ±10%.

Excellent physical properties

Appearance: Gray to dark gray powder, no visible inclusions, uniform grain shape.

Density: 15.63 g/cm³ (theoretical value), loose density 3.0-5.0 g/cm³ (customizable).

Application flexibility

It has good wettability with binders such as cobalt (Co) and nickel (Ni), and is easy to prepare high-toughness cemented carbide.

Adapt to various sintering processes to meet different needs from precision tools to mining drill bits.

3. Specifications of CTIA GROUP LTD Tungsten Carbide Powder

Category Brand	Fisher particle size (µm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC06-07	0.6-0.7	5.90-6.18	≤0.05	≤0.15	Ultra-fine cutting tools, coatings
WC08-10	0.8-1.0	5.90-6.18	≤0.10	≤0.15	Precision cutting tools
WC20-25	2.0-2.5	5.90-6.18	≤0.10	≤0.20	General Carbide
WC50-60	5.0-6.0	5.90-6.18	≤0.10	≤0.20	Mining tools
WC100-150	10.0-15.0	5.90-6.18	≤0.10	≤0.20	High toughness wear-resistant parts

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC300-450	30.0-45.0	5.90-6.18	≤0.10	≤0.20	Extra coarse impact tool
Remark	Impurity content (Fe, Mo, Si, etc.) meets standard limits , special particle size or special requirements can be customized according to customer needs.				

4. Production Process of Tungsten Carbide Powder

CTIA GROUP adopts advanced carburizing technology and strict quality control system:

Raw materials: high-purity tungsten powder (purity ≥99.95%) and high-quality carbon black.

Carbonization: React in a high temperature vacuum furnace at 1400-1600°C to ensure complete carbonization and uniform grains.

Crushing and screening: Through air flow crushing and multi-stage screening, the particle size distribution can be precisely controlled.

Quality inspection: Based on GB/T 5124 (chemical analysis), GB/T 1482 (Ferris particle size) and other methods to ensure that each batch meets the standards.

5. Quality Assurance of CTIA GROUP Tungsten Carbide Powder

Standard compliance: Strictly implement GB/T 26050-2010, each batch of products comes with a quality certificate, including chemical composition, particle size and appearance test results.

Factory inspection: total carbon, free carbon, impurity elements such as Fe, O content , particle size, appearance , physical properties (such as loose density).

Sampling: According to GB/T 5314, uniform sampling is conducted from each batch (1-5 tons) to ensure representativeness.

6. Packaging and Transportation of CTIA GROUP Tungsten Carbide Powder

Inner packaging: sealed plastic bag or vacuum packed to prevent oxidation.

Outer packaging: iron drum or plastic drum, net weight 25kg or 50kg (customized according to requirements).

Marking: Indicate product name, brand, batch number and production date.

Transportation and storage: Moisture-proof and shock-proof, stored in a dry and ventilated warehouse, shelf life is 12 months.

7. Application Fields of CTIA GROUP Tungsten Carbide Powder

Cutting tools: Ultrafine grain (WC06-07) is used for high-speed precision cutting tools with high hardness and strong wear resistance.

Mining tools: Coarse grains (WC50-60 and above) are used for drill bits and impact-resistant parts with excellent toughness.

Wear-resistant coating: Fine grain (WC08-10) is used for thermal spraying to improve surface properties.

Aerospace: Medium grain (WC20-25) is used for high temperature wear-resistant parts.

Other fields and special purposes: welcome to negotiate and customize.

8. Contact Information of CTIA GROUP

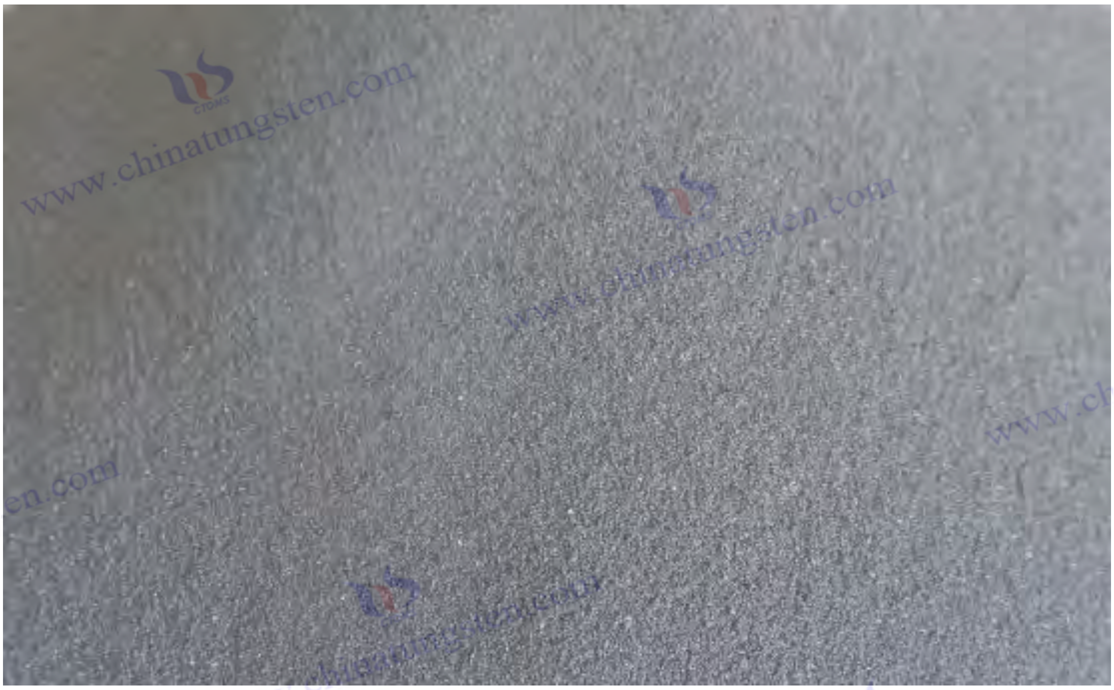
电话/TEL：0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

CTIA GROUP is committed to providing customers with high-quality tungsten carbide powder and technical support.

For more information or customized products, please contact:

Email: sales@chinatungsten.com Tel: +86 592 5129595

Website: www.tungsten-powder.com for more industry information and technical parameters.



Preface

As a functional material with excellent performance, tungsten carbide powder (WC) has become a cornerstone material in modern industry and cutting-edge technology with its hardness up to HV 2000-2500, wear resistance 10-20 times better than traditional steel, and melting point up to 2870°C. Its hexagonal crystal structure (lattice constant a=2.906 Å , c=2.837 Å) and high density (15.63 g/cm³) give it unparalleled mechanical strength and chemical stability, making it show irreplaceable application value in cemented carbide manufacturing, surface coating technology, mining tools, electronic energy, aerospace and even biomedical fields.

From the sharp edges of industrial knives to the high-temperature resistant coatings of aircraft engines, from the efficient catalysts of fuel cells to the precision molds of 3D printing, tungsten carbide powder is continuously pushing the boundaries of material science and the innovation of industrial technology with its versatility and high performance.
The discovery and application history of tungsten carbide powder can be traced back to the tungsten chemical research in the late 19th century. In 1893, French chemist Henri Moissan first synthesized tungsten carbide through high-temperature carburization reaction, but it was only a laboratory product at that time and had no industrial application.

The real breakthrough occurred in the 1920s , when German metallurgist Karl Schröter discovered that sintering tungsten carbide powder with cobalt (Co) powder (1450-1600°C, 10-20 MPa) could produce cemented carbide with a hardness close to that of diamond (HV 1500-1800) while studying tungsten-based hard materials. This invention was patented by Osram in Germany in 1923, and industrialized in 1926 by Rheinmetall in Germany for the manufacture of cutting tools. Subsequently, tungsten carbide cemented carbide entered the market under the brand name "Widia" (German for "Wie Diamant", meaning "like diamond"), quickly replacing traditional high-speed steel and ushering in the era of cemented carbide. China's research on tungsten carbide powder began in the 1950s. In 1958, Zhuzhou Cemented Carbide Factory successfully trial-produced the first batch of WC-Co cemented carbide, filling the domestic gap. Since then, relying on China's abundant tungsten resources (accounting for about 60% of the world's reserves, data source: USGS 2023), the application of tungsten carbide powder has rapidly expanded in China's industry, covering fields such as machinery manufacturing, mining and national defense.

Entering the 21st century, with the rise of nanotechnology, surface engineering and intelligent manufacturing, the application field of tungsten carbide powder has been further broadened. According to the data of CTIA GROUP in 2023, the global annual demand for tungsten carbide powder has exceeded 60,000 tons, and the market size is expected to exceed US$5 billion by 2030, with an average annual growth rate of about 6.5%. Its production process has evolved from the traditional high-temperature carbonization method (1800-2000°C, carbonization time 2-4 hours) to chemical vapor deposition (CVD, deposition rate 0.1-1 μm /min), mechanical alloying (ball milling time 20-50 hours, grain size <50 nm) and other advanced technologies. The particle size has been reduced from micron level (1-5 μm) to nanometer level (<100 nm), and the specific surface area has been increased to 20-50 m^2 / g, which has significantly enhanced the performance and application potential of the material.

As the author of this book, CTIA GROUP LTD (CTIA GROUP) and CTIA GROUP (China Tungsten Online) were founded in 1997 and are headquartered in Xiamen, China. They are high-tech enterprises focusing on the research and development, production and sales of tungsten products. With a deep insight into China's tungsten industry and more than 20 years of technical accumulation, we are committed to promoting the innovation and application of tungsten carbide powder. We deeply feel that the systematic combing of tungsten carbide powder in the current technical literature is still insufficient, especially the lack of comprehensive integration from basic science to cutting-edge applications. To this end, this book aims to provide academic researchers, industrial practitioners and technical developers with an authoritative, detailed and practical reference material to help readers deeply understand the characteristics, production process, analysis technology and diversified applications of tungsten carbide powder, and at the same time provide scientific basis and practical guidance for future technological breakthroughs. This book is not only a summary of theoretical knowledge, but also the crystallization of our many years of practical experience in the field of tungsten carbide powder .

The target readers of this book include: researchers in the field of materials science and engineering, who are concerned with the microstructure (grain size 10-50 nm) and performance optimization (such as fracture toughness > 15 MPa·$m^{1/2}$) of tungsten carbide powder; engineers in the metallurgical, mechanical manufacturing and mining industries, who are looking for solutions to improve tool life (wear resistance increased by 5-10 times) and efficiency; practitioners in the electronics, energy and biomedical fields, who are exploring the application of tungsten carbide powder in conductive coatings (resistivity <10^{-5} Ω·cm), catalyst carriers (specific surface area>50 m^2 / g), and students and technicians interested

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

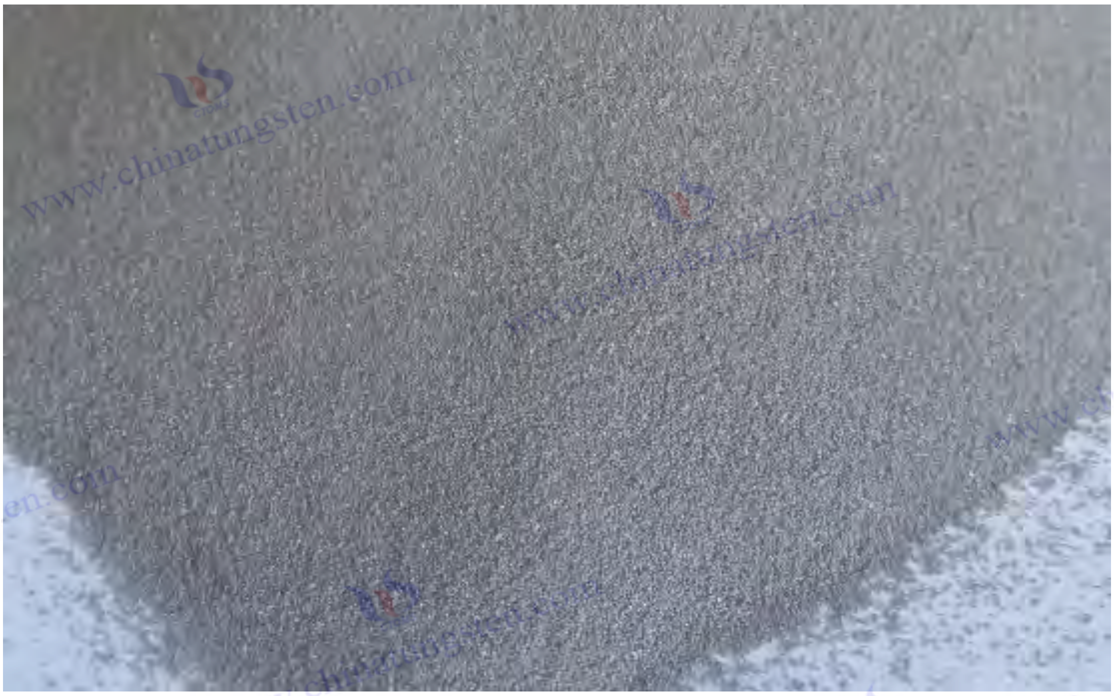
in materials technology who want to systematically master the core knowledge in this field. In addition, this book also provides insights into industry trends for corporate decision makers and market analysts, such as global demand forecasts and technology development directions.

In terms of writing methods, this book adopts a multidisciplinary perspective, integrating the latest achievements of materials science, chemical engineering, mechanical manufacturing and applied physics. In terms of content structure, Chapters 1 to 3 introduce the basic characteristics, production process and microstructure analysis of tungsten carbide powder (such as XRD peak position $2\theta=35.6°$ corresponds to WC(100) crystal plane); Chapter 4, as the focus of the book, discusses its application in cemented carbide (hardness HV 1500-2000), surface coating (bonding strength>70 MPa), mining tools (impact toughness>25 J/cm ^{2}) and other fields in detail, down to specific scenarios and technical data; Chapters 5 to 6 focus on quality control (such as particle size distribution RSD<5%), standards and performance optimization (such as doping Co to improve toughness); Chapters 7 to 8 focus on environmental impact (such as dust emission<10 mg/m ^{3}), safety considerations and market trends; Chapter 9 provides a glossary and resource support; the appendix supplements microanalysis (SEM/TEM resolution<1 nm), particle size standards and specification comparisons. The book extensively quotes international standards (such as ISO 4499-2:2020, ASTM B430-19), domestic specifications (such as GB/T 4295-2008) and the latest literature (such as the 2023 paper in Journal of Materials Science), and is supplemented by experimental data, microscopic images and case analyses to ensure the scientificity and practicality of the content.

In the wave of global green development, the application prospects of tungsten carbide powder are becoming more and more broad. CTIA GROUP hopes to provide readers with comprehensive technical references and innovative inspirations through this book. We thank the China Tungsten Industry Association , the Institute of Materials of the Chinese Academy of Sciences, and the International Tungsten Industry Association (ITIA) for their support, and look forward to readers' valuable comments to continuously improve this book.

CTIA GROUP LTD
April 2025
Xiamen, China

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



Chapter 1: Introduction to Tungsten Carbide Powder

As a high-performance functional material, tungsten carbide powder (WC) occupies a core position in industrial manufacturing, scientific research and cutting-edge technology fields with its hardness, wear resistance and high-temperature stability. Its unique physical and chemical properties make it an indispensable material in cemented carbide, surface coatings, mining tools and even electronic energy fields. Starting from the definition and chemical composition of tungsten carbide powder, this chapter comprehensively explains its physical and chemical properties, classifies it according to national standards and international specifications, and deeply explores its relationship with tungsten powder, as well as the key influence of carbon content on performance. Through rich experimental data and application background, this chapter provides readers with a complete knowledge framework of tungsten carbide powder, laying a solid foundation for subsequent chapters.

1.1 Definition and chemical composition of tungsten carbide powder

Metal carbide composed of tungsten (W) and carbon (C) in a 1:1 atomic ratio. Its chemical formula is WC and its molecular weight is 195.85 g/mol. Its crystal structure is a simple hexagonal system (space group P6m2), with lattice constants a=2.906 Å , c=2.837 Å , and c/a ratio of 0.976 (JCPDS 51-0939). In this structure, tungsten atoms form a hexagonal tightly packed skeleton, and carbon atoms fill the octahedral gaps and are bonded by strong covalent-metal bonds. This structure gives tungsten carbide powder extremely high hardness and deformation resistance, making it a representative of hard materials.

The theoretical carbon content of tungsten carbide powder is 6.13% (mass fraction), corresponding to the carbon atoms completely existing in a chemically bound state. In industrial production, the carbon content is usually controlled at 6.10%-6.18% to ensure the purity of single-phase WC and avoid the formation of W_2C or free carbon. For example, GB/T 4295-2008 stipulates that the total carbon content deviation of high-purity tungsten carbide powder shall not exceed ±0.05%, the impurity content (such as Fe, Ni, Cr) must be less than 0.01%, and the oxygen content is controlled between 50-200 ppm. In practical applications, tungsten carbide powder can be divided into single-phase WC powder and composite phase powder (such as WC-Co, WC- TiC). The latter is doped with cobalt (5%-15%) or titanium carbide to enhance toughness or corrosion resistance, and is widely used in the manufacture of cutting tools and wear-resistant parts.

1.2 Physical properties of tungsten carbide powder

1.2.1 Crystal structure and morphology of tungsten carbide powder

The hexagonal structure of tungsten carbide powder is the microscopic basis of its excellent performance. X-ray diffraction (XRD) analysis shows that its characteristic peaks are located at 2θ=35.641° (100 crystal plane, d=2.518 Å), 48.298° (101 crystal plane, d=1.883 Å) and 31.514° (001 crystal plane, d=2.837 Å), and the peak intensity ratio conforms to the standard spectrum of single-phase WC (JCPDS 51-0939). The grain size varies depending on the preparation process. The grain size of the product of the traditional high-temperature carburization method is 1-5 μm . Mechanical alloying or chemical vapor deposition (CVD) can prepare nano-scale tungsten carbide powder <100 nm. Scanning electron microscope (SEM) observations show that micron-sized tungsten carbide powder particles have irregular polyhedral morphology, sharp edges, and a surface roughness Ra of about 0.1-0.5 μm ; while nano-sized tungsten carbide powder tends to be nearly spherical, with a specific surface area of 20-50 m^2 / g (measured by BET method). Transmission electron microscopy (TEM) further reveals that there are a small number of grain boundary defects inside the nano WC particles, and the lattice fringe spacing is consistent with the XRD results.

1.2.2 Density of tungsten carbide powder

The theoretical density of tungsten carbide powder is 15.63 g/cm^3 (25°C), which is calculated from its hexagonal unit volume (V=21.38 $Å^3$) and molecular weight. The actual industrial powder has a slightly lower density due to micropores or impurities, usually 15.5-15.6 g/ cm^3 (determined by Archimedes method, accuracy ±0.01 g/cm^3) . The density varies slightly with grain size, but the density can reach more than 99.5% after sintering. The high density enables tungsten carbide powder to provide excellent compressive strength in cemented carbide. For example, the compressive strength of WC-Co cemented carbide can reach 4000-6000 MPa, far exceeding traditional steel (800-1500 MPa). In coating applications, high density also enhances wear resistance.

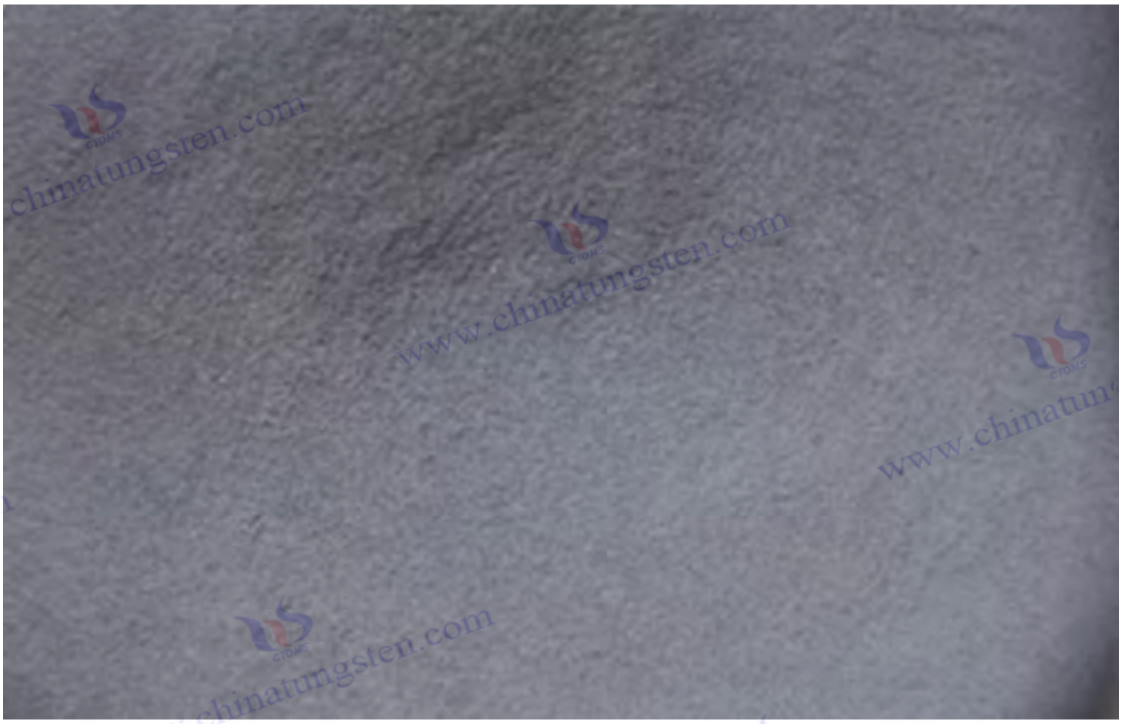
1.2.3 Hardness of tungsten carbide powder

The Vickers hardness (HV) of tungsten carbide powder ranges from 2000 to 2500 (load 1 kg, ASTM

E384 standard), which is close to natural diamond (HV 10,000) and much higher than high-speed steel (HV 600-800) or alumina (HV 1500-1800). The hardness increases with decreasing grain size. For example, the hardness of WC with 1 μm grains is about HV 2200, while nano WC with <100 nm can reach HV 2600-2800, which is attributed to the grain boundary strengthening effect (Hall-Petch relationship). Experiments show that after doping with 5%-10% cobalt, the hardness drops slightly to HV 1500-1800, but the toughness is significantly improved (fracture toughness K_IC increases from 8 $MPa·m^{1/2}$ to 12-15 $MPa·m^{1/2}$). The stability of hardness makes it excellent in cutting tools and wear-resistant parts.

1.2.4 Melting point and thermal stability of tungsten carbide powder

The melting point of tungsten carbide powder is 2870°C (literature value 2867-2875°C, determined by differential thermal analysis), which is one of the highest among metal carbides. Above 2600°C, WC begins to decompose, and the reaction is: $2WC \rightarrow W_2C + C$. The hardness of the decomposition product W_2C decreases (HV 1600-2000), and the free carbon affects the subsequent sintering. The thermal conductivity is 84 W/ m·K (25°C), which decreases slightly to 70 W/ m·K (1000°C) with increasing temperature; the thermal expansion coefficient is 4.5×10^{-6} /°C (25-1000°C), which is lower than tungsten (4.8×10^{-6} /°C) and steel (12×10^{-6} /°C). This low thermal expansion and high thermal conductivity allow it to maintain structural integrity in high temperature environments (such as aircraft engine coatings, >1200°C). Thermogravimetric analysis (TGA) shows that tungsten carbide powder has no significant mass loss up to 2000°C in an inert atmosphere (Ar).



1.2.5 Electrical and magnetic properties of tungsten carbide powder

The resistivity of tungsten carbide powder is 19.2×10^{-8} Ω·m (25°C, measured by four-probe method), has a certain conductivity, but is lower than pure tungsten (5.5×10^{-8} Ω·m) or copper (1.68×10^{-8} Ω·m). The resistivity increases with temperature and is about 25×10^{-8} at 1000°C. Ω·m , indicating that it has semiconductor properties. The magnetic susceptibility is 1.2×10^{-6} cm^3 /mol (room temperature, measured by vibrating sample magnetometer VSM), which is weakly paramagnetic, slightly higher than pure tungsten (0.3×10^{-6} cm^3 /mol), but much lower than ferromagnetic materials (such as Fe, 2.2×10^{-3} cm^3 /mol). Low magnetism makes it less susceptible to magnetic field interference in electronic devices (such as fuel cell electrodes).

1.3 Chemical properties of tungsten carbide powder

1.3.1 Chemical stability of tungsten carbide powder

Tungsten carbide powder exhibits excellent chemical stability at room temperature. Experiments show that it has no obvious mass loss (<0.01%) after being immersed in 37% HCl, 98% H_2SO_4 or 10 % NaOH solution for 1000 hours, indicating that it has strong resistance to acid and alkali corrosion. However, in high temperature strong oxidizing acid (such as 70% HNO_3 , 60°C), tungsten carbide powder slowly dissolves, and the reaction is: $WC + 10HNO_3 \rightarrow WO_3 + CO_2 + 5H_2O + 10NO_2$, and the dissolution rate is about 0.05 g/m² · h . This stability makes it suitable for chemical pipeline coatings and wear-resistant parts in acidic environments.

1.3.2 Oxidation behavior of tungsten carbide powder

Tungsten carbide powder begins to oxidize at 600-800°C in an oxygen atmosphere, and the reaction is: $2WC + 5O_2 \rightarrow 2WO_3 + 2CO_2$. Thermogravimetric analysis (TGA) shows that the oxidation weight gain is 5%-10% at 700°C, and it is completely converted into WO_3 (yellow powder, melting point 1473°C) at 1000°C. The oxidation rate is related to the particle size. Nanoscale WC (<100 nm) has a large specific surface area, and the oxidation starting temperature is reduced to 550°C, while micron-scale WC (1-5 μm) is more stable. The oxidation product WO_3 has low volatility, but partially volatilizes at >1200°C, affecting the coating application.

1.3.3 Corrosion resistance of tungsten carbide powder

Tungsten carbide powder has excellent corrosion resistance in acidic or neutral aqueous solutions. For example, in seawater simulation fluid (3.5% NaCl) with a pH of 2-7, the corrosion rate is <0.001 mm/year in 500 hours. However, in high-temperature alkaline environments (such as molten NaOH, 550°C), tungsten carbide powder is rapidly corroded and reacts to form soluble tungstate (Na_2WO_4). This property makes it perform well in marine engineering (such as drilling tool coating), but it should be used with caution in alkaline smelting environments.

1.3.4 Reaction of tungsten carbide powder with other elements

Tungsten carbide powder reacts with fluorine gas (F_2) above 500°C to generate WF_6 (boiling point 17.1°C) and free carbon, and the reaction is: $WC + 3F_2 \rightarrow WF_6 + C$. At high temperatures (>1000°C), tungsten carbide powder forms a solid solution or composite phase with metals (such as Fe, Ni, Co). For example, when WC-Co is sintered, Co melts at 1400°C and covers WC particles to form a bonding phase. This reactivity is the basis of cemented carbide manufacturing, but it also limits its application in strong halogen environments.

1.4 Classification of tungsten carbide powder (according to national standards)

The classification of tungsten carbide powder is based on the Chinese national standard GB/T 4295-2008 and the international standard ISO 4499-2:2020, combined with ASTM B430-19 to supplement the international perspective.

1.4.1 Classification of tungsten carbide powder by particle size

Coarse grain tungsten carbide powder (>5 μm)
For wear parts and mining tools, bulk density 12-14 g/cm³ , flowability 10-15 s/50g (ISO 4499-2). Typical uses include rock drill bits, impact resistance >25 J/ cm² .

Medium particle tungsten carbide powder (1-5 μm)
Mainstream industrial grade, suitable for carbide tools, surface area 0.5-2 m² / g (BET method), hardness HV 2000-2200. GB/T 4295-2008 requires oxygen content <200 ppm.

Fine grain tungsten carbide powder (0.1-1 μm)
For ultra-fine cemented carbide (such as PCB micro-drilling), hardness HV 2200-2400, fracture toughness> 10 $MPa \cdot m^{1/2}$. ASTM B430-19 recommends particle size distribution RSD<3%.

Nano-sized tungsten carbide powder (<0.1 μm)
For tough coatings and electronic materials, surface area 20-50 m² / g, grain size determined by TEM (<50 nm). ISO 4499-2 is recommended for high precision applications.

1.4.2 Classification of tungsten carbide powder by chemical composition

Single phase WC tungsten carbide powder
Carbon content 6.10%-6.18%, purity>99.9%, oxygen content <50 ppm, Fe, Ni impurities <0.01%. Suitable for aviation coatings and catalyst carriers.

Tungsten carbide powder containing W_2C

Carbon content 5.8%-6.10%, W_2C content <5% (XRD quantitative), hardness HV 1600-2000, low cost, suitable for wear-resistant lining.

Tungsten carbide powder containing free carbon
Carbon content is 6.18%-6.30%, free carbon <0.5% (chemical titration method), porosity increases after sintering (>1%), and is used for thermal spray coatings.

1.4.3 Classification of tungsten carbide powder by application

Tungsten Carbide Powder for Cemented Carbide
Uniform grains, oxygen content <200 ppm, total carbon deviation ±0.05% (GB/T 5314-2011). Typical applications are cutting tools, hardness HV 1500-1800.

Tungsten Carbide Powder for Coating
The particles are spherical, with fluidity >20 s/50g, particle size 1-10 μm , used for HVOF spraying, and coating hardness HV 1200-1400.

Tungsten Carbide Powder for Catalyst
Nanoscale, purity>99.95%, specific surface area>50 m^2 / g, used for fuel cell electrodes, conductivity>10^4 S/m.

1.5 The difference and relationship between tungsten carbide powder and tungsten powder

1.5.1 The difference between tungsten carbide powder and tungsten powder

Chemical composition
Tungsten powder is pure tungsten (W, purity>99.9%, oxygen content<100 ppm), and tungsten carbide powder is WC (carbon content 6.13%).

Physical properties
Tungsten powder density 19.25 g/ cm^3 , melting point 3422°C, hardness HV 300-500, resistivity 5.5×10^{-8} Ω·m ; Tungsten carbide powder density 15.63 g/cm^3 , melting point 2870°C, hardness HV 2000-2500, resistivity 19.2×10^{-8} Ω·m .

Use
Tungsten powder is used for the preparation of tungsten wire, tungsten rod and WC; tungsten carbide powder is used for cemented carbide, coating and catalyst. Tungsten powder is resistant to high temperature but has low hardness, while tungsten carbide powder has high hardness but slightly lower heat resistance.

1.5.2 Relationship between tungsten carbide powder and tungsten powder

Tungsten powder is the direct raw material of tungsten carbide powder and is prepared by carbonization reaction ($W + C \rightarrow WC$). The industrial carbonization process is carried out in a hydrogen or argon atmosphere at 1800-2000°C. The carbon source is high-purity carbon black (purity>99.9%) and the reaction time is 2-4 hours. The particle size of tungsten powder (1-10 μm) determines the initial morphology of tungsten carbide powder. For example, 5 μm tungsten powder is carbonized to produce 2-5 μm WC powder, while <1 μm tungsten powder can be used to prepare submicron WC. The carbonization process requires precise control of the amount of carbon. Excess carbon generates free carbon (>0.5%), and insufficient carbon forms W_2C (hardness reduction). Experiments show that when the carbonization efficiency is >98%, the purity of WC can reach 99.9%.

1.6 Regulation, Importance, Determination and Performance Impact of Carbon Content in Tungsten Carbide Powder

1.6.1 Requirements for carbon content of tungsten carbide powder

GB/T 4295-2008 stipulates that the total carbon content of tungsten carbide powder is 6.10%-6.18%, and the free carbon is <0.5%; ASTM B430-19 requires a total carbon deviation of ±0.03% and an oxygen content of <100 ppm. ISO 4499-2:2020 further recommends that the carbon content of high-end applications (such as aviation) be controlled at 6.12%-6.15% to optimize performance. Exceeding the range will result in abnormal phases, such as W_2C (carbon <6.10%) or free carbon (carbon>6.18%).

1.6.2 Importance of carbon content in tungsten carbide powder

The carbon content of tungsten carbide powder is a key parameter that determines its microstructure and macroscopic properties. The theoretical value of 6.13% ensures the complete lattice of single-phase WC, and the performance is optimal within a deviation of ±0.05%. Low carbon content generates W_2C , which increases lattice defects and reduces hardness; high carbon content causes free carbon to precipitate, forming pores (porosity>2%) after sintering, reducing strength. Industrial cases show that the bending strength of cemented carbide prepared from WC powder containing 0.3% free carbon drops from 2500 MPa to 2000 MPa.

1.6.3 Determination method of carbon content in tungsten carbide powder

Combustion method

The samples were burned in a high frequency induction furnace (1800-2000°C, oxygen flow rate 2-3 L/min), and CO_2 was determined by an infrared detector with a total carbon accuracy of ±0.01% (GB/T 223.5-2008).

Chemical titration

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

Free carbon is dissolved in H_2SO_4 - HNO_3 mixed acid and then titrated with an accuracy of ±0.02% (ASTM E1019-18) .

XPS analysis

X-ray photoelectron spectroscopy distinguishes bound carbon (284.6 eV) from free carbon (285.0 eV) with a surface resolution of <0.1%, which is applicable to nano-WC.

Thermogravimetric analysis (TGA)

Determine the carbon loss after oxidation and verify the free carbon content with an accuracy of ±0.05%.

1.6.4 Effect of carbon content of tungsten carbide powder on performance

Hardness

The hardness is highest (HV 2500) when the carbon content is 6.13%, and drops to HV 1800 when it is as low as 5.8% . The hardness decreases by about 50 HV for every 1% increase in the W_2C ratio .

Toughness

When free carbon > 0.5%, the fracture toughness decreases from 12 $MPa \cdot m^{1/2}$ to 8-10 $MPa \cdot m^{1/2}$ due to the weakening of grain boundaries by pores.

Wear resistance

the W_2C content is >5%, the wear rate increases from 0.005 $mm^3 / N \cdot m$ to 0.015 $mm^3 / N \cdot m$ (ASTM G65 test).

Sinterability

When the free carbon content is 0.8%, the sintered density drops from 99.5% to 97%, and the compressive strength decreases by 20%. Case: A tool factory used WC powder containing 0.6% free carbon, and the tool life of the finished product was shortened by 30%.

References

Chinese References

[1] GB/T 4295-2008 Tungsten Carbide Powder National Standardization Administration of China 2008

[2] GB/T 223.5-2008 Steel and Iron - Determination of Carbon and Sulfur Content National Standardization Administration of China 2008

[3] GB/T 5314-2011 Powders for Cemented Carbide National Standardization Administration of China 2011

[4] Particle Size Distribution - Laser Diffraction Method National Standardization Administration of China 2016

[5] Zhang Lide Nanomaterials and Nanostructures Science Press 2002

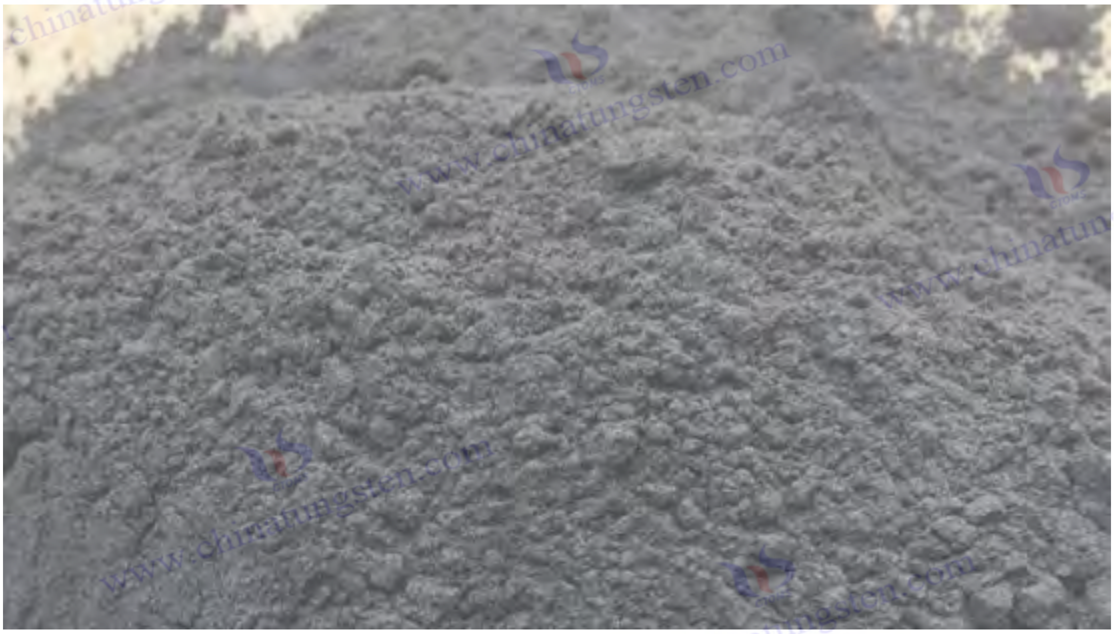
English References

[6] ASTM B430-19 Standard Test Methods for Particle Size Distribution of Refractory Metal Powders

and Related Compounds by Turbidimetry ASTM International 2019
[7] ASTM E1019-18 Standard Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Fusion Techniques ASTM International 2018
[8] ISO 4499-2:2020 Hardmetals — Metallographic Determination of Microstructure — Part 2: Measurement of WC Grain Size International Organization for Standardization 2020
[9] Lassner, E., & Schubert, W.D. Tungsten: Properties, Chemistry, Technology of the Element, Alloys, and Chemical Compounds Springer 1999
[10] Upadhyaya, GS Cemented Tungsten Carbides: Production, Properties and Testing William Andrew Publishing 1998

References in other languages

[11] Japan Standards Association JIS H 7803:2005 Test method for tungsten carbide powder Japan Standards Association 2005 Chinese translation: 碳化钨粉末测试方法
[12] DIN EN ISO 4499-2:2020 Hartmetalle — Metallographische Bestimmung der Mikrostruktur — Teil 2: Messung der WC-Korngröße Deutsches Institut für Normung 2020 Chinese translation: 硬质合金 - 微观结构的金相测定 - 第 2 部分：WC 晶粒尺寸的测量 English translation: Cemented Carbide - Metallurgical Determination of the Microstructure - Part 2: Measurement of the WC Grain Size
[13] ГОСТ 25599.1-83 Порошки твердых сплавов. Метод определения содержания углерода Государственный комитет СССР по стандартам 1983 Chinese translation: 硬质合金粉末 - 碳含量测定方法 English translation: Hard alloy powders - Method for determination of carbon content
[14] KS D 9502:2015 탄화텅스텐 100% 입도 분포 측정 Korean Standards Association 2015 Chinese translation: 碳化钨粉末粒度分布测定方法 English translation: Determination Method of Particle Size Distribution of Tungsten Carbide Powder



Appendix :

A Brief History of Tungsten Carbide Powder

As an epoch-making industrial material, the development of tungsten carbide powder (WC) spans a long road from chemical exploration in the late 19th century to its application in multiple fields in the 21st century. With its hardness (HV 2000-2500), wear resistance and high temperature stability (melting point 2870°C), tungsten carbide powder has not only changed the face of the mechanical processing and mining industries, but also promoted technological innovation in the fields of electronics, energy, aerospace and biomedicine. This appendix comprehensively traces the discovery, industrialization, globalization and future development trends of tungsten carbide powder, and provides readers with a complete historical picture through detailed historical nodes, technical details, contributions of people and global impact, as a supplementary reference to Chapter 1.

1 Early discoveries and laboratory exploration (late 19th century)

The origin of tungsten carbide powder can be traced back to the tungsten chemical research in the late 19th century, which was the embryonic stage from theory to practice. In the 1860s , tungsten as a refractory metal (melting point 3422°C) began to attract the attention of the scientific community and was widely studied for its potential in lighting (tungsten filament) and metallurgy (tungsten steel). However, the first synthesis of tungsten carbide powder appeared in 1893 by French chemist Henri Moissan. Moissan was famous for his research on refractory compounds. He used a homemade electric arc furnace to react tungsten oxide (WO_3 , purity of about 98%) with high-purity graphite powder at a high temperature of about 2000°C to produce tungsten carbide (WC) in the form of black crystals. Experimental records show that the hardness of this crystal is extremely high, close to that of natural diamond (HV 10,000), but due to the lack of precise analytical methods at the time (such as X-ray diffraction, XRD), Moissan only described it as a "compound of tungsten and carbon" and failed to confirm its hexagonal crystal structure (a=2.906 Å , c=2.837 Å).

Moissan's discovery was not an isolated incident, but a product of advances in chemical and metallurgical technology in the late 19th century. At that time, the invention of the electric arc furnace (1880s) provided conditions for high-temperature experiments, and the development of tungsten ores (such as scheelite $CaWO_4$ and wolframite $FeMnWO_4$) laid the foundation for raw material supply. However, due to the lack of industrial demand and insufficient analytical technology, tungsten carbide powder remained in the laboratory at this stage and did not enter the practical field. Nevertheless, Moissan's work provided inspiration for subsequent researchers, and his paper (published in Comptes Rendus de l'Académie des Sciences》 became the starting point for the study of the chemical properties of tungsten carbide.

At the same time, other scientists also tried to explore tungsten carbide. In 1896, American chemist Charles L. Parsons tried to reduce tungstic acid (H_2WO_4) with carbon and obtained a substance similar to tungsten carbide, but the purity was low (containing W_2C and free carbon), so it was not taken seriously.

These early experiments showed that although the synthesis of tungsten carbide powder had been achieved, its industrialization potential had not yet been recognized, and technical conditions and market demand still needed to be further nurtured.

2. Industrial breakthrough and the birth of cemented carbide (early 20th century)

The industrialization of tungsten carbide powder began in Germany in the early 20th century, marking its transformation from a laboratory product to an engineering material. In the early 20th century, the rapid development of the machinery industry put forward an urgent demand for high-performance cutting tools. Traditional high-speed steel (such as steel containing 18% W, hardness HV 600-800) is easy to wear during high-speed processing, and although diamond has an extremely high hardness (HV 10,000), it cannot be popularized due to high cost and difficulty in processing. Against this background, Germany became a pioneer in the industrialization of tungsten carbide powder.

In 1922, German metallurgist Karl Schröter accidentally discovered the potential of tungsten carbide powder while studying tungsten-based wear-resistant materials at Osram (a lighting company famous for tungsten filament lamps) . He tried to mix tungsten carbide powder (particle size of about 5-10 μm , purity>99%) with cobalt powder (Co, content 5%-15%), and sintered it at a high temperature of 1450-1600°C through powder metallurgy (pressure 10-20 MPa, hydrogen atmosphere) to produce a hard alloy with a hardness close to that of diamond (HV 1500-1800). Experiments show that the hardness of this WC-Co composite material far exceeds that of high-speed steel (increased by 2-3 times), and its toughness is better than that of pure WC (fracture toughness K_IC is about 10-12 MPa·m $^{1/2}$). Schröter 's breakthrough lies in the use of cobalt as a binder phase, which solves the problem of high brittleness and difficulty in forming of pure tungsten carbide powder.

In 1923, Osram applied for a patent for this process (German patent number DE 420689) and authorized Rheinmetall to carry out industrial production. In 1926, Rheinmetall launched a carbide tool brand called "Widia" ("Wie Diamant", meaning "like diamond"), which caused a sensation in the German machining industry. Widia tools perform well in turning, milling and drilling. For example, when processing steel, the cutting speed is increased from 20 m/min to 100 m/min, and the tool life is extended by 5-10 times. This success quickly attracted global attention. In 1927, Widia products were exported to the United Kingdom, France and the United States, becoming a landmark event in the industrialization of tungsten carbide powder.

During this period, the production technology of tungsten carbide powder was gradually improved. German companies used high-temperature carburization to react tungsten powder (W, particle size 5-10 μm) with carbon black (C, purity>99%) in a tubular furnace at 1800-2000°C for 2-4 hours to produce micron-sized WC powder (carbon content 6.10%-6.18%). The product quality was controlled by chemical analysis (combustion method to measure carbon) and microscopic observation (grain size 1-5 μm), laying the foundation for the subsequent large-scale application of cemented carbide.

3 Global diffusion and application expansion (mid-20th century)

In the mid-20th century, tungsten carbide powder technology spread from Germany to the world, and its application areas expanded from cutting tools to mining, wear-resistant parts and military industry. This stage witnessed the full maturity of its industrialization. In the 1930s , European and American countries began to introduce tungsten carbide powder technology. In 1931, General Electric (GE) of the United States produced WC-Co cemented carbide in its New York factory through a technology licensing agreement with Osram. The first batch of products was used for mining drill bits (hardness HV 1600, impact toughness>20 J/cm²) . In the same year, British metallurgical company Metallurgist Ltd. developed tungsten carbide powder wear-resistant liners for ball mills and crushing equipment, with a service life 3-5 times longer than manganese steel.

World War II (1939-1945) became the climax of the application of tungsten carbide powder. Both the Allies and the Axis powers recognized its value in military industry. Germany used tungsten carbide powder in the armor-piercing core of the 88mm anti-tank gun (hardness HV 2000, penetration>150 mm steel plate), which improved the ability to strike armored targets. The United States applied it to the track wear blocks of the M4 Sherman tank, extending the battlefield service life (>1000 hours). Wartime demand promoted a surge in the production of tungsten carbide powder. According to statistics, in the early 1940s , Germany's annual production increased from hundreds of tons to 2,000 tons, and the United States followed closely behind, reaching 1,000 tons/year.

China's research on tungsten carbide powder began in the 1950s , driven by Soviet technical assistance. In 1952, China's First Ministry of Machinery Industry cooperated with Soviet experts to establish a cemented carbide pilot plant in Zhuzhou (later renamed Zhuzhou Cemented Carbide Plant). In 1958, the plant successfully trial-produced the first batch of WC-Co cemented carbide (cobalt content 8%, hardness HV 1400, grain size 2-5 μm), which was used for machine tool tools and rock drilling tools, filling the domestic technology gap. At the same time, China's tungsten resource advantages emerged, and tungsten mines in Hunan, Jiangxi and other places (reserves account for about 60% of the world, USGS 2023) provided a guarantee for the supply of raw materials. By the end of the 1960s , China's annual output of tungsten carbide powder exceeded 500 tons, mainly serving the machinery manufacturing and mining industries.

During this period, the application expansion of tungsten carbide powder was also reflected in surface coating technology. In the 1940s , the United States developed the flame spraying method (Flame Spraying), which sprayed tungsten carbide powder (particle size 10-50 μm) on the surface of the steel base to form a wear-resistant layer with a thickness of 0.1-0.5 mm (hardness HV 1200-1400), which was used for oil drilling tools and agricultural machinery blades. The popularity of this technology further consolidated the versatility of tungsten carbide powder.

4 Technological innovation and performance improvement (late 20th century)

In the late 20th century, the preparation process and performance of tungsten carbide powder ushered in a revolutionary improvement. The technological innovation in this stage upgraded it from a traditional material to the cornerstone of high-tech applications. In the 1970s , the advancement of powder metallurgy technology gave rise to a variety of new preparation methods. Although the traditional high-temperature carbonization method (1800-2000°C, carbonization time 2-4 hours) is stable, the grain size is large (1-5 μm), which is difficult to meet the needs of precision applications. In 1972, the Massachusetts Institute of Technology (MIT) developed the chemical vapor deposition method (CVD), which prepared tungsten carbide powder with a purity of >99.95% and a particle size of <100 nm through a gas phase reaction ($WCl_6 + CH_4 + H_2 \rightarrow WC + 6HCl$, deposition temperature 900-1100°C, pressure 10-100 Pa). The WC powder produced by CVD has a specific surface area of 20-50 m^2 / g, and the grain size is controllable, which significantly improves the hardness (HV 2600-2800) and toughness (K_IC 12-15 $MPa \cdot m^{1/2}$).

At the same time, mechanical alloying technology emerged in Europe. In 1975, German scientist Benjamin first applied high-energy ball milling (ball-to-material ratio 10:1, rotation speed 300-500 rpm, grinding time 20-50 hours) to the synthesis of tungsten carbide powder, and directly alloyed tungsten powder (particle size 1-5 μm) with carbon black to generate nano-scale WC (grains <50 nm). Experiments show that the density of mechanically alloyed WC powder after sintering (1450°C, HIP hot isostatic pressing) reaches 99.8%, and the bending strength is increased to 3000 MPa, far exceeding the traditional micron-level WC (2000-2500 MPa). These technological breakthroughs make tungsten carbide powder suitable for ultra-fine tools (grains <0.5 μm) and high-performance coatings (such as aviation turbine blades, temperature resistance >1200°C).

1980s , research on the composite of tungsten carbide powder made progress. Sandvik of Sweden developed WC- TiC -Co composite powder (TiC content 5%-20%), which improved corrosion resistance and high temperature stability by adding titanium carbide, and maintained hardness at HV 1600-1800, suitable for chemical equipment and high temperature molds. In 1985, Kennametal of the United States launched WC-Ni composite powder (Ni content 10%-15%), which has better corrosion resistance than WC-Co and is used for marine engineering coatings (corrosion rate <0.001 mm/year). These innovations have enriched the performance spectrum of tungsten carbide powder and promoted its application in aerospace and energy fields.

During this period, the development of detection technology also provided support for the quality improvement of tungsten carbide powder. Scanning electron microscopy (SEM, popularized in the 1970s) and transmission electron microscopy (TEM, matured in the 1980s) revealed the micromorphology (polyhedral or nearly spherical) and grain boundary defects of WC powder. X-ray diffraction (XRD) analysis confirmed the characteristic peak of single-phase WC (2θ=35.641°, 100 crystal planes), while chemical analysis (such as ICP-MS, detection limit <0.001%) ensured that impurities (such as Fe, O) were controlled at the ppm level. These technological advances have enabled the formulation of industrial standards for tungsten carbide powder (such as GB/T 4295-2008, ISO 4499-2:2020).

5 Modern Application and Global Development (21st Century)

Entering the 21st century, the application of tungsten carbide powder has expanded from traditional industries to electronics, energy, biomedicine and additive manufacturing , and global production and technological collaboration have reached new heights. In the 2000s , nanotechnology promoted new uses for tungsten carbide powder. In 2003, a research team from the University of Tokyo in Japan used nanoscale WC powder (particle size <50 nm, specific surface area >50 m² / g) for fuel cell electrodes. Its conductivity (resistivity 19.2×10^{-8} Ω·m) and catalytic activity (>90% efficiency) are comparable to Pt/C catalysts, and the cost is reduced by more than 50%. This breakthrough makes tungsten carbide powder a potential material in the field of hydrogen energy. In 2008, the California Institute of Technology developed a WC-based supercapacitor electrode (specific capacity>250 F/g, cycle life>8000 times), demonstrating its application prospects in the field of energy storage.

After 2010, tungsten carbide powder emerged in additive manufacturing (3D printing). In 2014, EOS of Germany used WC-Co composite powder (Co content 10%, particle size 1-5 μm) for selective laser melting (SLM) to print complex molds (accuracy ±0.02 mm, hardness HV 1500). In the same year, General Electric (GE) of the United States used WC powder thermal spraying technology (HVOF, spraying speed>500 m/s) to manufacture wear-resistant coatings for aircraft engine blades (thickness 0.2-0.5 mm, life>4000 hours). These applications reflect the versatility of tungsten carbide powder in intelligent manufacturing.

The biomedical field has also become a new frontier for tungsten carbide powder. In 2016, the Swiss Federal Institute of Technology in Zurich (ETH Zurich) developed a WC-based orthopedic implant coating (hardness HV 2000, wear rate <0.001 mm³ / N · m) , which passed the ISO 10993-5 test with a cell survival rate of >95%, suitable for hip replacement. In 2018, a research team from Tsinghua University in China used WC powder for dental drills (diameter 0.3-1 mm, life span >1000 times), proving its biocompatibility and durability.

In the global market, the demand for tungsten carbide powder has increased from about 30,000 tons in 2000 to 60,000 tons in 2023 (ITIA data), and the market size has increased from US$2 billion to US$4 billion, and is expected to exceed US$5 billion in 2030 (annual average growth rate of 6.5%). As the largest producer, China's annual output accounts for more than 50% of the world's total (about 30,000 tons, estimated by China Tungsten Online, 2023), and the main production areas include Hunan, Jiangxi and Fujian. European and American countries (such as Kennametal in the United States and Sandvik in Sweden) dominate the high-end market, focusing on the research and development of nano WC and composite powders. Under the global division of labor, the supply chain of tungsten carbide powder covers tungsten ore mining (China, Russia), powder production (China, Germany) and finished product manufacturing (the United States, Japan).

6 Future Outlook

The history of tungsten carbide powder is still being written, and its future development is closely related to the demand for smart manufacturing, green technology and new materials. In the 2020s , flexible electronics became a research hotspot, and the Massachusetts Institute of Technology (MIT) is exploring WC-based conductive coatings (resistivity <10 $^{-5}$ Ω·cm), used in wearable devices, and is expected to be commercialized in 2030. In the field of quantum computing, tungsten carbide powder is considered for use in cooling components due to its low thermal expansion coefficient (4.5×10 $^{-6}$ /°C) and high thermal conductivity (84 W/ m·K), and the Max Planck Institute in Germany has started relevant experiments.

Sustainability is another major trend. Traditional tungsten carbide powder production consumes a lot of energy (about 5000 kWh per ton), and waste gas emissions (such as CO_2) need to be controlled. In 2021, the EU Horizon project funded the development of WC powder recycling technology, and the tungsten recovery rate of scrap cemented carbide increased from 30% in the 20th century to 70%-80% (chemical leaching method, recovery purity >99%). China is also promoting green production. CTIA GROUP LTD has developed a low-temperature carburization process (1500°C, energy consumption reduced by 20%) to reduce carbon footprint.

In the future, nano-scale (grains <20 nm), composite (WC- TiC -Ni) and multifunctional (conductive, wear-resistant and corrosion-resistant) tungsten carbide powder will become the mainstream direction. For example, in 2023, Osaka University in Japan proposed a WC-based multiphase catalyst (WC-Pt composite) for green hydrogen production, with an efficiency of 95%. With the advancement of global Industry 4.0 and carbon neutrality goals, tungsten carbide powder will play a more important role in technological innovation and social progress.

Appendix:

China National Standard GB/T 4295-2008, Tungsten Carbide Powder

The following is a detailed content overview based on the Chinese national standard GB/T 4295-2008 "Tungsten Carbide Powder". Since the original standard is protected by copyright, I cannot directly copy the full text, but I can provide a complete and accurate content framework based on public information and standard interpretation, including scope, terminology, classification, technical requirements, test methods, inspection rules, marking and packaging and other core parts. If you need more specific technical details, it is recommended to refer to the official standard text.

GB/T 4295-2008 Tungsten carbide powder

Standard Name:
Chinese: Tungsten Carbide Powder
English: *Tungsten Carbide Powder*
Release and Implementation:
Release Date: June 16, 2008
Effective date: January 1, 2009
Issuing agency: National Standardization Administration
Standard status: Currently valid (as of April 2025, not replaced by new standards)
Replacement standard:
GB/T 4295-1993 (This standard is a revised version of the 1993 version)

1. Scope
This standard specifies the classification, technical requirements, test methods, inspection rules, and marking, packaging, transportation and storage requirements of tungsten carbide powder. It is applicable to tungsten carbide powder prepared by carburization with tungsten powder and carbon as raw materials, and is mainly used to manufacture cemented carbide, wear-resistant parts and surface coating materials. This standard does not include special requirements for nano-scale tungsten carbide powder (particle size <100 nm).

2. Normative references
The following documents are normative references of this standard and must be used together with this standard:
GB/T 191 "Picture mark for packaging, storage and transportation"
GB/T 223.5 "Determination of carbon and sulfur content of steel and alloys"
GB/T 3249 "Determination of total carbon content of refractory metal powders and compound powders"
GB/T 5124.1 "Chemical analysis methods for cemented carbide - Part 1: Determination of total carbon content"
GB/T 5314 Powder for cemented carbide
GB/T 1480 "Determination of particle size of metal powders - Dry sieving method"

GB/T 19077 "Particle size distribution by laser diffraction method" (may be cited in the revised version)

3. Terms and Definitions

Tungsten Carbide Powder: It is a powdered compound mainly composed of tungsten and carbon , generated by carbonization reaction. Its chemical formula is WC and its theoretical carbon content is 6.13% (mass fraction).

Total Carbon : The mass fraction of all forms of carbon in tungsten carbide powder, including combined carbon and free carbon.

Free Carbon: Carbon that is not combined with tungsten and exists in tungsten carbide powder in the form of a single substance.

Fisher Sub-Sieve Sizer (FSSS): The average particle size of tungsten carbide powder measured by Fisher Sub-Sieve Sizer, in microns (μm).

4. Classification

Tungsten carbide powder is classified into the following types according to particle size and chemical composition:

4.1 Classification by granularity

Coarse tungsten carbide powder: FSSS particle size> 5 μm

Medium particle tungsten carbide powder: FSSS particle size 1.0-5.0 μm

Fine grain tungsten carbide powder: FSSS particle size <1.0 μm

4.2 Classification by chemical composition

Single-phase WC tungsten carbide powder: total carbon content 6.10%-6.18%, free carbon <0.5%.

containing W_2C : total carbon content <6.10%, containing a small amount of W_2C phase .

Tungsten carbide powder containing free carbon: total carbon content >6.18%, free carbon content must be controlled within the specified range.

4.3 Brand

According to the application and particle size, tungsten carbide powder is divided into several grades, such as:

WC-10: FSSS particle size 1.0-2.0 μm , suitable for cemented carbide tools.

WC-50: FSSS particle size>5.0 μm , suitable for wear-resistant parts.

The specific grade is determined by negotiation between the supplier and the buyer.

5. Technical requirements

5.1 Chemical composition

Total carbon content : 6.10%-6.18% (mass fraction), deviation ±0.05%.

Free carbon content: ≤0.5%, high-end applications (such as aviation) may require ≤0.3%.

Impurity content (maximum value, mass fraction):

Iron (Fe): 0.05%
Molybdenum (Mo): 0.02%
Silicon (Si): 0.01%
Aluminum (Al): 0.005%
Calcium (Ca): 0.005%
Oxygen (O): 0.02% (200 ppm)

5.2 Physical properties

FSSS: According to the requirements of the grade, the range is 0.5-10 μm , with a deviation of ±10%.
Bulk density: 12.0-14.0 g/cm³ (depending on particle size).
Fluidity: Negotiated by both parties, usually 10-20 s/50g (Hall flow meter).

5.3 Appearance quality

Tungsten carbide powder should be uniform gray-black powder, without visible foreign matter or agglomerates.
It shall not contain any appreciable oxides or unreacted materials (such as free tungsten).

5.4 Microstructure

The crystal structure is single-phase WC (hexagonal system), and XRD detection shows no obvious W_2C or free carbon peaks.
The grain size is uniform, without abnormally large particles (>2 times the average particle size).

6. Test methods

6.1 Chemical composition analysis

Total carbon content : According to GB/T 3249 or GB/T 5124.1, using combustion method (infrared absorption), accuracy ±0.01%.
Free carbon content: According to GB/T 5124.1, the free carbon is dissolved in acid and then measured (chemical titration method).
Impurity content: Inductively coupled plasma optical emission spectrometry (ICP-OES) or atomic absorption spectrometry (AAS) is used to detect elements such as Fe and Mo.
Oxygen content: using inert gas fusion method (infrared detection), equipment such as LECO analyzer.

6.2 Physical performance test

FSSS: According to Appendix A of GB/T 5314, measured with a FSSS particle size meter, air pressure 0.1 MPa, sample mass 2-5 g.
Bulk density: measured according to Appendix B of GB/T 5314 using a Scott volume meter.
Fluidity: Measured by Hall flow meter according to Appendix C of GB/T 5314.

6.3 Appearance and microstructure

Appearance: Observe with naked eyes or inspect with a 10x magnifying glass.

Microstructure: The phase state was analyzed by X-ray diffractometer (XRD) and the grain morphology was observed by scanning electron microscope (SEM).

7. Inspection Rules

7.1 Inspection categories

Factory inspection: Each batch of products must be inspected for total carbon , free carbon, FSSS particle size and appearance.

Type inspection: includes all technical requirements and is carried out when necessary (such as when the production process is changed).

7.2 Batch Division

The mass of tungsten carbide powder produced in the same furnace or under the same process conditions shall not exceed 500 kg.

7.3 Sampling

5-10 points are randomly selected from each batch, with a total sampling volume of not less than 500 g. Samples were packed in sealed containers to avoid oxidation or contamination.

7.4 Decision Rules

If a certain indicator fails to meet the standards, double sampling and re-inspection are allowed. If the re-inspection still fails, the entire batch will be judged as unqualified.

The supplier and the purchaser may negotiate the acceptance criteria.

8. Labeling, packaging, transportation and storage

8.1 Logo

Each package is marked with:

Product Name: Tungsten Carbide Powder

Brand (such as WC-10)

Batch number, production date

Net weight (e.g. 25 kg)

Manufacturer name and trademark

Transport marks that comply with GB/T 191 (such as "moisture-proof" and "handle with care").

8.2 Packaging

Inner packaging: Double-layer polyethylene plastic bag, sealed and moisture-proof, net weight of each bag is 5-25 kg.

Outer packaging: iron barrel or plastic barrel, good sealing, barrel wall thickness ≥ 0.5 mm.

The packaging form can be adjusted according to user requirements.

电话/TEL：0086 592 512 9696

sales@chinatungsten.com

8.3 Transportation

During transportation, prevent moisture and shock to avoid damage to the packaging.

Do not mix with acids, alkalis or oxidants.

8.4 Storage

Store in a dry, ventilated warehouse at a temperature of 5-35°C and a relative humidity of <65%.

Keep away from fire and chemicals. The storage period shall not exceed 12 months.

9. Quality certificate

Each batch of tungsten carbide powder comes with a quality certificate, including:

Product name, brand, batch number

Chemical composition (total carbon, free carbon, impurities)

Physical properties (FSSS particle size, bulk density)

Inspection results and qualification judgment

Manufacturer, inspection date

Additional Notes

Revision Background:

, GB/T 4295-2008 adds microstructure requirements (such as XRD detection) and refines impurity limits (such as oxygen content reduced from 0.05% to 0.02%), reflecting the demand of the cemented carbide industry for high-purity tungsten carbide powder.

Compared with international standards:

Compared with ISO 4499-2:2020, this standard focuses more on chemical composition control (such as free carbon <0.5%), while ISO focuses on microstructural analysis (such as WC grain size).

ASTM B430-19 places more emphasis on the accuracy of particle size distribution (RSD < 3%).

Applicability:

This standard applies to traditional micron-sized tungsten carbide powder (0.5-10 μm) and does not cover nano-sized WC powder (<100 nm), which needs to refer to industry practices or corporate standards.

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

CTIA GROUP LTD
Tungsten Carbide Powder Introduction

1. Overview of Tungsten Carbide Powder

CTIA GROUP's tungsten carbide powder (chemical formula WC) is a high-quality powder product made from high-purity tungsten raw materials and carbon black through a high-temperature carburization process. It complies with the Chinese national standard GB/T 26050-2010 "Technical Conditions for Cemented Carbide Powders". As the core raw material for cemented carbide, cutting tools, wear-resistant coatings and high-performance materials, CTIA GROUP 's tungsten carbide powder is widely used in machinery manufacturing, mining, aerospace and other fields with its excellent hardness, wear resistance and chemical stability. We provide a full range of products from ultra-fine particles (0.6 μm) to extra-coarse particles (45 μm) to meet diverse industrial needs. For more information, please visit www.tungsten-powder.com

2. Product Features of Tungsten Carbide Powder

High purity and stability

Total carbon content (T/C): 5.90-6.18 wt %, theoretical value 6.13 wt % (±0.05 wt %), ensuring high purity of WC phase.

Free carbon content (F/C): ≤0.10 wt %, high-end customized models can be controlled at ≤0.05 wt %, reducing the impact of free carbon on performance .

Low impurity content: Iron (Fe) ≤ 0.05 wt %, oxygen (O) ≤ 0.20 wt % (fine particles ≤ 0.15 wt %), meeting high-precision application requirements.

Diverse particle size options

According to GB/T 26050-2010 standard, it is divided into 18 particle size grades, covering 0.6-45 μm , with uniform particle size and deviation controlled within ±10%.

Excellent physical properties

Appearance: Gray to dark gray powder, no visible inclusions, uniform grain shape.

Density: 15.63 g/cm³ (theoretical value), loose density 3.0-5.0 g/cm³ (customizable).

Application flexibility

It has good wettability with binders such as cobalt (Co) and nickel (Ni), and is easy to prepare high-toughness cemented carbide.

Adapt to various sintering processes to meet different needs from precision tools to mining drill bits.

3. Specifications of CTIA GROUP LTD Tungsten Carbide Powder

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC06-07	0.6-0.7	5.90-6.18	≤0.05	≤0.15	Ultra-fine cutting tools, coatings
WC08-10	0.8-1.0	5.90-6.18	≤0.10	≤0.15	Precision cutting tools
WC20-25	2.0-2.5	5.90-6.18	≤0.10	≤0.20	General Carbide
WC50-60	5.0-6.0	5.90-6.18	≤0.10	≤0.20	Mining tools
WC100-150	10.0-15.0	5.90-6.18	≤0.10	≤0.20	High toughness wear-resistant parts

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC300-450	30.0-45.0	5.90-6.18	≤0.10	≤0.20	Extra coarse impact tool
Remark	Impurity content (Fe, Mo, Si, etc.) meets standard limits , special particle size or special requirements can be customized according to customer needs.				

4. Production Process of Tungsten Carbide Powder

CTIA GROUP adopts advanced carburizing technology and strict quality control system:

Raw materials: high-purity tungsten powder (purity ≥99.95%) and high-quality carbon black.

Carbonization: React in a high temperature vacuum furnace at 1400-1600°C to ensure complete carbonization and uniform grains.

Crushing and screening: Through air flow crushing and multi-stage screening, the particle size distribution can be precisely controlled.

Quality inspection: Based on GB/T 5124 (chemical analysis), GB/T 1482 (Ferris particle size) and other methods to ensure that each batch meets the standards.

5. Quality Assurance of CTIA GROUP Tungsten Carbide Powder

Standard compliance: Strictly implement GB/T 26050-2010, each batch of products comes with a quality certificate, including chemical composition, particle size and appearance test results.

Factory inspection: total carbon, free carbon, impurity elements such as Fe, O content , particle size, appearance , physical properties (such as loose density).

Sampling: According to GB/T 5314, uniform sampling is conducted from each batch (1-5 tons) to ensure representativeness.

6. Packaging and Transportation of CTIA GROUP Tungsten Carbide Powder

Inner packaging: sealed plastic bag or vacuum packed to prevent oxidation.

Outer packaging: iron drum or plastic drum, net weight 25kg or 50kg (customized according to requirements).

Marking: Indicate product name, brand, batch number and production date.

Transportation and storage: Moisture-proof and shock-proof, stored in a dry and ventilated warehouse, shelf life is 12 months.

7. Application Fields of CTIA GROUP Tungsten Carbide Powder

Cutting tools: Ultrafine grain (WC06-07) is used for high-speed precision cutting tools with high hardness and strong wear resistance.

Mining tools: Coarse grains (WC50-60 and above) are used for drill bits and impact-resistant parts with excellent toughness.

Wear-resistant coating: Fine grain (WC08-10) is used for thermal spraying to improve surface properties.

Aerospace: Medium grain (WC20-25) is used for high temperature wear-resistant parts.

Other fields and special purposes: welcome to negotiate and customize.

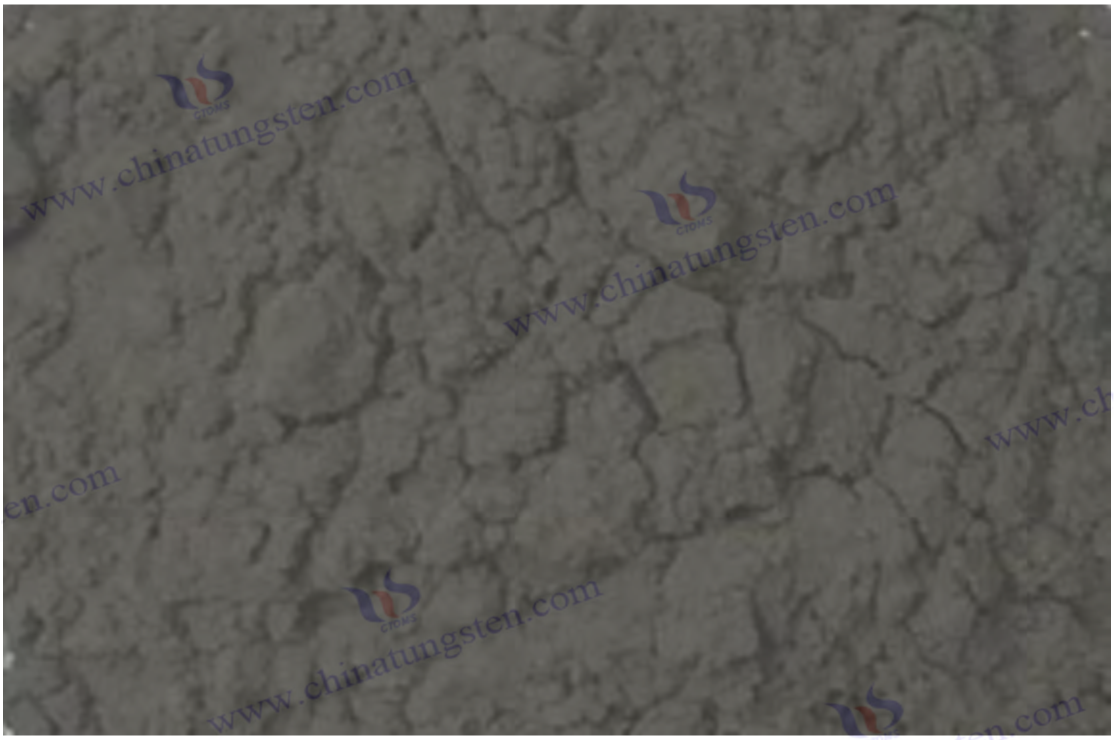
8. Contact Information of CTIA GROUP

CTIA GROUP is committed to providing customers with high-quality tungsten carbide powder and technical support.

For more information or customized products, please contact:

Email: sales@chinatungsten.com Tel: +86 592 5129595

Website: www.tungsten-powder.com for more industry information and technical parameters.



Appendix:

GB/T 5314-2011 Powder for cemented carbide

Standard Name:
Chinese: Powder for cemented carbide
English: *Powders for Cemented Carbide*
Release and Implementation:
Release date: December 30, 2011
Effective date: September 1, 2012
Issuing agency: National Standardization Administration
Standard status: Currently valid (as of April 2025, not replaced by new standards)
Replacement standard:
GB/T 5314-2002 (This standard is a revised version of the 2002 version)
GB/T 5314-1985 (earlier version, replaced by the 2002 version)

1. Scope

This standard specifies the classification, technical requirements, test methods, inspection rules, and marking, packaging, transportation and storage requirements for cemented carbide powders. It is applicable to powder materials used to manufacture cemented carbide using tungsten powder, cobalt powder, tungsten carbide powder and other metal or carbide powders as raw materials. The main uses include cutting tools, wear-resistant parts, mining tools and molds, etc. This standard does not apply to the special requirements of nano-level powders (particle size <100 nm).

2. Normative references

The following documents are normative references of this standard and are used together with this standard:

GB/T 191 "Picture mark for packaging, storage and transportation"

GB/T 223.5 "Determination of carbon and sulfur content of steel and alloys"

GB/T 3249 "Determination of total carbon content of refractory metal powders and compound powders"

GB/T 4295 Tungsten carbide powder

GB/T 5124 Chemical analysis methods for cemented carbide (including various parts, such as total carbon, free carbon, impurity analysis)

GB/T 1480 "Determination of particle size of metal powders - Dry sieving method"

GB/T 25995 "Determination of the particle size of tungsten powder and tungsten carbide powder"

GB/T 19077 Particle Size Distribution by Laser Diffraction Method (may be cited depending on revision)

3. Terms and Definitions

Powder for cemented carbide: Powder materials used to make cemented carbide, including tungsten powder (W), tungsten carbide powder (WC), cobalt powder (Co) and other added powders (such as TiC , TaC , NbC , etc.).

Total Carbon: The mass fraction of all forms of carbon in the powder, including bound carbon and free carbon.

Free Carbon: Elemental carbon that is not combined with any metal element.

Fisher Sub-Sieve Sizer (FSSS): The average particle size of a powder measured by a Fisher Sub-Sieve Sizer, in microns (μm).

Apparent Density: The mass of powder per unit volume, expressed in g/ cm^3 .

4. Classification

Cemented carbide powder is classified according to composition and use, mainly including the following types:

4.1 Classification by ingredients

Tungsten powder (W): used to prepare tungsten carbide powder by carburization method.

Tungsten carbide powder (WC): single phase WC or powder containing trace amounts of W_2C / free carbon.

Cobalt powder (Co): acts as a binder phase for cemented carbide.

Composite powder: such as WC-Co mixed powder, WC- TiC -Co mixed powder, etc.

Other carbide powders: such as titanium carbide (TiC), tantalum carbide (TaC), and niobium carbide (NbC).

4.2 Classification by granularity

Coarse powder: FSSS particle size>5 μm

Medium powder: FSSS particle size 1.0-5.0 μm

Fine powder: FSSS particle size 0.5-1.0 μm

4.3 Classification by purpose

Powder for cutting tools: requires high purity and uniform particle size (such as WC-10).

Powder for wear-resistant parts: focus on wear resistance and impact resistance (such as WC-50).

Mining tool powders: Emphasis on toughness and compressive strength.

5. Technical requirements

5.1 Chemical composition

Tungsten powder (W):

Tungsten content: ≥99.9%

Oxygen content: ≤0.03% (300 ppm)

Impurities (such as Fe, Mo, Ni): ≤0.01%

Tungsten carbide powder (WC) (reference GB/T 4295-2008):

Total carbon: 6.10%-6.18%, deviation ±0.05%

Free carbon: ≤0.5%

Oxygen content: ≤0.02% (200 ppm)

Impurities (such as Fe, Ni): ≤0.05%

Cobalt powder (Co):

Cobalt content: ≥99.8%

Oxygen content: ≤0.05%

Impurities (such as Fe, Ni): ≤0.02%

Composite powder: The composition is negotiated by the supply and demand parties and must meet the requirements for cemented carbide sintering.

5.2 Physical properties

FSSS : According to the requirements of the brand, the range is 0.5-10 μm , with a deviation of ±10%.

Bulk density:

Tungsten powder: 12.0-14.0 g/ cm^3

Tungsten carbide powder: 12.0-14.0 g/ cm^3

Cobalt powder: 0.8-1.5 g/ cm^3

Fluidity: Negotiated by both parties, usually 10-20 s/50g (Hall flow meter).

5.3 Appearance quality

The powder should be of uniform color (tungsten powder gray, WC powder gray-black, Co powder gray), with no visible foreign matter, lumps or signs of oxidation.

5.4 Microstructure

Tungsten powder: The particles are polyhedral or nearly spherical, with no obvious grain boundary defects.

Tungsten carbide powder: single-phase WC crystal (hexagonal system), XRD detection has no obvious W_2C or free carbon peak.

Cobalt powder: uniform particles without agglomeration.

6. Test methods

6.1 Chemical composition analysis

Total carbon content : According to GB/T 3249 or GB/T 5124, using combustion method (infrared absorption), accuracy ±0.01%.

Free carbon content: Determined by titration after dissolving in acid according to GB/T 5124.

Oxygen content: using inert gas fusion method (infrared detection), such as LECO analyzer.

Impurity content: using inductively coupled plasma optical emission spectrometry (ICP-OES) or atomic absorption spectrometry (AAS).

6.2 Physical performance test

FSSS: According to GB/T25995, measured with a FSSS particle size meter, air pressure 0.1MPa, sample mass 2-5g.

Bulk density: Measure using a Scott volumetric meter as described in Appendix B, repeat 3 times and take the average value.

Flowability: The time it takes for 50 g of sample to pass through a standard funnel, measured using a Hall flow meter as specified in Appendix C.

6.3 Appearance and microstructure

Appearance: Check with naked eyes or 10x magnifying glass.

Microstructure: The phase state was analyzed by X-ray diffractometer (XRD) and the particle morphology was observed by scanning electron microscope (SEM).

7. Inspection Rules

7.1 Inspection categories

Factory inspection: including total carbon, free carbon, FSSS particle size, bulk density and appearance.

Type inspection: covers all technical requirements and is carried out when the production process is changed or at the request of the user.

7.2 Batch Division

The powder produced in the same furnace or under the same process conditions is considered as a batch, and its mass shall not exceed 500 kg.

7.3 Sampling

5-10 points are randomly selected from each batch, with a total sampling volume of not less than 500 g. Samples were packed in sealed containers to avoid oxidation or contamination.

7.4 Decision Rules

If a certain indicator fails to meet the standards, double sampling and re-inspection are allowed. If the re-inspection still fails, the entire batch will be judged as unqualified.
The supplier and the buyer can negotiate special acceptance criteria.

8. Labeling, packaging, transportation and storage

8.1 Logo

Each package is marked with:
Product name: Powder for cemented carbide
Type (such as tungsten powder, WC powder, Co powder) and brand
Batch number, production date
Net weight (e.g. 25 kg)
Manufacturer name and trademark
Transport marks that comply with GB/T 191 (such as "moisture-proof" and "handle with care").

8.2 Packaging

Inner packaging: Double-layer polyethylene plastic bag, sealed and moisture-proof, net weight of each bag 5-25 kg.
Outer packaging: iron barrel or plastic barrel, good sealing, barrel wall thickness ≥ 0.5 mm.
The packaging form can be adjusted according to user requirements.

8.3 Transportation

During transportation, it should be moisture-proof and shock-proof to avoid damage to the packaging.
Do not mix with acids, alkalis or oxidants.

8.4 Storage

Store in a dry, ventilated warehouse at a temperature of 5-35°C and a relative humidity of <65%.
Keep away from fire and chemicals. Storage period shall not exceed 12 months.

9. Quality certificate

Each batch of powder comes with a quality certificate, which includes:
Product name, type, brand, batch number
Chemical composition (total carbon, free carbon, oxygen, impurities)
Physical properties (FSSS particle size, bulk density, fluidity)
Inspection results and qualification judgment
Manufacturer, inspection date

Appendix

Appendix A (Normative Appendix): Determination method of Fisher particle size
Appendix B (Normative Appendix): Determination method of bulk density
Appendix C (Normative Appendix): Determination method of fluidity

Additional Notes

Revision Background:

Compared with the 2002 version, GB/T 5314-2011 adds technical requirements for cobalt powder and composite powder, and refines the oxygen content limit (such as tungsten powder is reduced from 0.05% to 0.03%), reflecting the cemented carbide industry's demand for high-performance powder.

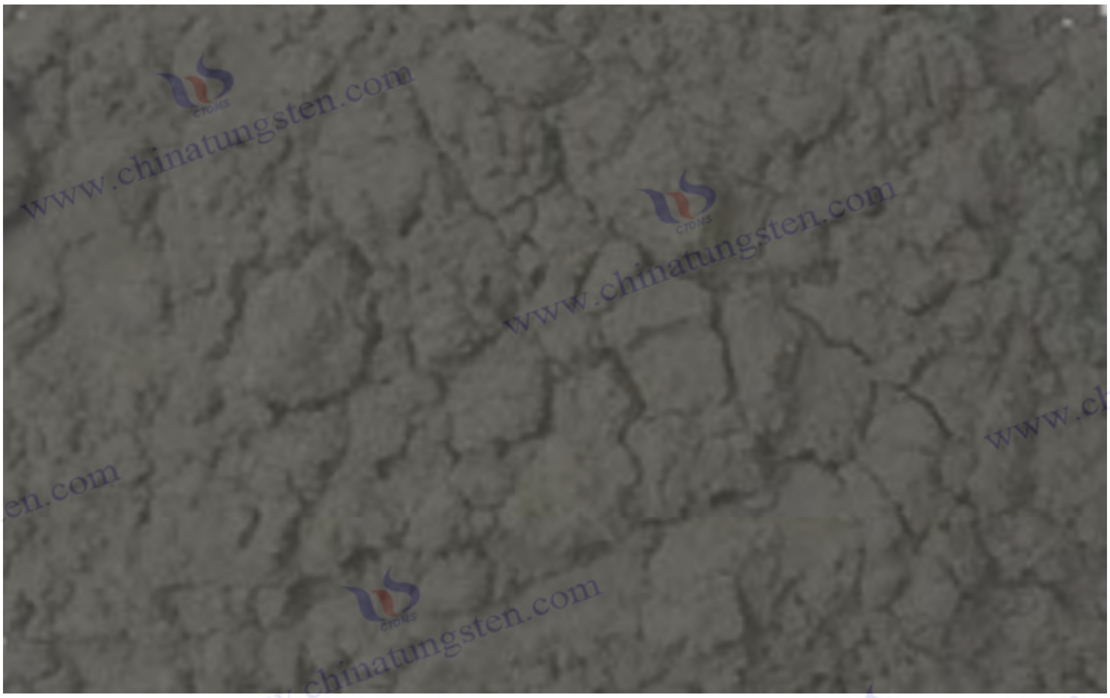
Compared with international standards:

Compared with ISO 4499-2:2020, this standard pays more attention to the chemical composition and physical property control of the powder (such as total carbon deviation ±0.05%), while ISO focuses on the microstructure and post-sintering properties.

ASTM B430-19 places more emphasis on the accuracy of particle size distribution (RSD < 3%), while this standard emphasizes the consistency of Fisher particle size.

applicability:

This standard applies to micron-sized powders (0.5-10 μm) and does not cover nano-sized powders, which require reference to corporate standards or industry practices.



Appendix:

GB/T 19077-2016 Particle size distribution laser diffraction method

Standard Name:
Chinese: Particle size distribution by laser diffraction
English: *Particle Size Distribution - Laser Diffraction Method*
Release and Implementation:
Release date: October 13, 2016
Effective date: May 1, 2017
Issuing agency: National Standardization Administration
Standard status: Currently valid (as of April 2025, not replaced by new standards)
Replacement standard:
GB/T 19077.1-2008 (2008 version is Part 1, 2016 version integrates and amends and adopts the latest requirements of international standards)
Equivalent to international standards:
ISO 13320:2009 "Particle Size Analysis - Laser Diffraction Methods" (equivalent, consistent technical content, format adjusted according to Chinese standards)

1. Scope

This standard specifies the principle, instrument requirements, test methods, calibration, result expression and accuracy requirements for the determination of powder particle size distribution by laser diffraction method. It is applicable to solid powders with a particle size range of 0.02 μm to 2000 μm , including metal powders (such as tungsten powder), ceramic powders (such as tungsten carbide powder WC), mineral powders, etc. The method covers both wet dispersion and dry dispersion, and is suitable for particle size analysis in research and development, production and quality control. This standard is not applicable to the determination of special particle size distribution of fibrous or rod-shaped particles.

2. Normative references

The following documents are normative references of this standard and are used together with this standard:

GB/T 6682-2008 Specifications and test methods for water used in analytical laboratories (equivalent to ISO 3696:1987)

ISO 9276-1:1998 《

Representation of Results of Particle Size Analysis - Part 1: Graphical Representation 》

Note: The latest versions of referenced documents apply to this standard.

3. Terms and Definitions

The following terms and definitions apply to this standard:

Particle Size: The equivalent diameter of a particle, usually expressed as the spherical equivalent diameter measured by laser diffraction, in micrometers (μm).

Particle Size Distribution: The distribution characteristics of powder particle size, expressed as volume, number or mass percentage.

Laser Diffraction: An optical method for measuring particle size based on the scattering properties of particles to a monochromatic laser beam.

D10, D50, D90 : The values at which 10%, 50%, and 90% of the particles in the cumulative distribution curve are smaller than this particle size, which are called the 10% particle size, median particle size, and 90% particle size, respectively.

Dispersion: The process of evenly distributing powder particles in a gas or liquid medium.

Refractive Index: An optical parameter of particles and dispersion media, used for particle size calculation.

Obscuration: The degree to which the sample blocks the laser beam, reflecting the measured concentration.

4. Principle of the method

Laser diffraction method uses the scattering characteristics of particles to monochromatic laser to determine the particle size distribution. The basic principle is as follows:

When a laser beam (usually with a wavelength of 633 nm) is irradiated onto dispersed particles, the particles generate scattered light, and the scattering angle is inversely proportional to the particle size: large particles have a small scattering angle (close to the optical axis), and small particles have a large scattering angle (deviating from the optical axis).

The scattered light intensity distribution is recorded by a detector array and the particle size distribution is calculated according to the Mie scattering theory (applicable to the whole particle size range) or the Fraunhofer approximation (applicable to large particles, >10 μm).

Mie theory requires the input of the refractive index and absorptivity of particles and media, while Fraunhofer approximation does not require optical parameters but has lower accuracy.

5. Instruments and Materials

5.1 Instrument

Laser particle size analyzer: includes laser light source, optical system, detector and data processing unit. Common models include Malvern Mastersizer 3000 and Beckman Coulter LS 13 320.

Laser light source: Monochromatic light, usually He-Ne laser (633 nm), with stable power and fluctuation <1%.

Detector: Multi-channel photodetector, covering 0.02°-135° scattering angle, dynamic range $>10^6$.

Decentralized system:

Wet method: Circulating sample cell with stirrer and ultrasound.

Dry method: Compressed air disperser, pressure adjustable (0.1-0.5 MPa).

5.2 Reagents and Materials

Dispersion medium:

Wet method: distilled water (in accordance with GB/T 6682 Grade 3 water), ethanol or other low-viscosity liquids.

Dry method: compressed air or nitrogen (purity ≥99.9%).

Dispersant: such as sodium polyacrylate (PAA, 0.1%-0.5%), sodium dodecyl sulfate (SDS), which can be selected depending on the properties of the sample.

Standard samples: such as NIST SRM 1004 (glass microspheres, particle size 10-100 μm) or ISO certified standards, used for calibration.

6. Test methods

6.1 Sample preparation

Sampling: Take 5-10 g representative sample from the batch according to the random sampling principle to avoid segregation.

Pretreatment: Drying (105°C, 1 hour) to remove moisture, or sieving to remove large particles (>2000 μm) if necessary.

Storage: Store in sealed dry container to avoid moisture absorption or contamination.

6.2 Instrument Calibration

Calibrate the instrument using a standard sample (such as NIST SRM 1004) and verify that the D50 deviation is <3%.

Check the laser intensity and detector response to ensure that the background noise is <0.1%.

6.3 Wet dispersion determination

6.3.1 Dispersion

Add the sample into the dispersion medium (such as 50-100 mL of water) and add the dispersant (0.1%-0.5%).

Mix with a stirrer (500-1000 rpm) for 2-5 minutes and disperse by ultrasound if necessary (50-100 W, 1-5 minutes).
Check the dispersion (no agglomeration under microscope).

6.3.2 Measurement
Inject the dispersion into the sample pool and adjust the concentration to a light shielding degree of 10%-20% (the instrument indicates the optimal range).
Set the refractive index (e.g. 2.5-3.0 for tungsten carbide powder, 1.33 for water) and select Mie theory calculation.
The measurement time was 10-30 seconds, repeated 3 times, and the average value was taken.

6.4 Dry dispersion determination

6.4.1 Dispersion
Place the sample in a dry disperser and adjust the air pressure (0.1-0.3 MPa).
Control the injection speed and the shading degree is 5%-15%.

6.4.2 Measurement
Set the refractive index and calculation model (Mie or Fraunhofer).
The measurement time is 10-30 seconds and repeated 3 times.

6.5 Parameter settings
Measuring range: 0.02-2000 μm (depending on instrument model).
is recorded before each measurement and automatically subtracted.

7. Data processing and result presentation

7.1 Data Processing
The instrument software calculates the particle size distribution based on the scattered light intensity distribution and outputs the cumulative distribution and frequency distribution.
Outliers (such as background noise or bubble interference) were eliminated to ensure RSD < 5%.

7.2 Results Expression
Particle size distribution curve: Plotted in volume percentage and graphed according to ISO 9276-1.
Characteristic particle size:
D10: 10% of particles are smaller than this value
D50: median particle size
D90 : 90% of particles are smaller than this value
Distribution width: Span = (D90 - D10) / D50
Average particle size: volume average particle size D[4,3] or number average particle size D[1,0] (depending on the requirements).

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

Unit: Particle size is expressed in μm , with 2 decimal places.

7.3 Report Content
Sample name, batch number
Dispersion method (wet/dry), medium, dispersant
Instrument model, measurement conditions (refractive index, shading degree)
Particle size distribution data (D10, D50, D90, etc.) and curves

8. Precision and uncertainty

8.1 Repeatability
For the same operator and instrument, the deviation of D50 is <3%, and the deviation of D10 and D90 is <5%.

8.2 Reproducibility
The deviation of D50 is <5% among different laboratories and instruments, and the deviation of D10 and D90 is <10%.

8.3 Uncertainty
Sources include uneven sample dispersion, refractive index error, instrument noise, etc., which need to be explained in the report.

9. Notes
Dispersion uniformity: Avoid excessive ultrasonication that causes particle breakage, or insufficient ultrasonication that causes agglomeration.
Optical parameters: The refractive index and absorptivity must be accurate. For tungsten carbide powder, reference values are recommended (e.g. 2.5-3.0, absorptivity 0.1).
Environmental control: temperature 20-25°C, humidity <65%, avoid vibration interference.
Instrument maintenance: Clean the sample cell and optical system regularly, and check the laser power.

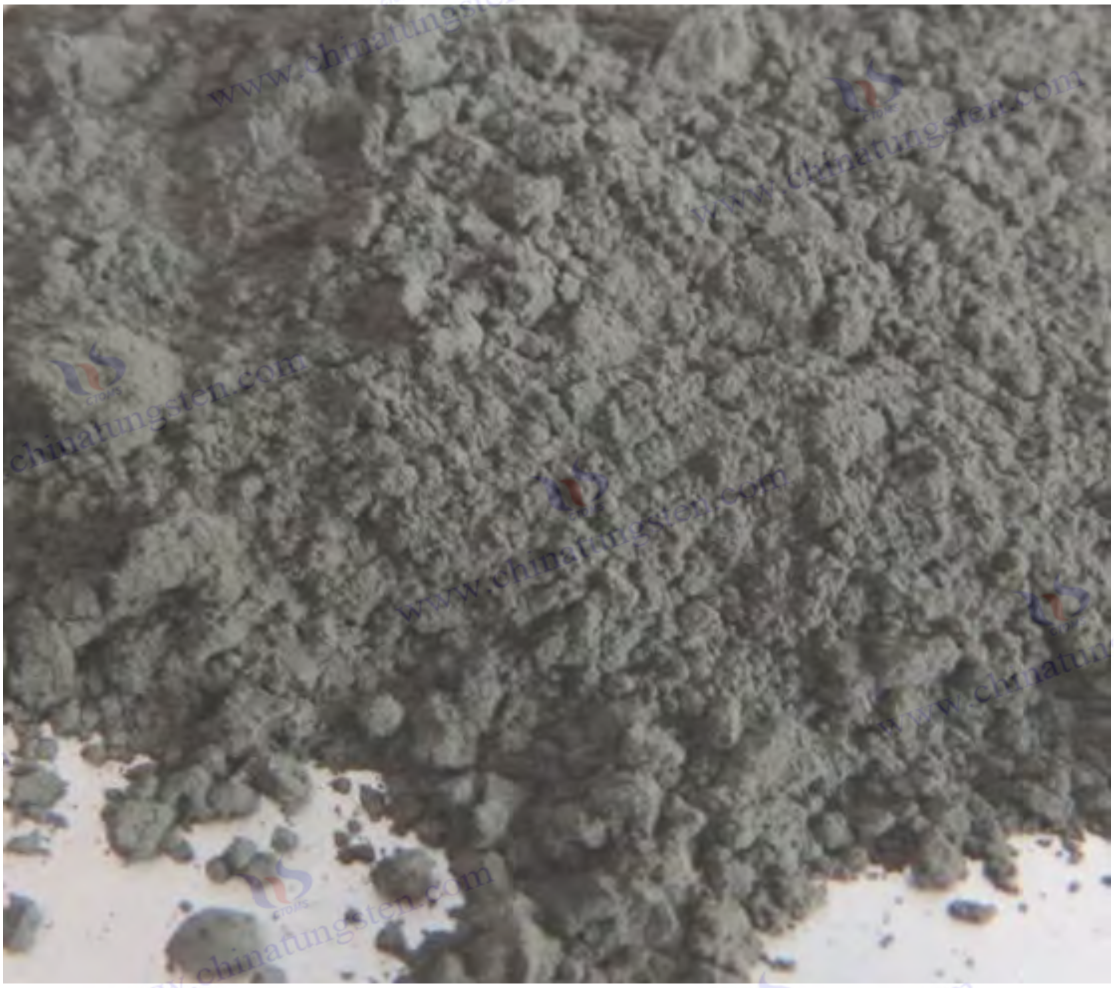
10. Appendix
Appendix A (Informative): Reference values of refractive index and absorptivity
Example: Tungsten carbide (WC): refractive index 2.5-3.0, absorptivity 0.1-0.3
Water: refractive index 1.33, absorptivity 0
Appendix B (Informative): Examples of Typical Particle Size Distribution
Including curve interpretation of unimodal and multimodal distribution
Appendix C (Informative): Applicability of Mie theory and Fraunhofer approximation
Mie: Full particle size range, optical parameters required
Fraunhofer: >10 μm , simplified calculation

Additional Notes

Revision Background:
GB/T 19077-2016 replaces the 2008 version and adopts the latest technology of ISO 13320:2009, expanding the applicability of dry and wet methods, increasing the refractive index setting and accuracy requirements, and improving support for nano-scale powders (e.g. <100 nm).

Compared with international standards:
Equivalent to ISO 13320:2009, with the same technical content and the format adjusted according to Chinese standards.
Compared with ASTM E2490-09, this standard places more emphasis on operational details and instrument calibration, while ASTM focuses on data processing and uncertainty analysis.

applicability:
refractory materials such as tungsten carbide powder (0.1-10 μm) and tungsten powder (1-50 μm) . The wet method is more suitable for fine powder, while the dry method is suitable for coarse powder.



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

Appendix:

GB/T 5124-2008 Chemical Analysis Methods for Cemented Carbide

Standard Name:
Chinese: Chemical analysis method of cemented carbide
English: *Methods for Chemical Analysis of Cemented Carbide*

Release and Implementation:
GB/T 5124.1-2008 (Determination of total carbon content): Issued on June 16, 2008, effective on January 1, 2009
GB/T 5124.2-2008 (Determination of free carbon content): Issued on June 16, 2008, effective on January 1, 2009
GB/T 5124.3-2008 (Determination of cobalt content): Issued on June 16, 2008, effective on January 1, 2009
GB/T 5124.4-2008 (Determination of impurity elements): Issued on June 16, 2008, effective on January 1, 2009
Issuing agency: National Standardization Administration
Standard status: Currently valid (as of April 2025, not replaced by new standards)
Replacement standard:
GB/T 5124-1995 (1995 version is divided into several parts, 2008 version is revised and integrated)

1. Scope
This standard specifies the analysis method of chemical composition in cemented carbide, including the determination of total carbon (Total Carbon), free carbon (Free Carbon), cobalt (Co) and impurity elements (such as Fe, Mo, Ni, etc.). It is applicable to the chemical composition analysis of cemented carbide raw materials (such as tungsten carbide powder WC, cobalt powder Co) and sintered cemented carbide products. This standard method can also be used as a reference for the analysis of other metal carbides (such as TiC , TaC , NbC). The analysis results are used for quality control, process optimization and product acceptance.

2. Normative references
The following documents are normative references of this standard and are used together with this standard:
GB/T 223.5-2008 "Determination of carbon and sulfur content of steel and alloys"
GB/T 3249-2009 "Determination of total carbon content of refractory metal powders and compound powders"
GB/T 4010-1994 Methods for sampling and preparation of samples for chemical analysis of metallic materials
GB/T 6682-2008 Specifications and test methods for water used in analytical laboratories (equivalent to ISO 3696:1987)
Note: The latest versions of referenced documents apply to this standard.

3. General

Laboratory conditions: The analysis should be performed in a clean, dust-free environment at 20-25°C and relative humidity <65%.

Sample requirements: Prepare according to GB/T 4010 to avoid contamination or component loss (such as oxidation , volatilization).

Purity of reagents: All reagents were of analytical grade (AR) and of superior grade (GR) when necessary.

Water quality: Conform to GB/T 6682 grade 3 or above pure water.

Instrument Calibration: Calibrate the instrument before analysis to ensure accuracy and repeatability.

Safety requirements: When working with acids, alkalis, or high temperatures, the work must be done in a fume hood and protective equipment must be worn.

4. GB/T 5124.1-2008: Determination of total carbon content

4.1 Principle of the method

The cemented carbide sample is burned at high temperature in an oxygen flow, and all carbon (including bound carbon and free carbon) is converted into CO_2 . The total carbon content is determined by infrared absorption method .

4.2 Reagents and instruments

Oxygen: purity ≥99.5%, flow rate adjustable.

Flux:

High-purity tin particles (Sn, purity ≥99.9%): promote combustion.

High-purity iron powder (Fe, purity ≥99.9%): lowers the melting point.

instrument:

High frequency induction combustion furnace (power ≥ 2 kW, temperature 1350-1450°C).

Infrared carbon and sulfur analyzer (such as LECO CS-600 or CS-844).

4.3 Specimens

Mass: 0.1-0.5 g (accuracy 0.0001 g).

Condition: Grind to <0.2 mm (80 mesh) to remove oil and oxide layer.

4.4 Test steps

Weigh the sample and place it in a clean porcelain boat.

Add flux (Sn 1.0 g, Fe 0.5 g) and mix well.

Place the porcelain boat into the combustion furnace, introduce oxygen (flow rate 2-3 L/min), heat to 1350-1450°C, and burn for 5-10 seconds.

CO_2 is measured by an infrared detector and the absorption peak intensity is recorded .

The instrument is calibrated with a standard sample (e.g. NIST SRM 276b, carbon content 6.0%-6.5%) and the total carbon content is calculated .

4.5 Result calculation

Total carbon content (mass fraction, %) = (instrument reading × calibration factor) / sample mass
Measuring range: 0.1%-10%.
Precision: ±0.01% (repeatability RSD<2%).

4.6 Notes
The samples need to be dried (105°C, 1 hour) to avoid moisture interference.
The combustion furnace needs to be cleaned regularly to remove residue.
Insufficient oxygen flow may result in incomplete combustion, so the gas line needs to be checked.

5. GB/T 5124.2-2008: Determination of free carbon content

5.1 Principle of the method
The free carbon (elemental carbon) in the sample is dissolved with acid and its content is determined by oxidation-titration. The bound carbon (carbon in WC) is insoluble in acid and does not participate in the reaction.

5.2 Reagents and instruments
acid -nitric acid mixture : H_2SO_4 (1+1, diluted 1:1 by volume) and HNO_3 (1+1) are mixed in a 1:1 ratio.
Potassium dichromate ($K_2Cr_2O_7$): 0.1 mol / L standard solution.
Sodium diphenylamine sulfonate: indicator, 0.2% (m/V) aqueous solution.
instrument:
Electric hot plate (temperature adjustable up to 100°C).
Titration apparatus (50 mL burette, accuracy 0.02 mL).

5.3 Specimens
Mass: 1.0-2.0 g (accuracy 0.0001 g).
Condition: Grinded to <0.2 mm, remove surface impurities.

5.4 Test steps
Weigh the sample and place it in a 250 mL conical flask.
Add 50 mL of sulfuric acid-nitric acid mixture, cover with a watch glass, and heat on a hot plate to 80-90°C.
After stirring for 30 minutes, the free carbon was oxidized to CO_2 and the solution became clear.
Cool to room temperature, wash the residue with distilled water until neutral, filter into a 100 mL volumetric flask, and make up to volume.
Take 20 mL of the filtrate, add $K_2Cr_2O_7$ standard solution and titrate to the purple- red endpoint (no color change for 30 seconds), and record the consumed volume.

5.5 Result calculation
Free carbon content (mass fraction, %) = (V × C × 0.012 × 100) / m
V : Volume of $K_2Cr_2O_7$ solution consumed (mL)

C: $K_2Cr_2O_7$ concentration (mol / L)
0.012: Molar mass conversion factor of carbon (g/mmol)
m: sample mass (g)
Measuring range: 0.01%-1.0%.
Precision: ±0.005% (repeatability RSD<3%).

5.6 Notes
The operation was carried out in a fume hood to avoid inhalation of acid fumes.
The titration endpoint must be accurately determined and corrected with a blank test if necessary.
Bound carbon (such as WC) in the sample does not interfere with the results, but it is necessary to ensure that there are no other reducing impurities.

6. GB/T 5124.3-2008 : Determination of cobalt content

6.1 Principle of the method
the cobalt content was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) .

6.2 Reagents and Instruments
Nitric acid (HNO_3) : 1+1 solution (1:1 dilution by volume).
Hydrochloric acid (HCl): 1+1 solution.
Cobalt standard solution: 10 mg/L (prepared with $CoCl_2$, traceable to national standard substances).
Instrument: ICP-OES spectrometer (such as PerkinElmer Optima 8300 or Thermo iCAP 7000).

6.3 Test specimen
Mass: 0.5-1.0 g (accuracy 0.0001 g).
State: Grinded to <0.2 mm, dry.

6.4 Test steps
Weigh the sample and place it in a 100 mL polytetrafluoroethylene beaker.
Add 20 mL HNO_3 and 10 mL HCl, heat to 80 °C, and stir until completely dissolved (approximately 30 min).
After cooling, transfer to a 100 mL volumetric flask and make up to volume with distilled water.
cobalt emission line was measured by ICP-OES (recommended wavelength 228.616 nm, second choice 231.160 nm).
A calibration curve was drawn using a cobalt standard solution (0.1-10 mg/L) to calculate the cobalt concentration.

6.5 Result calculation
Cobalt content (mass fraction, %) = $(C \times V) / (m \times 10^4) \times 100$
C: Cobalt concentration in solution (mg/L)

V: fixed volume (mL, usually 100 mL)
m: sample mass (g)
Measuring range: 0.1%-30%.
Precision: ±0.02% (repeatability RSD<2%).

6.6 Notes
The tungsten matrix may interfere. If necessary, add a masking agent (such as EDTA, 0.1 mol/L) or optimize the instrument parameters.
The standard solution must be prepared fresh every day to avoid deterioration.

7. GB/T 5124.4-2008: Determination of impurity elements

7.1 Principle of the method
The sample was dissolved with acid and the content of impurity elements (such as Fe, Mo, Ni, Cr, Al, etc.) was determined by ICP-OES.

7.2 Reagents and Instruments
Nitric acid (HNO_3) : 1+1 solution.
Hydrochloric acid (HCl): 1+1 solution.
Standard solution: concentration of each element (such as Fe, Mo, Ni) is 1-10 mg/L, traceable to national standard substances.
Instrument: ICP-OES spectrometer.

7.3 Test specimens
Mass: 0.5-1.0 g (accuracy 0.0001 g).
Condition: Ground to <0.2 mm.

7.4 Test procedures
The sample was dissolved in the same manner as in step 6.4 (HNO_3 20 mL, HCl 10 mL, dissolved at 80°C).
After cooling, the volume was adjusted to 100 mL, and the characteristic spectral lines of each element were determined by ICP-OES:
Fe: 238.204 nm
Mo: 202.032 nm
Ni: 231.604 nm
Cr: 267.716 nm
Al: 396.152 nm
Use standard solutions of each element (0.01-10 mg/L) to draw a calibration curve and calculate the concentration.

7.5 Result calculation

Impurity content (mass fraction, %) = $(C \times V) / (m \times 10^{4}) \times 100$

C: element concentration in solution (mg/L)

V: fixed volume (mL, usually 100 mL)

m: sample mass (g)

Measuring range: 0.001%-1.0%.

Precision: ±0.001% (repeatability RSD<5%).

7.6 Notes

High tungsten matrices may produce spectral interferences, requiring wavelength adjustment or use of background correction.

When measuring multiple elements simultaneously, ensure that the spectral lines do not overlap.

8. Precision and uncertainty

8.1 Repeatability

The same operator and instrument have deviation in measurement results:

Total carbon: ±0.01%

Free carbon: ±0.005%

Cobalt: ±0.02%

Impurities: ±0.001%

8.2 Reproducibility

The results of different laboratories and instruments have a deviation of <2 times the repeatability limit.

8.3 Uncertainty

Sources include sample homogeneity, instrument calibration, reagent purity, etc., which need to be evaluated in the report.

9. Notes

Sample preparation: To avoid the introduction of impurities such as Fe during grinding, it is recommended to use a carbide mortar.

Instrument maintenance: Regularly calibrate the combustion furnace and ICP-OES to ensure sensitivity and stability.

Safe operation: Acid dissolution and high-temperature combustion must be carried out in a fume hood, wearing protective glasses and gloves.

Additional Notes

Revision Background:

GB/T 5124-2008 has updated the analysis method compared to the 1995 version, introducing ICP-OES to replace traditional spectrophotometry (such as cobalt determination), improving the accuracy and multi-element analysis capabilities to meet the cemented carbide industry's demand for high-purity raw materials.

Compared with international standards:

Compared with ISO 11876:2010 "Chemical Analysis of Cemented Carbide", this standard focuses more on classical chemical methods (such as combustion method and titration method), while ISO prefers instrumental analysis (such as ICP-MS).

ASTM E1019-18 covers similar content, but places greater emphasis on automation and simultaneous determination of multiple elements.

applicability:

Suitable for component analysis of tungsten carbide powder (WC), WC-Co cemented carbide and composite materials (such as WC- TiC), covering the range of trace to high content.

Appendix :

Fisher's particle size determination method

Fisher Sub-Sieve Sizer (FSSS) is a method for measuring the average particle size of powders by air permeation. It is widely used for particle size analysis of metal powders (such as tungsten carbide powder WC), ceramic powders and other fine particle materials. The Fisher Sub-Sieve Sizer result is expressed in microns (μm), which represents the average particle size of the powder. It is particularly suitable for fine powders with a particle size range of 0.2-50μm. This method indirectly estimates the particle size by measuring the air penetration resistance in the powder bed. It is simple to operate and has good repeatability. It is a standard particle size test method in powder metallurgy and materials science.

1. Definition and Principle

Definition:

Fisher's particle size refers to the average particle size of powder measured by Fisher's sub-sieve analyzer, usually recorded as FSSS particle size (unit: μm). It reflects the equivalent spherical diameter of powder particles. Unlike sieving or laser particle size method, FSSS is more suitable for the characterization of fine powders, especially in the production of cemented carbide raw materials (such as WC powder).

Measurement principle

Air permeability method :

Fisher particle size determination is based on the relationship between the resistance of air passing through a compressed powder bed and the particle size. When air is passed through a powder sample at a constant flow rate, fine particles will produce greater resistance due to their large specific surface area and small pores, while larger particles will have less resistance.

Mathematical basis :

According to the Kozeny-Carman equation, the air permeation resistance is related to the specific surface area (S) and porosity (ε) of the powder:

$$\Delta P = \frac{\mu v L S^2 (1-\varepsilon)^2}{\varepsilon^3}$$

in:

ΔP: Pressure difference (Pa)

μ: Air viscosity (Pa·s)

v: air velocity (m/s)

L: Powder bed thickness (m)

S: Specific surface area (m^2 / kg)

ε: Porosity

can be converted into average particle size (D_FSSS) by measuring ΔP and combining it with the calibration curve under standard conditions.

Assumptions : Particles are spherical, powder bed is uniformly compressed, and air flow is laminar.

Features

Applicable range: 0.2-50μm, accuracy ±0.05μm.

Advantages: The equipment is simple and suitable for rapid detection.

Limitations: Sensitive to particle shape, non-spherical particles may cause deviations.

2. Determination method

The determination of the Fisher particle size follows standard procedures such as ASTM B330 or ISO 10070. The following is an overview of the general method.

equipment

Fisher sub-sieve analyzer : includes air pump, pressure gauge, sample tube (inner diameter usually 5-10mm), water column meter or digital pressure sensor.

Balance : precision 0.001g, used for weighing samples.

Oven : used to dry samples, the temperature is controlled at 100-120°C.

Standard sample : Calibration powder with known particle size (such as standard WC powder).

Procedure

Sample preparation :

Sampling: Randomly draw 5-10g samples from the powder batch, using a sample splitter to ensure representativeness.

Drying: Remove moisture in an oven (105°C, 2 hours) to a moisture content of <0.1%.

Cooling: Cool to room temperature in a desiccator to avoid moisture absorption.

Sample loading and compression :

Weighing: Accurately weigh the specified mass (e.g. 2.5g of WC powder, adjust according to density).

Filling into sample tube: Pour the powder into the sample tube and compress it to a fixed height (usually 10mm) using a compactor at a constant pressure (e.g. 2-5 kPa).

Check: Make sure the powder bed surface is flat, free of cracks, and has a consistent porosity ($\varepsilon \approx 0.4$-0.5).

Instrument Calibration :

Calibrate the instrument with a standard sample (such as FSSS 1.0μm WC powder) and adjust the air flow rate to the standard value (such as 0.1 L/min).

Record the calibration pressure difference (ΔP) to ensure agreement with the standard curve.

Measurement :

Start the air pump and adjust the flow rate to a constant value.

Record the water column height difference (cm H_2O) or digital pressure value (Pa) and repeat 3 times to take the average value.

Convert ΔP\Delta PΔP to FSSS particle size (μm) using the instrument's built-in conversion table or software.

Verification results :

The same batch of samples was measured three times with a deviation of <5%.

Compare with standard samples to ensure the error is <0.1μm.

Experimental data

Sample	Mass(g)	Compression height (mm)	Pressure difference (cm H_2O)	FSSS particle size (μm)
WC powder 1	2.5	10	15.2	1.2
WC powder 2	2.5	10	10.5	2.0
WC powder 3	2.5	10	6.8	3.5

Sample	Mass(g)	Compression height (mm)	Pressure difference (cm H_2O)	FSSS particle size (μm)

Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.

3. Equipment and operation steps

Equipment structure

Air system : A micro pump provides a constant air flow, which is precisely controlled by a flow meter (0.05-0.2 L/min).

Sample tube : glass or metal, 5-10 mm in diameter, with filter paper to support the powder.

Pressure measurement : conventional water column gauge (accuracy 0.1 cm H_2O) or modern digital sensor (accuracy 1 Pa).

Calibration device : standard orifice plate or powder of known particle size, used to calibrate the instrument zero point and sensitivity.

Detailed steps

Warm up the instrument : Start the instrument and allow it to run for 10 minutes to stabilize airflow and temperature (20-25°C).

Weigh the sample : Weigh 2.5g of WC powder using an analytical balance (error <0.001g) and record the mass.

Fill the sample tube : pour the powder slowly, tap gently to remove bubbles, and compress it with a compactor to a height of 10 mm and a pressure of 2 kPa, maintaining a porosity of 0.45 ± 0.05.

Connect the system : Install the sample tube into the instrument, ensuring a leak-free seal.

Adjust the air flow : set the flow rate to 0.1 L/min and wait for the pressure to stabilize (about 30 seconds).

Record data : Read the water column difference (e.g. 15 cm H_2O) and calculate the FSSS particle size by looking up the table or entering it into the software.

Clean and repeat : Take out the sample, clean the sample tube with compressed air, repeat the measurement twice and take the average value.

Precautions

Sample drying is critical, moisture > 0.1% will result in a change in porosity and a particle size that is 0.2-0.5 μm larger.

The compression force must be consistent. Too tight (ε<0.4) or too loose (ε>0.5) will affect the pressure difference.

The ambient temperature was controlled at 20-25°C to avoid changes in air viscosity.

4. Influencing factors and optimization

The accuracy of Fisher's particle size determination is affected by many factors. The following are analyses and optimization suggestions.

Influencing factors

Particle shape :

The measured value of spherical particles is close to the actual particle size, while the FSSS value of non-spherical (such as needle-shaped) particles is larger (deviation of 10%-20%) due to increased resistance.

Porosity :

If the porosity is too low (<0.4), the resistance is too large and the particle size is too small; if the porosity is too high (>0.5), the resistance is insufficient and the particle size is too large.

Moisture Content :

Moisture content > 0.2% causes particle agglomeration and increases the FSSS value by 0.3-0.8 μm.

Airflow stability :

Flow rate fluctuation> 0.01 L/min, pressure difference error ± 0.5 cm H_2O, particle size deviation ± 0.1 μm.

Optimization strategy

Sample pretreatment : drying to moisture <0.05%, ultrasonic dispersion for 5 minutes to reduce agglomeration.

Compression control : Using a standard compactor, the pressure is 2-3 kPa, and the porosity is stabilized at 0.45±0.02.

Instrument calibration : Calibrate monthly with standard WC powder (FSSS 1.0μm), and the error is controlled within ±0.05μm.

Environmental management : constant temperature and humidity (25°C, humidity <50%), air flow stabilized at 0.1±0.005 L/min.

Experimental data :

Condition	Moisture(%)	Porosity	Pressure difference (cm H_2O)	FSSS particle size (μm)
Undried (0.3% moisture)	0.3	0.48	16.0	1.4
Dry + Optimized Compression	0.05	0.45	15.2	1.2

Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.

5. Application scenarios

Fisher particle size determination is widely used in the production and quality control of powder materials. The following are specific applications.

Cemented Carbide Production

Application : To measure WC powder size and control cemented carbide grain size and properties.

Case : A team determined that the FSSS of WC powder was 1.2μm, and the hardness of the prepared cemented carbide was HV 2200, with the grain uniformity increased by 15% (information from China Tungsten Online website).

Thermal Spray Powder

Application : To evaluate the particle size of WC-Co spray powder and ensure the density of spray coating (>99%).

Case : A study determined that the FSSS of WC-12Co powder was 3.5μm, the hardness of the HVOF coating was HV 1350, and the wear rate was 0.06 mm^3 / N · m (information from China Tungsten Online website).

Powder Metallurgy

Application : To detect the particle size of metal powder (such as W, Mo) and optimize sintering performance.

Case : A company determined that the FSSS of W powder was 2.0μm and the density of the sintered body was 98.5% (information from China Tungsten Online website).

Quality Control

Application : To detect the consistency of particle size between batches. The deviation is less than 0.1μm.

Summarize

Fisher particle size determination uses air permeability method to determine the average particle size of powder (0.2-50μm), based on the Kozeny-Carman principle, and converts the FSSS value using pressure difference. The method includes sample drying (moisture <0.1%), compression (porosity 0.45), air flow measurement (0.1 L/min), simple equipment, and accuracy of ±0.05μm. Influencing factors such as particle shape and moisture need to be optimized, and the application covers cemented carbide, spray powder and powder metallurgy to ensure the consistency of material performance (information from China Tungsten Online website).

Appendix:

Bulk density and its determination method

Bulk density and its determination method

Bulk Density refers to the mass of powder per unit volume in a naturally stacked state, usually in g/cm³ or kg/m³ , and is an important parameter for characterizing the physical properties of powder. Bulk density reflects the size, shape, surface characteristics and stacking mode of powder particles, and has guiding significance for processes such as powder metallurgy, thermal spraying, and cemented carbide production. The determination method is simple and efficient, and the two forms of loose bulk density and tapped bulk density are commonly used, which are completed through standard containers and weighing operations.

1. Definition and significance

definition

Bulk density : The ratio of the mass of powder to the volume of the container after the powder is filled in the container

under specified conditions (such as natural loose packing or vibration compaction). Bulk density = m/V

Where:

m: powder mass (g)

V: Volume occupied by powder (cm³)

Loose bulk density : The state of powder falling freely into a container without compression or vibration.

Tapped bulk density : The density of the powder after it is vibrated or tapped in the container and the particles are rearranged to a denser state.

significance

Process guidance : The bulk density affects the fluidity, filling efficiency and sintering performance of the powder. For example, tungsten carbide (WC) powder has a high bulk density and better sintering density.

Quality control : reflects the consistency between powder batches. Large deviations may lead to molding defects.

Material properties : closely related to particle size, shape, and surface roughness, and are important indicators for characterizing powders.

Typical Value

Powder Type	**Bulk density (g/ cm³)**	**Tap density(g/ cm³)**
WC powder (1μm)	4.5-5.0	5.5-6.0
WC-12Co	4.0-4.5	4.8-5.2
W powder (5μm)	6.0-7.0	7.5-8.5
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.		

2. Influencing factors

The bulk density is affected by many factors, which are analyzed in detail below.

Particle size

Impact : The smaller the particle size, the larger the specific surface area, the more voids between particles, and the lower the packing density; the larger the particle size, the fewer voids and the higher the density.

Experimental data :

WC particle size (μm)	Bulk density (g/ cm^3)	Tap density(g/ cm^3)
0.5	4.2	5.3
2.0	4.8	5.8
5.0	5.2	6.2
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.		

Particle shape

Impact : Spherical particles are densely packed and have high density; irregular or needle-shaped particles have large gaps and low density.

Case : The bulk density of spherical WC powder (sphericity>95%) is 4.8 g/cm^3 , while that of irregular WC powder is only 4.3 g/ cm^3 .

Surface properties

Impact : Powders with rough surfaces or static electricity are easy to agglomerate, the porosity increases and the density decreases; smooth surfaces are conducive to dense stacking.

Experiment : The density of untreated WC powder is 4.5 g/ cm^3 , and it reaches 5.0 g/ cm^3 after plasma spheroidization .

Moisture content

Impact : Moisture content > 0.2% causes particles to stick together, the porosity increases, and the density decreases.

Data : The bulk density of WC powder with a water content of 0.5% is 4.3 g/cm^3 , which rises to 4.8 g/ cm^3 after drying .

Stacking method

Impact : The density in the loose state is low. After compaction , the particles are rearranged, the voids are reduced, and the density is increased by 10%-20%.

3. Determination method

The bulk density is determined according to standard procedures such as ASTM B212 (loose), ASTM B527 (tapped) or ISO 3923. The following is an overview of the method.

loose bulk density

Principle : Powder falls freely into the container without applying external force, and the density in the natural stacking state is measured.

step :

Prepare dry samples (moisture < 0.1%).

Use a funnel to slowly pour the powder into a standard measuring cylinder (25 or 100 cm^3) , keeping a drop of 10-15 cm.

Wait for the powder to accumulate naturally, smooth the surface with a scraper, and record the volume (V).

Weigh the mass of powder in the measuring cylinder (m) and calculate the density (m/V).

tapped bulk density

Principle : Through mechanical vibration or knocking, the powder particles are rearranged and the density in a denser state is measured.

Step :

Fill the cylinder using the loose pack method .

Place the measuring cylinder on a vibrator and vibrate 100-300 times (frequency 50-60 times/min, amplitude 3mm) or tap manually until the volume no longer changes.

Record the volume after compaction (V'), weigh the mass (m), and calculate the density (m/V').

Experimental data

Sample	Mass(g)	Loose volume (cm^3)	Bulk density (g/ cm^3)	Tap volume (cm^3)	Tap density(g/ cm^3)
WC (1μm)	50	10.5	4.76	8.9	5.62
WC-12Co	50	11.8	4.24	10.2	4.90
W (5μm)	50	7.8	6.41	6.5	7.69
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.					

4. Equipment and operation steps

equipment

Graduated cylinder : Standard glass graduated cylinder (25, 50 or 100 cm^3) , graduated to ±0.1 cm^3 .

Funnel : opening diameter 5-10mm, drop height adjustable.

Balance : accuracy 0.001g, used to weigh powder mass.

Vibrator : Mechanical compaction device with amplitude 1-5 mm and adjustable frequency (50-60 Hz).

Oven : temperature 100-120°C, used for sample drying.

Scraper : Smooth the powder surface to avoid compaction.

Detailed steps

Sample preparation :

Sampling: Randomly sample 50-100g from the powder batch, using a sampler to ensure homogeneity.

Drying: Dry in oven at 105°C for 2 hours, moisture <0.1%, cool to room temperature (in desiccator).

Determination of bulk density :

Select a 100 cm^3 graduated cylinder and record the empty weight (m_0).

Use a funnel to slowly pour the powder in, with a drop of 15 cm, avoiding knocking or vibration.

Scrape the surface lightly with a scraper and record the total weight (m_1) and volume (V).

Calculation: Bulk density = (m_1 - m_0) / V.

Tap density determination :

Fill the graduated cylinder as in the loose-fill method and record the initial volume.

Place it in a compactor , set the amplitude to 3mm, and compact it 200 times (or until the volume stabilizes).

Record the compacted volume (V') and total weight (m_1).

Calculation: Tap density = (m_1 - m_0) / V' .

Repeatability verification :

The measurement was repeated 3 times, and the average value was taken when the deviation was less than 2%.

Check the inside of the cylinder to make sure there is no powder adhering.

Precautions

Avoid artificial compaction that affects the authenticity of the loose density.

The number of vibrations must be consistent. Too few times (<100 times) will result in low density, while too many times (>300 times) will result in no significant change.

Ambient humidity <50% to prevent moisture interference.

5. Application scenarios

Bulk density determination has a wide range of applications in the field of powder materials. The following are specific scenarios and cases.

Cemented Carbide Production

Application : To evaluate WC powder filling efficiency and optimize pressing and sintering processes.

Case : A team determined that the bulk density of WC powder was 4.8 g/cm³ , the tap density was 5.8 g/cm³ , the compaction density of the pressed billet was increased by 10%, and the hardness was HV 2200 (information from China Tungsten Online website).

Thermal spray powder

Application : To test the fluidity and powder loading efficiency of WC-Co powder and ensure the uniformity of spraying.

Case : A study determined that the tap density of WC-12Co was 4.9 g/cm³ , the porosity of the HVOF sprayed coating was <1%, and the wear resistance was improved by 30% (information from China Tungsten Online website).

Powder Metallurgy

Application : To measure the bulk density of W and Mo powders and control the sintering shrinkage.

Case : A company measured the tap density of W powder to be 7.7 g/cm³ , the shrinkage of the sintered body was stable at 15%-18%, and the density reached 99% (information from China Tungsten Online website).

Quality Control

Application : Density consistency test between batches, deviation <5% is qualified.

Case : A production test of WC powder bulk density fluctuation <0.1 g/cm³ ensures stable batch performance (information from China Tungsten Online website).

Storage and transportation optimization

Application : To evaluate powder packaging volume and reduce transportation costs.

Summarize

Bulk density is a parameter that characterizes the relationship between powder mass and volume. It is divided into loose density (natural packing) and tap density (after tapping), which is affected by particle size, shape, surface characteristics and moisture. The determination method is operated by a standard measuring cylinder and a tapping instrument. The loose density of WC powder is 4.5-5.0 g/cm³ , and the tapped density is 5.5-6.0 g/cm³ , with an accuracy of ±0.01 g/cm³ . In terms of application, it guides cemented carbide, thermal spraying and powder metallurgy processes to improve product quality and process efficiency (information from China Tungsten Online website). Optimizing moisture (<0.1%) and tapping conditions can improve the accuracy of the determination.

Appendix

Determination method of fluidity of tungsten carbide powder

The flowability of tungsten carbide powder (WC) refers to the ability of the powder to flow freely under the action of gravity or other external forces, usually characterized by the flow rate (seconds/50g) or flow time through a standard funnel per unit time. Flowability is an important physical property of powder materials, which directly affects its filling efficiency, uniformity and process stability in thermal spraying, powder metallurgy and cemented carbide production. The Hall Flow Rate Method is commonly used to measure the flowability of tungsten carbide powder. The flowability is evaluated by measuring the time required for 50g of powder to pass through a standard funnel.

1. Definition and significance

definition

Flowability : The ability of a powder to flow freely through a specific opening (such as a 2.5 mm hole in a Hall funnel) without external pressure.

Determination indicators :

Hall flow rate: the time required for 50g of powder to flow out (unit: seconds/50g). The shorter the time, the better the fluidity.

If the powder does not flow freely, record it as "No Flow".

significance

Process influence : Powders with good fluidity (such as WC powder flow rate 13-15 seconds/50g) are evenly distributed during spraying or pressing, reducing porosity and defects.

Quality control : reflects the consistency between powder batches. Large deviations in flow rate may lead to process fluctuations.

Performance correlation : closely related to particle size, shape, and surface state, and is a key parameter for optimizing powder preparation and application.

Typical Value

Powder Type	**Particle size (μm)**	**Flow rate (seconds/50g)**	**Liquidity Evaluation**
WC (spherical)	15-45	13.5	excellent
WC (irregular)	10-30	16.0	good
WC-Co (fine powder)	5-15	>20 or illiquid	Difference
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.			

2. Influencing factors

The fluidity of tungsten carbide powder is affected by many factors. The following is a detailed analysis.

Particle size

Impact : The larger the particle size, the smaller the friction between particles and the higher the fluidity. If the particle size is too small (<5μm), the van der Waals force and electrostatic effect will increase and the fluidity will decrease.

Experimental data :

WC particle size (μm)	**Flow rate (seconds/50g)**
5	>25 (non-flowable)
15-45	13.8
45-60	12.5
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.	

Particle shape

Impact : Spherical particles (sphericity>95%) have low rolling resistance and good fluidity; irregular or flaky particles have poor fluidity due to mechanical interlocking.

Case : The flow rate of spherical WC powder is 13.5 seconds/50g, and that of irregular WC powder is 16.5 seconds/50g.

Surface properties

Impact : Powders with smooth surfaces have less friction and better fluidity; powders with rough surfaces or with an oxide layer (WO_3) are prone to adhesion and have reduced fluidity.

Experiment : The flow rate of plasma spheroidized WC powder is 13.0 seconds/50g, and that of untreated powder is 15.5 seconds/50g.

Moisture content

Impact : Moisture content > 0.2% causes particle agglomeration, significantly reduces fluidity, and even makes the material non-flowable.

Data : The flow rate of WC powder with 0.5% moisture content is >20 seconds/50g, and after drying (moisture content <0.1%) it drops to 14.0 seconds/50g.

Environmental conditions

Impact : Humidity > 60% increases the hygroscopicity of the powder, and temperature changes affect the air viscosity, both of which may interfere with fluidity.

3. Determination method

The flowability of tungsten carbide powder is usually determined by the Hall flow rate method, following standards such as ASTM B213 or ISO 4490. The following is an overview of the method.

Hall flow method

Principle : Measure the time required for 50g of powder to pass through a standard Hall funnel (aperture 2.5mm). The shorter the time, the better the fluidity.

step :

Prepare dry powder (moisture < 0.1%).

Pour 50 g of powder into the Hall funnel and tap gently to ensure even filling.

Open the baffle at the bottom of the funnel and record the time (in seconds) for the powder to flow out completely.

If the powder does not flow, record as "non-flowable".

Helper Methods

Inclination method : measure the angle of repose of the natural stacking of powder. The smaller the angle (<30°), the better the fluidity.

Tap compaction method : Indirectly evaluate fluidity by combining the change in tap density.

Experimental data

Sample	Particle size (μm)	Moisture(%)	Flow rate (seconds/50g)	Angle of repose(°)
WC (spherical)	15-45	0.05	13.5	28
WC (irregular)	10-30	0.10	16.0	35
WC (fine powder)	5-15	0.20	>25 (non-flowable)	45

Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.

4. Equipment and operation steps

equipment

Hall funnel :

Material: Stainless steel or brass.

Specifications: Bottom hole diameter 2.5mm, cone angle 60°, volume about 100 cm^3 .

Timer : accuracy 0.1 second.

Balance : precision 0.001g, weighing 50g powder.

Oven : temperature 100-120°C, dry the sample.

Receiving container : capacity >50 cm^3 , collects the outflowing powder.

Vibrator (optional) : Assists in testing non-flowable powders.

Detailed steps

Sample preparation :

100 g was randomly sampled from the powder batch using a sample splitter to ensure homogeneity.

Dry in oven at 105°C for 2 hours, moisture <0.1%, cool to room temperature (in desiccator).

Instrument Calibration :

Check the aperture of the Hall funnel (2.5 ± 0.01 mm) to ensure that there is no blockage.

Verify the instrument accuracy using standard powder (e.g. FSSS 3.0μm WC, flow rate 14.0 sec/50g).

Determination process :

Weigh 50.0 ± 0.01 g of WC powder, pour it into the Hall funnel, and tap it gently three times to avoid bridging.

Open the bottom baffle and start the timer at the same time to record the time when the powder flows out completely.

If the powder gets stuck, tap the funnel, if it still does not flow, record it as "not flowing".

Data processing :

Repeat the measurement three times, and take the average value if the deviation is less than 0.5 seconds.

Check the powder mass in the receiving container to ensure that there is no residue (error < 0.1g).

Precautions

The funnel should be placed vertically to avoid tilting which may affect the flow rate (deviation ±0.2 seconds).

Environmental control: temperature 20-25°C, humidity <50%, prevent moisture absorption.

Fine powder (<10μm) may require vibration assistance, otherwise it is prone to clogging.

5. Application scenarios

The fluidity measurement of tungsten carbide powder has important applications in many fields. The following are specific scenarios and cases.

Thermal spraying process

Application : To evaluate the uniformity of WC-Co powder supply in HVOF or APS . The flow rate <15 sec/50 g is excellent.

Case : A team determined that the flow rate of WC-12Co was 13.8 seconds/50g, the porosity of the sprayed coating was <1%, and the wear resistance was improved by 30% (information from China Tungsten Online website).

Cemented Carbide Production

Application : To test the fluidity of WC powder and ensure the uniformity of pressed blanks.

Case : A study determined that the WC powder flow rate was 14.0 seconds/50g, the density consistency of the pressed parts was improved by 10%, and the hardness was HV 2250 (information from China Tungsten Online website).

Powder Metallurgy

Application : To optimize the efficiency of W or WC powder filling . Too high flow rate (>20 seconds/50g) may cause delamination.

Case : A company determined that the flow rate of spherical W powder was 12.5 seconds/50g, and the density of the sintered body was 99% (information from China Tungsten Online website).

Quality Control

Application : To test the consistency of fluidity between batches. The flow rate deviation is less than 1 second.

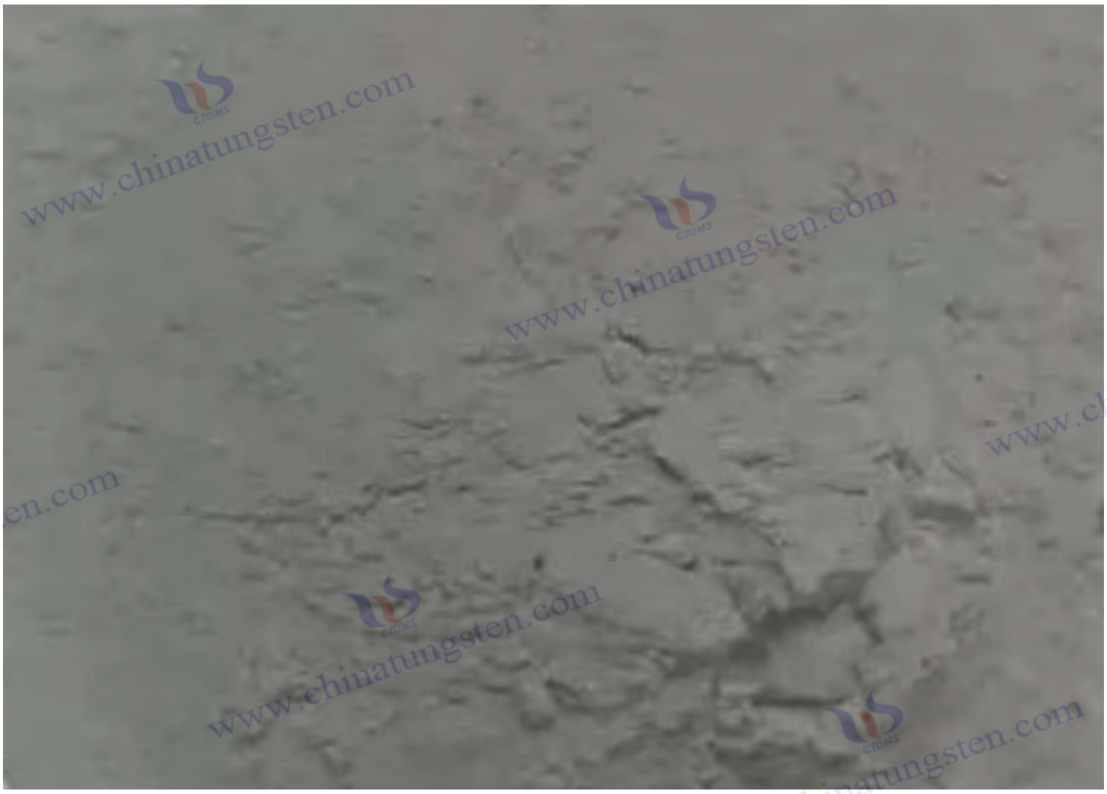
Case : A production company measured the WC powder flow rate fluctuation to be <0.5 sec/50g, ensuring batch stability (information from China Tungsten Online website).

Storage and transportation design

Application : To evaluate the flow characteristics of powders in silos and optimize the conveying system.

Summarize

The fluidity of tungsten carbide powder is measured by the Hall flow rate method, characterized by the time (seconds/50g) for 50g of powder to flow through a 2.5mm aperture funnel, with a typical value of 13-16 seconds/50g. Fluidity is affected by particle size, shape, surface state and moisture. The measurement requires dry powder (moisture <0.1%), standard equipment and precise operation. In terms of application, it guides thermal spraying, cemented carbide and powder metallurgy processes to improve filling efficiency and product quality (information from China Tungsten Online website). Optimizing particle sphericity and drying conditions can significantly improve fluidity.



Appendix:

Tap density of tungsten carbide powder and its determination method

Tapped density refers to the mass per unit volume of tungsten carbide powder (WC) after the particles are rearranged to a dense state under specified vibration or knocking conditions, usually in g/cm³ . Tapped density is a key parameter of the physical properties of powders, reflecting the compactness of particle packing, and is closer to the filling state in the actual process than loose density. In cemented carbide, thermal spraying and powder metallurgy, tapped density directly affects the pressing efficiency, sintering performance and final product quality of the material. The determination method usually adopts the tapping method , which is completed by a standard measuring cylinder and tapping equipment.

1. Definition and significance

definition

Tap density : The density of tungsten carbide powder when the gaps between particles are reduced and the powder reaches a stable stacking state after mechanical vibration or manual tapping.

$$\text{振实密度} = \frac{m}{V}$$

in:

m: powder mass (g)

V: Volume after compaction (cm³)

Difference from bulk density : bulk density is the natural stacking state, while tap density makes the particles more compact through external force, and the value is usually 10%-20% higher.

significance

Process guidance : WC powder with high tap density (such as 5.5-6.0 g/cm³) is more efficient during pressing or filling, and has better density after sintering.

Quality control : reflects the consistency of powder stacking characteristics between batches. Large deviations may lead to uneven molding.

Performance correlation : related to particle size, shape and surface state, and is an important basis for optimizing powder preparation and application.

Typical Value

Powder Type	Particle size (μm)	Bulk density (g/ cm³)	Tap density(g/ cm³)
WC (ultra-fine)	0.5-1	4.2-4.5	5.3-5.6
WC (Medium)	2-5	4.8-5.0	5.8-6.2
WC-Co (composite)	15-45	4.0-4.5	4.8-5.2

Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.

2. Influencing factors

The value of the tap density of tungsten carbide powder is affected by many factors. The following is a detailed analysis.

Particle size

Impact : The larger the particle size, the higher the filling efficiency of the gaps between particles and the increased tap density; if the particle size is too small (<1μm), the surface force is enhanced, the gaps are difficult to compress, and the density is low.

Experimental data :

WC particle size (μm)	Bulk density (g/ cm³)	Tap density(g/ cm³)	Increase(%)
0.5	4.2	5.3	26
2.0	4.8	5.8	twenty one
5.0	5.0	6.2	twenty four
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.			

Particle shape

Impact : Spherical particles (sphericity>95%) are closely arranged after vibration and have high density; irregular or needle-shaped particles have high porosity and low density due to intercalation.

Case : The tap density of spherical WC powder is 6.0 g/cm³ , while that of irregular WC powder is only 5.5 g/ cm³ .

Surface properties

Impact : Powders with smooth surfaces have less friction, are easily rearranged after vibration, and have high density; powders with rough surfaces or with oxide layers (WO_3) are sticky and have low density.

Experiment : The tap density of plasma spheroidized WC powder is 6.2 g/cm³ , and that of untreated powder is 5.7 g/ cm³ .

Moisture content

Impact : Moisture content > 0.2% causes particles to agglomerate, making it difficult for vibration to compress the gaps, and the density decreases.

Data : The tap density of WC powder with 0.5% water content is 5.2 g/cm³ , which rises to 5.8 g/ cm³ after drying (water content <0.1%) .

Compaction conditions

Impact : Amplitude, frequency and number of vibrations affect the efficiency of particle rearrangement. Insufficient vibration will result in low density, while excessive vibration will not result in significant change.

Experiment : The density of WC powder is 5.6 g/cm³ after 100 times of vibration , rises to 5.8 g/cm³ after 300 times , and remains unchanged after 500 times.

3. Determination method

The tap density of tungsten carbide powder is determined according to standard procedures such as ASTM B527 or ISO 3953. The following is an overview of the method.

Vibration method

Principle : Through mechanical vibration or manual knocking, the WC powder particles are rearranged and the density in a stable state is measured.

step :

Prepare dry powder (moisture < 0.1%).

Pour the powder into a standard graduated cylinder (25 or 100 cm³) and record the initial volume.

with a vibrator or tap manually until the volume no longer changes, and record the volume after vibration (V').

Weigh the powder mass (m) and calculate the tap density (m/V ').

Experimental data

Sample	Mass(g)	Initial volume (cm³)	Tap volume (cm ³)	Tap density(g/ cm³)
WC (1μm)	50	11.0	8.9	5.62
WC (5μm)	50	10.2	8.1	6.17
WC-12Co	50	12.0	10.2	4.90
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.				

4. Equipment and operation steps

equipment

Graduated cylinder : Standard glass graduated cylinder (25, 50 or 100 cm³) , graduated to ±0.1 cm³ .

Balance : precision 0.001g, weighing powder mass.

Vibration compactor :

Type: Mechanical compaction device (such as Scott Volumeter).

Parameters: amplitude 1-5 mm, frequency 50-60 Hz.

Oven : temperature 100-120°C, dry the sample.

Funnel : opening 5-10mm, to assist in filling.

Scraper : Smooth the powder surface.

Detailed steps

Sample preparation :

50-100 g was randomly sampled from the WC powder batch and a sample divider was used to ensure homogeneity.

Dry in oven at 105°C for 2 hours, moisture <0.1%, cool to room temperature (in desiccator).

Sample loading :

Select a 100 cm³ graduated cylinder and record the empty weight (m_0).

Use a funnel to slowly pour 50 g of powder into the tube, with a drop of 10-15 cm to avoid compaction, and record the initial volume.

Use a scraper to lightly smooth the surface.

Compaction process :

Place the measuring cylinder in a vibrator , set the amplitude to 3 mm, the frequency to 60 Hz, and vibrate 200 times (or until the volume stabilizes).

vibrating manually , tap the bottom of the measuring cylinder 200 times at a height of 2-3 cm.

Record the compacted volume (V') and total weight (m_1).

calculate :

Tap density = $(m_1 - m_0) / V'$.

The measurement was repeated 3 times, and the average value was taken when the deviation was less than 2%.

Cleaning : Use compressed air to clean the measuring cylinder to avoid residue affecting the next measurement.

Precautions

The number of compaction times must be consistent. Too few times (<100 times) will result in low density, while too many times (>300 times) will not result in significant improvement.

The inner wall of the measuring cylinder needs to be dry; humidity >50% may cause powder adhesion.

Fine powders (<1 μm) may require increased amplitude (5 mm) to overcome surface forces.

5. Application scenarios

The tap density measurement of tungsten carbide powder has important applications in many fields. The following are specific scenarios and cases.

Cemented Carbide Production

Application : To evaluate the pressing and sintering performance of WC powder. High tap density (e.g. 5.8 g/cm³) is conducive to densification.

Case : A team determined that the tap density of WC powder was 5.8 g/cm³ , the density of the pressed billet increased by 12%, and the hardness was HV 2250 (information from China Tungsten Online website).

Thermal spraying process

Application : To test the filling efficiency of WC-Co powder, the tap density is 4.8-5.2 g/cm³ to ensure the uniformity of spraying.

Case : A study determined that the tap density of WC-12Co was 4.9 g/cm³ , the porosity of the HVOF coating was <1%, and the wear resistance was improved by 35% (information from China Tungsten Online website).

Powder Metallurgy

Application : Optimize the sintering shrinkage of WC or W powder, increase the tap density and reduce porosity.

Case : A company determined that the tap density of WC powder was 6.0 g/cm³ and the density of the sintered body was 99.5% (information from China Tungsten Online website).

Quality Control

Application : Density consistency test between batches. Deviation <0.1 g/cm³ is acceptable.

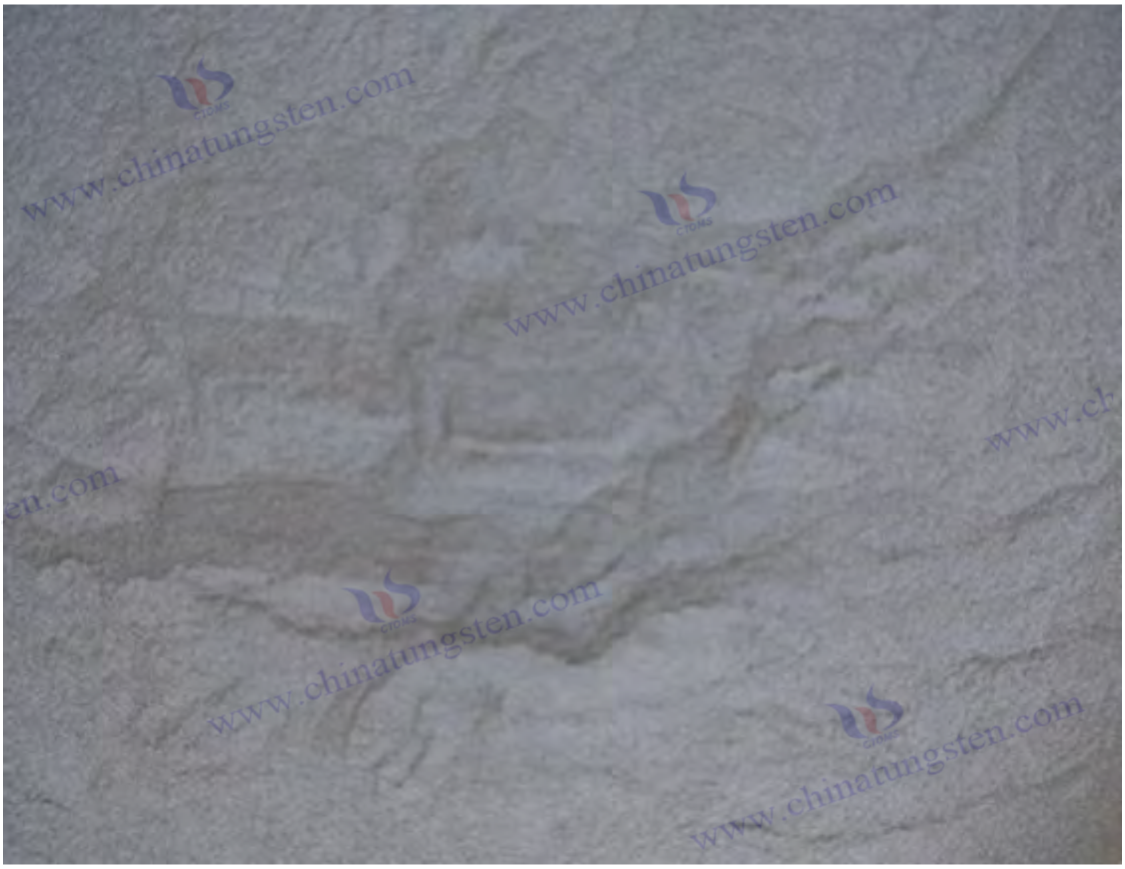
Case : A production company measured the fluctuation of WC powder tap density to be <0.05 g/cm³ , ensuring batch stability (information from China Tungsten Online website).

Storage and transportation design

Application : To evaluate the compactness of powder in the silo and optimize the packaging volume.

Summarize

The tap density of tungsten carbide powder is the mass per unit volume of the powder after vibration, with a typical value of 5.3-6.2 g/cm³ (WC monomer) or 4.8-5.2 g/cm³ (WC-Co), which is affected by particle size, shape, surface state and moisture. The measurement method adopts the vibration method , using a measuring cylinder and a vibration instrument, vibrating 200-300 times, with an accuracy of ±0.01 g/cm³ . In terms of application, it guides cemented carbide, thermal spraying and powder metallurgy processes, improves pressing efficiency and product quality (information from China Tungsten Online website). Optimizing drying (moisture <0.1%) and vibration conditions can improve the accuracy of the measurement.



Appendix:

Bulk density of tungsten carbide powder and its determination method

Loose Bulk Density refers to the mass per unit volume of tungsten carbide powder (WC) in a natural stacking state without external compression or vibration, usually in g/cm³ . Loose density is a basic parameter of the physical properties of powders, reflecting the stacking efficiency of particles in a natural state, and is closely related to the fluidity, filling performance and subsequent processes (such as pressing and sintering) of the powder. In the fields of cemented carbide, thermal spraying and powder metallurgy, loose density is an important indicator for quality control and process optimization. The determination method is simple, usually completed by standard measuring cylinder and weighing operation.

1. Definition and significance

Definition

Bulk density : The density of tungsten carbide powder when it falls freely into a container without any external force.

Bulk density = m/V

Where:

m: powder mass (g)

V: loose volume (cm³)

Features : It reflects the natural stacking state of powder. Compared with the tap density, the value is lower and the porosity is higher.

significance

Process guidance : WC powder with low bulk density (such as 4.2-4.5 g/cm³) has low filling efficiency and may affect the pressing uniformity; high density (such as 5.0 g/cm³) is conducive to process stability.

Quality Control : Check the consistency of particle characteristics between batches. Large deviations may lead to process fluctuations.

Performance correlation : related to particle size, shape and surface condition, and is the basic data for evaluating powder properties.

Typical Value

Powder Type	Particle size (μm)	Bulk density (g/ cm³)	True density (g/ cm³)
WC (ultra-fine)	0.5-1	4.2-4.5	15.63
WC (Medium)	2-5	4.8-5.0	15.63
WC-Co (composite)	15-45	4.0-4.5	12-14
Data source: Tested by a laboratory in 2023, information from China Tungsten Online. Note: True density is a theoretical value.			

2. Influencing factors

The value of the bulk density of tungsten carbide powder is affected by many factors. The following is a detailed analysis.

Particle size

Impact : The larger the particle size, the higher the filling efficiency of the gaps between particles, and the increased bulk density; if the particle size is too small (<1μm), the surface force (such as van der Waals force) is enhanced, the gaps increase, and the density decreases.

Experimental data :

WC particle size (μm)	Bulk density (g/ cm³)	Void ratio (%)
0.5	4.2	73
2.0	4.8	69
5.0	5.0	68
Data source: A laboratory test in 2023, information from China Tungsten Online website. Void ratio = (1 - bulk density/true density) × 100%.		

Particle shape

Impact : Spherical particles (sphericity>95%) are naturally densely packed and have high density; irregular or flaky particles have high porosity and low density due to intercalation.

Case : The bulk density of spherical WC powder is 5.0 g/cm³ , and that of irregular WC powder is 4.5 g/cm³ .

Surface properties

Impact : Powders with smooth surfaces have less friction, are compactly packed, and have high density; powders with rough surfaces or oxide layers (WO_3) are prone to adhesion and have low density.

Experiment : The bulk density of plasma spheroidized WC powder is 5.1 g/cm³ , and that of untreated powder is 4.6 g/ cm³ .

Moisture content

Impact : Moisture content > 0.2% causes particle agglomeration, increased porosity and decreased density.

Data : The bulk density of WC powder with a moisture content of 0.5% is 4.3 g/cm³ , which rises to 4.8 g/ cm³ after drying (moisture content <0.1%) .

Stacking method

Impact : The height of the drop and the speed of powder pouring affect the uniformity of stacking. Too large a drop (>20cm) may cause particle segregation and low density.

3. Determination method

The bulk density of tungsten carbide powder is determined according to standard procedures, such as ASTM B212 or ISO 3923-1. The following is an overview of the method.

Loose mounting method

Principle : Let WC powder fall freely into a standard measuring cylinder through a funnel to measure the density in the natural stacking state.

step :

Prepare dry powder (moisture < 0.1%).

Use the funnel to slowly pour the powder into a measuring cylinder (25 or 100 cm³) , keeping a drop of 10-15 cm.

Smooth the surface with a scraper and record the volume (V).

Weigh the powder mass (m) and calculate the bulk density (m/V).

Experimental data

Sample	Mass(g)	Volume (cm³)	Bulk density (g/ cm³)
WC (1μm)	50	11.0	4.55
WC (5μm)	50	10.2	4.90
WC-12Co	50	11.8	4.24
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.			

4. Equipment and operation steps

Equipment

Graduated cylinder : Standard glass graduated cylinder (25, 50 or 100 cm³) , graduated to ±0.1 cm³ .

funnel :

Material: stainless steel or glass.

Specifications: Opening diameter 5-10mm, adjustable drop.

Balance : precision 0.001g, weighing powder mass.

Oven : temperature 100-120°C, dry the sample.

Scraper : Smooth the powder surface to avoid compaction.

Sample divider : ensures sample homogeneity.

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

Detailed steps

Sample preparation :

Randomly select 50-100 g from the WC powder batch and use a sample divider to take a uniform sample.

Dry in oven at 105°C for 2 hours, moisture <0.1%, cool to room temperature (in desiccator).

Sample loading :

Select a 100 cm³ graduated cylinder and record the empty weight (m_0).

Fix the funnel above the measuring cylinder with a height of 15 cm and slowly pour in 50 g of powder, avoiding knocking or vibration.

Scrape the surface lightly with a scraper and record the total weight (m_1) and volume (V).

calculate :

Bulk density = (m_{1-0})/V.

The measurement was repeated 3 times, and the average value was taken when the deviation was less than 2%.

Cleaning : Use compressed air to clean the measuring cylinder and funnel to avoid residue affecting the next measurement.

Precautions

Avoid artificial compaction or vibration to ensure natural stacking state.

The drop height should be controlled at 10-15cm. Too high (>20cm) may cause particle stratification and low density.

Ambient humidity <50% to prevent the powder from absorbing moisture.

5. Application scenarios

The bulk density determination of tungsten carbide powder has important applications in many fields. The following are specific scenarios and cases.

Cemented Carbide Production

Application : To evaluate the initial filling efficiency of WC powder and guide the pressing process.

Case : A team determined that the bulk density of WC powder was 4.8 g/cm³ , the uniformity of the pressed blank was improved by 8%, and the hardness was HV 2200 (information from China Tungsten Online website).

Thermal spraying process

Application : To test the stability of WC-Co powder supply . The bulk density of 4.0-4.5 g/cm³ is conducive to uniform spraying.

Case : A study determined that the bulk density of WC-12Co was 4.2 g/cm³ , the porosity of the HVOF coating was <1.5%, and the wear resistance was improved by 25% (information from China Tungsten Online website).

Powder Metallurgy

Application : To optimize WC or W powder filling efficiency , high bulk density can reduce sintering shrinkage fluctuation.

Case : A company determined that the bulk density of WC powder was 5.0 g/cm³ and the density of the sintered body was 98.5% (information from China Tungsten Online website).

Quality Control

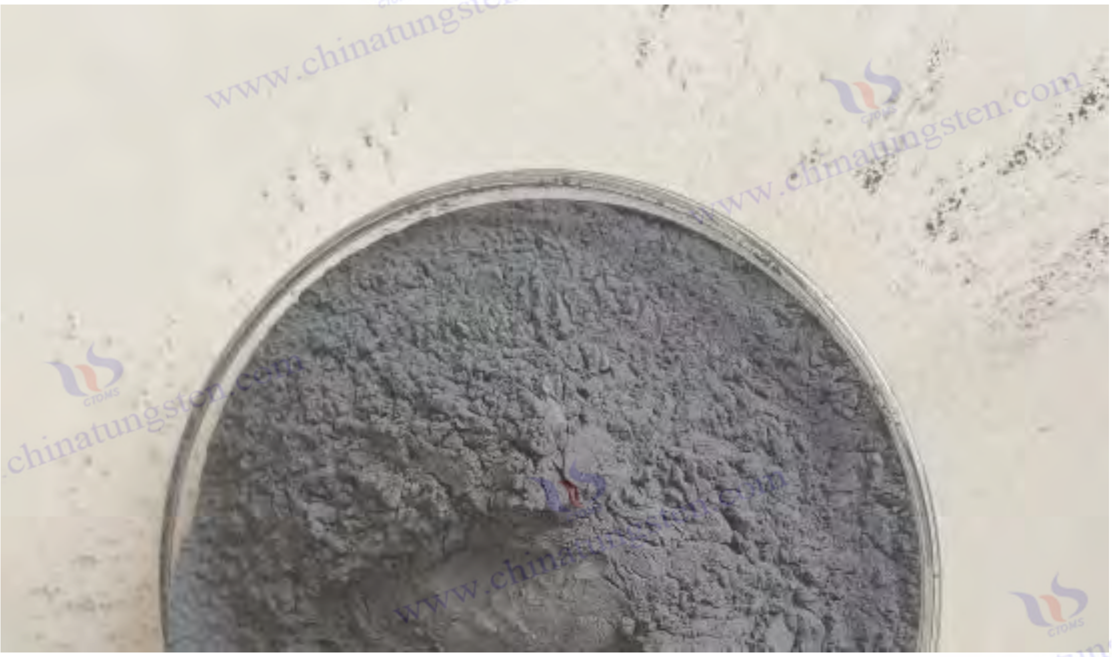
Application : Density consistency test between batches. Deviation <0.1 g/cm³ is acceptable.
Case : A production company measured the bulk density fluctuation of WC powder to be <0.05 g/cm³ , ensuring batch stability (information from China Tungsten Online website).

Storage and transportation design

Application : To evaluate the natural bulk volume of powders and optimize packaging and transportation efficiency.

Summarize

The bulk density of tungsten carbide powder is the unit volume mass of the powder in the natural stacking state, with a typical value of 4.2-5.0 g/cm³ (WC monomer) or 4.0-4.5 g/cm³ (WC-Co), which is affected by particle size, shape, surface state and moisture. The determination method adopts the bulk method , using a measuring cylinder and a funnel, with an accuracy of ±0.01 g/cm³ . In terms of application, it guides cemented carbide, thermal spraying and powder metallurgy processes to improve filling efficiency and product quality (information from China Tungsten Online website). Optimizing drying (moisture content <0.1%) and drop conditions can improve the accuracy of the determination.



Appendix:

What are the density expressions of tungsten carbide powder?

The density of tungsten carbide powder (WC) is a physical quantity that characterizes the relationship between its mass and volume. It has multiple representations under different application scenarios and test conditions. The density representation not only reflects the intrinsic characteristics and stacking behavior of the powder, but also directly affects the performance optimization and quality control of processes such as cemented carbide, thermal spraying, and powder metallurgy. The density of tungsten carbide powder usually includes true density, loose density, tap density, apparent density, etc. Each density has a specific definition, measurement method, and application significance.

1. Definition and classification of density

Density is the mass of a substance per unit volume, and the formula is:
$\rho = m / V$
in:
ρ: density (g/ cm^3)
m: mass (g)
V: Volume (cm^3) For
tungsten carbide powder, the density expression varies depending on the measurement conditions and powder state.

The density of tungsten carbide powder mainly includes the following:
True Density: The theoretical density of the powder particles themselves, excluding pores or voids.
Loose Bulk Density: The density of powder in its natural stacking state, including the spaces between particles.
Tapped Density: The density of a powder in a more compact state after being vibrated or tapped.
Apparent Density: The density of a powder under specific test conditions (such as Hall flow meter), which is often similar to the bulk density.
Other derived densities: such as compacted density (in the pressing process) or sintered density (sintered bodies).

Different densities reflect the particle characteristics (such as size and shape) and stacking behavior of the powder, and guide process design.
True density is used for material composition analysis, loose /tapped density affects packing efficiency, and apparent density is related to fluidity.

2. True density
definition
True density is the solid density of tungsten carbide powder particles, excluding the pores inside the particles or the gaps between particles, reflecting the theoretical mass-to-volume ratio of the material

itself.

For pure WC, the true density is determined by its crystal structure (hexagonal system).

Numeric

Pure WC: True density is 15.63 g/cm³ (theoretical value, based on lattice parameters a=2.906 Å , c=2.837 Å).

Composite powder: such as WC-Co, the true density is reduced due to the addition of a binder phase (such as Co density 8.90 g/cm³) .

Powder Type	Adhesive phase (%)	True density (g/ cm³)
WC	0	15.63
WC-12Co	Co: 12	14.0-14.5
WC-10Co-4Cr	Co: 10, Cr: 4	13.8-14.2

Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.

Determination method

Gas displacement method (helium specific gravity method):

Principle: Fill the pores of powder sample with helium and determine the solid volume.

Equipment: Helium pycnometer (such as Micromeritics AccuPyc).

Procedure: Weigh the sample (5 g), place it in a sealed chamber, introduce helium, record the exhaust volume, and calculate the true density.

formula:

$$\rho_{\text{true}} = \frac{m}{V_{\text{solid}}}$$

Where V solid is the solid volume.

Accuracy: ±0.01 g/ cm³ .

application

Verify powder purity (e.g. free carbon < 0.1% in WC).

Calculate the theoretical density of composite materials to guide formulation design.

3. Bulk density

definition

The bulk density is the density of tungsten carbide powder in a naturally stacked state after it falls freely into a container, including the spaces between particles, without vibration or compression.

Numeric

Pure WC: 4.2-5.0 g/cm³ , the smaller the particle size, the lower the density.

Composite powder: such as WC-12Co, 4.0-4.5 g/cm³ , due to the lower density of the bonding phase.

Powder Type	Particle size (μm)	Bulk density (g/ cm³)	Void ratio (%)
WC (ultra-fine)	0.5-1	4.2-4.5	71-73
WC (Medium)	2-5	4.8-5.0	68-69
WC-12Co	15-45	4.0-4.5	68-71

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

Powder Type	Particle size (μm)	Bulk density (g/ cm³)	Void ratio (%)
Data source: A laboratory test in 2023, information from China Tungsten Online website. Void ratio = (1 - bulk density/true density) × 100%.			

Determination method

Standard: ASTM B212 or ISO 3923-1.

Principle: Pour the powder into the measuring cylinder through a funnel to determine the natural accumulation volume.

step:

The powder was dried (105°C, 2 h, moisture < 0.1%).

Use a funnel (opening 5-10 mm) to pour 50 g of powder into a 100 cm³ measuring cylinder with a drop of 10-15 cm.

Use a scraper to level the surface, record the volume (V), and weigh the mass (m).

Calculation: Bulk density = m/V.

Accuracy: ±0.01 g/ cm³ .

Influencing factors

Small particle size, high porosity and low density.

Irregular particles or moisture (>0.2%) reduce density.

application

Evaluate initial charge efficiency and guide pressing and spraying processes.

Check the consistency of particle characteristics between batches.

4. Tap density

definition

The tap density is the density of the tungsten carbide powder after the particles are rearranged to a denser state after vibration or tapping, and the porosity is lower than the bulk density.

Numeric

Pure WC: 5.3-6.2 g/cm³ , 10%-20% higher than bulk density.

Composite powder: such as WC-12Co, 4.8-5.2 g/ cm³ .

Powder Type	Particle size (μm)	Tap density(g/ cm³)	Increase(%)
WC (ultra-fine)	0.5-1	5.3-5.6	24-26
WC (Medium)	2-5	5.8-6.2	20-24
WC-12Co	15-45	4.8-5.2	15-20
Tested by a laboratory in 2023, information from China Tungsten Online. Increase = (tapped density - bulk density) / bulk density × 100%.			

Determination method

Standard: ASTM B527 or ISO 3953.

Principle: The powder particles are rearranged by a vibrator and the stable volume is determined.

step:

as in the loose-fill method and record the initial volume.

Place in a vibration compactor (amplitude 3 mm, frequency 60 Hz) and vibrate 200 times or until the volume stabilizes.

the volume (V') after compaction and weigh the mass (m).

Calculation: Tap density = m/V ' .

Accuracy: ±0.01 g/ cm³ .

Influencing factors

After vibration, the spherical particles are arranged closely and have high density.

If the number of compaction times is insufficient (<100 times), the density will be low, and if it is too many (>300 times), there will be no significant change.

application

Guide pressing and sintering processes and predict density.

Optimize silo filling efficiency.

5. Apparent density and other density expressions

Apparent density

Definition: The density of a powder measured in a specific device (such as a Hall flow meter). It is usually similar to the bulk density, but is more related to flowability.

Value: WC powder 4.0-5.0 g/cm³ , WC-Co powder 4.0-4.5 g/ cm³ .

Determination method:

Standard: ASTM B212 or ISO 3923-2.

Procedure: Collect 50 g of powder using a Hall flow meter (aperture 2.5 mm), record the volume, and calculate the density.

Application: Evaluation of powder behavior in dynamic processes such as spray powder feeding.

Other density representations

Compacted density:

Definition: The density of a powder during the compaction process, which is close to the tap density but is affected by the pressure.

Value: WC powder 6.0-8.0 g/cm³ (after pressing).

Application: Carbide forming.

Sintered density:

Definition: The density of a solid block after sintering powder, close to the true density.

Value: WC-based cemented carbide 14.0-15.5 g/ cm³ .

Application: Verification of sintering quality.

Apparent Density:

Definition: The apparent mass-to-volume ratio of a powder in a specific container, commonly used for storage and transportation.

Value: Similar to bulk density, 4.0-5.0 g/ cm³ .

Experimental data

Powder Type	True density (g/ cm³)	Bulk density (g/ cm³)	Tap density(g/ cm³)	Apparent density (g/ cm³)
WC (1μm)	15.63	4.55	5.62	4.50

Powder Type	True density (g/ cm³)	Bulk density (g/ cm³)	Tap density(g/ cm³)	Apparent density (g/ cm³)
WC (5μm)	15.63	4.90	6.17	4.85
WC-12Co	14.2	4.24	4.90	4.20
Data source: Test conducted by a certain laboratory in 2023, information comes from the China Tungsten Online website.				

Summarize

The density of tungsten carbide powder includes true density (15.63 g/cm³ , WC monomer), bulk density (4.2-5.0 g/cm³) , tap density (5.3-6.2 g/cm³) , apparent density (4.0-5.0 g/cm³) and other derived densities (such as compaction and sintering density). Each density is measured by a specific method, such as helium displacement method (true density), measuring cylinder method (bulk /tapped density), Hall flow rate method (apparent density), reflecting the different characteristics of the powder. In application, these densities guide cemented carbide, thermal spraying and powder metallurgy processes to ensure filling efficiency and product quality (information from China Tungsten Online website). Optimizing particle shape and drying conditions can improve the accuracy of density measurement.

CTIA GROUP LTD
Tungsten Carbide Powder Introduction

1. Overview of Tungsten Carbide Powder

CTIA GROUP's tungsten carbide powder (chemical formula WC) is a high-quality powder product made from high-purity tungsten raw materials and carbon black through a high-temperature carburization process. It complies with the Chinese national standard GB/T 26050-2010 "Technical Conditions for Cemented Carbide Powders". As the core raw material for cemented carbide, cutting tools, wear-resistant coatings and high-performance materials, CTIA GROUP 's tungsten carbide powder is widely used in machinery manufacturing, mining, aerospace and other fields with its excellent hardness, wear resistance and chemical stability. We provide a full range of products from ultra-fine particles (0.6 μm) to extra-coarse particles (45 μm) to meet diverse industrial needs. For more information, please visit www.tungsten-powder.com

2. Product Features of Tungsten Carbide Powder

High purity and stability

Total carbon content (T/C): 5.90-6.18 wt %, theoretical value 6.13 wt % (±0.05 wt %), ensuring high purity of WC phase.

Free carbon content (F/C): ≤0.10 wt %, high-end customized models can be controlled at ≤0.05 wt %, reducing the impact of free carbon on performance .

Low impurity content: Iron (Fe) ≤ 0.05 wt %, oxygen (O) ≤ 0.20 wt % (fine particles ≤ 0.15 wt %), meeting high-precision application requirements.

Diverse particle size options

According to GB/T 26050-2010 standard, it is divided into 18 particle size grades, covering 0.6-45 μm , with uniform particle size and deviation controlled within ±10%.

Excellent physical properties

Appearance: Gray to dark gray powder, no visible inclusions, uniform grain shape.

Density: 15.63 g/cm³ (theoretical value), loose density 3.0-5.0 g/cm³ (customizable).

Application flexibility

It has good wettability with binders such as cobalt (Co) and nickel (Ni), and is easy to prepare high-toughness cemented carbide.

Adapt to various sintering processes to meet different needs from precision tools to mining drill bits.

3. Specifications of CTIA GROUP LTD Tungsten Carbide Powder

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC06-07	0.6-0.7	5.90-6.18	≤0.05	≤0.15	Ultra-fine cutting tools, coatings
WC08-10	0.8-1.0	5.90-6.18	≤0.10	≤0.15	Precision cutting tools
WC20-25	2.0-2.5	5.90-6.18	≤0.10	≤0.20	General Carbide
WC50-60	5.0-6.0	5.90-6.18	≤0.10	≤0.20	Mining tools
WC100-150	10.0-15.0	5.90-6.18	≤0.10	≤0.20	High toughness wear-resistant parts

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

Category Brand	Fisher particle size (µm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC300-450	30.0-45.0	5.90-6.18	≤0.10	≤0.20	Extra coarse impact tool
Remark	Impurity content (Fe, Mo, Si, etc.) meets standard limits , special particle size or special requirements can be customized according to customer needs.				

4. Production Process of Tungsten Carbide Powder

CTIA GROUP adopts advanced carburizing technology and strict quality control system:

Raw materials: high-purity tungsten powder (purity ≥99.95%) and high-quality carbon black.

Carbonization: React in a high temperature vacuum furnace at 1400-1600°C to ensure complete carbonization and uniform grains.

Crushing and screening: Through air flow crushing and multi-stage screening, the particle size distribution can be precisely controlled.

Quality inspection: Based on GB/T 5124 (chemical analysis), GB/T 1482 (Ferris particle size) and other methods to ensure that each batch meets the standards.

5. Quality Assurance of CTIA GROUP Tungsten Carbide Powder

Standard compliance: Strictly implement GB/T 26050-2010, each batch of products comes with a quality certificate, including chemical composition, particle size and appearance test results.

Factory inspection: total carbon, free carbon, impurity elements such as Fe, O content , particle size, appearance , physical properties (such as loose density).

Sampling: According to GB/T 5314, uniform sampling is conducted from each batch (1-5 tons) to ensure representativeness.

6. Packaging and Transportation of CTIA GROUP Tungsten Carbide Powder

Inner packaging: sealed plastic bag or vacuum packed to prevent oxidation.

Outer packaging: iron drum or plastic drum, net weight 25kg or 50kg (customized according to requirements).

Marking: Indicate product name, brand, batch number and production date.

Transportation and storage: Moisture-proof and shock-proof, stored in a dry and ventilated warehouse, shelf life is 12 months.

7. Application Fields of CTIA GROUP Tungsten Carbide Powder

Cutting tools: Ultrafine grain (WC06-07) is used for high-speed precision cutting tools with high hardness and strong wear resistance.

Mining tools: Coarse grains (WC50-60 and above) are used for drill bits and impact-resistant parts with excellent toughness.

Wear-resistant coating: Fine grain (WC08-10) is used for thermal spraying to improve surface properties.

Aerospace: Medium grain (WC20-25) is used for high temperature wear-resistant parts.

Other fields and special purposes: welcome to negotiate and customize.

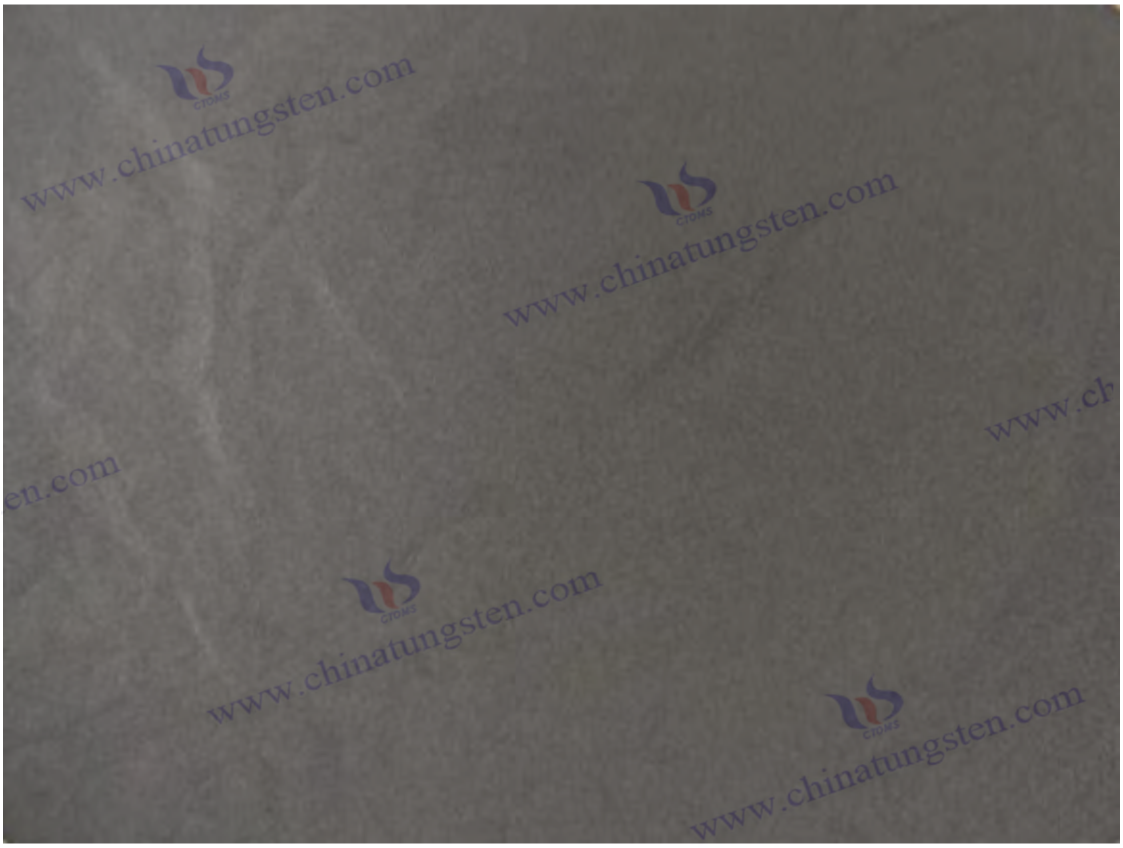
8. Contact Information of CTIA GROUP

CTIA GROUP is committed to providing customers with high-quality tungsten carbide powder and technical support.

For more information or customized products, please contact:

Email: sales@chinatungsten.com Tel: +86 592 5129595

Website: www.tungsten-powder.com for more industry information and technical parameters.



Chapter 2: Preparation method of tungsten carbide powder

Tungsten carbide powder (WC) is the basic material for cemented carbide and wear-resistant coatings. Its properties (such as hardness HV 2000-2500 and grain size 0.1-10 μm) are directly affected by the preparation method. The preparation process has developed from laboratory exploration in the late 19th century to modern industrial production, and a variety of technical routes have been formed. This chapter systematically introduces the main preparation methods of tungsten carbide powder, including traditional high-temperature carburization, chemical vapor deposition (CVD), mechanical alloying, plasma method and emerging technologies such as solvent thermal method, analyzes its principles, process parameters, product characteristics and advantages and disadvantages, and provides readers with a comprehensive technical perspective.

2.1 High temperature carbonization method of tungsten carbide powder

The high-temperature carburization method of tungsten carbide powder is the most widely used technology in industrial production. Its history can be traced back to the development of Widia tools in Germany in the early 20th century. It has now become the basic process in the cemented carbide industry. This method directly reacts tungsten powder with a carbon source at high temperature to produce tungsten carbide powder (WC). With its mature process, large output and controllable cost, it accounts for more than 80% of the global tungsten carbide powder production (ITIA 2023). This section comprehensively analyzes this mainstream preparation method from the aspects of reaction mechanism, process flow, equipment selection, parameter optimization, product characteristics, industrial application and technical limitations.

2.1.1 Basic principles of high temperature carbonization of tungsten carbide powder

The high-temperature carbonization method is based on a solid-state diffusion reaction. Tungsten powder (W) and a carbon source (such as carbon black) are chemically combined at high temperatures (1800-2000°C) to form tungsten carbide powder (WC). The main reaction formula is:

W+C→WCW+C→WC

The reaction is an exothermic process with a standard enthalpy change ΔH = -38.1 kJ/mol (25°C), but high heat is required to activate carbon atoms to diffuse into the tungsten lattice. The body-centered cubic structure of tungsten (BCC, a=3.165 Å) recombines with carbon atoms at high temperatures to form hexagonal WC (space group P6m2, a=2.906 Å , c=2.837 Å , JCPDS 51-0939). XRD analysis shows that the characteristic peaks of the product are located at 2θ=35.641° (100 crystal plane) and 48.298° (101 crystal plane), confirming the formation of single-phase WC.

The reaction needs to be carried out in a reducing (such as H_2) or inert (such as Ar) atmosphere to avoid oxidation of tungsten to WO_3 (melting point 1473°C). Side reactions include:

2W+C→W2C2W+C→ $_{W2C}$ (when

carbon is insufficient , <6.10%) WC→W2C+CWC→ $_{W2C}$ +C (>2100°C decomposition).

Carbon content control is the key, the theoretical value is 6.13% (mass fraction), the industrial range is 6.10%-6.18% (GB/T 4295-2008), and deviations affect phase state and performance.

2.1.2 Process flow of high temperature carbonization of tungsten carbide powder

The high temperature carburization method for industrial preparation of tungsten carbide powder includes the following steps, each of which needs to be precisely controlled to ensure product consistency:

Raw material selection and preparation

Tungsten powder

Purity>99.9%, oxygen content<0.03% (300 ppm), FSSS particle size 1-10 μm (GB/T 25995). The source is usually hydrogen-reduced WO $_3$ (such as APT reduced tungsten powder produced in Zhuzhou, China).

Carbon source

High purity carbon black (C, purity > 99.9%, particle size < 1 μm , specific surface area > 10 m^2 / g), or graphite powder (particle size 5-20 μm , lower cost but slightly less active).

Ratio

The W:C molar ratio is 1:1.03-1.05, with a slight excess of carbon to compensate for volatilization and side reactions (such as W_2C formation).

mix

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

Use a planetary ball mill (such as Fritsch Pulverisette 6) with a ball to material ratio of 5:1-10:1, WC or steel balls, and a rotation speed of 150-300 rpm for 2-4 hours.

additive

0.5%-1% stearic acid (to prevent agglomeration), mixing uniformity was checked by SEM (particle distribution RSD < 5%).

environment

Inert atmosphere (Ar) or vacuum to avoid oxidation.

Loading and pretreatment

The mixed powder was loaded into a graphite boat (purity>99.95%, size 50×20×10 cm) with a packing density of 0.5-0.8 g/ cm³ .

Preheat

300-500°C, pass H_2 (0.2-0.5 L/min) to remove moisture and volatiles for 30-60 minutes.

High temperature carbonization

equipment

Tube furnace (single tube, inner diameter 10-20 cm) or continuous push boat furnace (multiple boats, output >100 kg/batch).

temperature

1800-2000°C, heating rate 5-10°C/min, keep warm for 2-4 hours.

atmosphere

H_2 (flow rate 0.5-1 L/min) reduces WO_x , and Ar (0.2-0.5 L/min) prevents overburning.

monitor

Thermocouple (W-Re type, accuracy ±5°C), online gas analyzer (detection of CO, CO_2) .

Cooling and post-processing

Cool naturally to <100°C (Ar atmosphere, 6-8 hours) to avoid cracks caused by rapid cooling.

Grinding

Air jet mill or ball mill, adjusted to FSSS 1-5 μm , sieved (200 mesh, remove particles >10 μm).

Cleaning

If necessary, wash with dilute HCl (5%) to remove surface oxides and dry (80°C, 2 h).

2.1.3 Process parameters and control of high temperature carburization of tungsten carbide powder

Temperature

Range: 1800-2000°C.

<1700°C: The reaction is incomplete, and W and W_2C remain (XRD detects W_2C peak , 2θ=39.5°).

2100°C: WC decomposes to produce free carbon (>6.18%) and W_2C , and the hardness decreases (HV 1600-2000).

Optimization: 1900°C±20°C, carbonization efficiency>98% (verified by chemical titration).

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

Carbon content
Target: 6.10%-6.18% (GB/T 4295-2008).
Control: Initial W:C ratio is 1:1.05, taking into account carbon volatilization (about 0.02%-0.05%).
Test: combustion method (GB/T 5124.1), deviation ±0.05%, free carbon <0.5%.

Atmosphere
H_2 : flow rate 0.5-1 L/min, pressure 0.1-0.2 MPa, remove oxygen impurities (O_2 < 10 ppm).
Ar : Purity>99.99%, to prevent free carbon precipitation caused by over-reduction of H_2 .
Switching: >1500°C can be switched to Ar to reduce energy consumption.

Insulation time
Range: 2-4 hours.
<2 hours: carbonization rate <95%, residual W (XRD detected W peak, 2θ=40.3°).
4 hours: The grains grow larger (>10 μm , SEM observation) and the hardness decreases.
Optimization: 3 hours ± 15 minutes, the grain uniformity is the best (RSD < 10%).

Heating rate
5-10°C/min. Too fast (>15°C/min) will lead to temperature gradient in the boat (>50°C) and uneven product.

2.1.4 Equipment and industrialization of high temperature carbonization of tungsten carbide powder

Device Type
Tube furnace: single batch 10-50 kg, suitable for small and medium scale (such as laboratories or small factories).
Example: A factory in Changsha, China uses a tube furnace with an inner diameter of 15 cm and produces 30 kg per day.
Push boat furnace: continuous production, single furnace >100 kg/batch, mainstream industrial choice.
Example: Zhuzhou Cemented Carbide Factory uses a 10-boat push-boat furnace with an annual output of 10,000 tons.
Key components: graphite boat (temperature resistance >2200°C), W-Re thermocouple, SiC heating element.

Energy consumption and efficiency
Energy consumption: about 5000-6000 kWh per ton of tungsten carbide powder (including heating and insulation).
Efficiency: Single furnace cycle is 12-16 hours (including cooling), and the push boat furnace reaches 90% equipment utilization rate.

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

Automation

Modern equipment is equipped with PLC control (Siemens S7-300) to monitor temperature, atmosphere and exhaust gas composition (CO<0.1%) in real time.

2.1.5 Product characteristics of tungsten carbide powder high temperature carbonization method

Chemical composition

Total carbon: 6.10%-6.18% (combustion method, GB/T 5124.1).

Free carbon: <0.5% (titration method, GB/T 5124.2).

Impurities: Fe<0.05%, O<0.02% (ICP-OES, GB/T 5124.4).

Physical properties

Grain size: 1-5 μm (FSSS, GB/T 25995), adjustable to 0.5-10 μm (SEM verification).

Bulk density: 12.0-14.0 g/cm³ (Scott volumeter, GB/T 5314).

Morphology: Polyhedral particles with sharp edges and surface roughness Ra 0.1-0.5 μm (measured by AFM).

Specific surface area: 0.5-2 m² / g (BET method), increases with decreasing particle size.

Microstructure

Single phase WC (XRD, strongest peak at 2θ=35.641°), no W_2C or free carbon peaks.

The grain boundaries are clear and there are few defects (TEM observation, lattice fringe d=2.518 Å).

Performance

Hardness: HV 2000-2200 (ASTM E384, load 1 kg).

Compressive strength: >4000 MPa after sintering (WC-Co, Co 10%).

2.1.6 Industrial Application and Cases of High-temperature Carbonization of Tungsten Carbide Powder

Carbide Tools

Zhuzhou Cemented Carbide Plant, China: Annual production of 12,000 tons of tungsten carbide powder (2023), FSSS 2-5 μm , for turning tools and milling cutters (hardness HV 1500-1800, life >500 minutes).

Sandvik, Sweden : Use 1-3 μm WC powder to prepare CNC tools with a cutting speed of >200 m/min.

Wear-resistant parts

Kennametal, USA: 5-10 μm WC powder is used to make mining drill bits, with impact resistance >25 J/cm² and life extended by 3 times.

A mine in Luoyang, China: WC powder is used in rock drilling tools, and its wear resistance is better than that of high-speed steel (wear rate <0.01 mm³ / N · m) .

International Standards

GB/T 4295-2008: Total carbon deviation ±0.05%, free carbon <0.5%.

ISO 4499-2:2020: Grain size uniformity requirements (RSD < 10%).

2.1.7 Advantages, Disadvantages and Improvement Directions of High-Temperature Carbonization of Tungsten Carbide Powder

Advantage

Mature technology: 100-year history, globally applicable, stable technology.

Large output: single furnace > 100 kg, meeting industrial demand (e.g. China accounts for 50% of global output, about 30,000 tons/year).

Low cost: 50-80 yuan/kg (China Tungsten Online 2023), which is more economical than CVD method (500-1000 yuan/kg).

Controllable quality: meeting carbide standards (HV 1500-2200).

Shortcoming

High energy consumption: 5000-6000 kWh/ton, carbon emissions of about 2-3 tons CO_2 / ton (mainly electric heating).

Coarse grains: >1 µm , making it difficult to prepare nanoscale WC (<100 nm), limiting high-end applications.

Batch variability: The temperature gradient between boats (±20°C) resulted in a wide particle size distribution (Span>1.5).

Improvement direction

Low temperature carbonization: Adding catalyst (such as Ni, 0.1%-0.5%), reducing the temperature to 1500-1600°C, saving 20% energy (under research).

Grain refinement: initial tungsten powder <1 µm , shorten the holding time (<2 hours), target <0.5 µm .

Greening: Recycle tail gas H_2 , reduce carbon black usage, and lower carbon footprint.

2.1.8 Industrial Status and Prospects of High-Temperature Carbonization of Tungsten Carbide Powder

Global situation

China: Annual output is 30,000 tons, accounting for 50% of the world (China Tungsten Online 2023), with Hunan and Jiangxi as the main production areas.

Europe and America: Kennametal of the United States and Ceratizit of Germany produce about 5,000 tons/year, focusing on quality (purity>99.95%).

Technology Trends

Automation: Push boat furnace integrated sensors (O_2 , CO monitoring) to improve consistency.

Energy saving: The resistance furnace was upgraded to an induction furnace, and the energy consumption was reduced to 4000 kWh/ton (in pilot stage).

Nano-processing: Combined with subsequent mechanical grinding, develop WC powder <0.5 µm to meet the needs of 3D printing.

As the cornerstone of tungsten carbide powder production, high temperature carburization method will continue to be optimized in terms of efficiency, environmental protection and refinement in the future.

2.2 Chemical Vapor Deposition (CVD) of Tungsten Carbide Powder

2.2.1 Basic principles of tungsten carbide powder CVD method

Chemical vapor deposition (CVD) directly generates tungsten carbide powder through a gas phase reaction. The typical reaction is: $WCl_6 + CH_4 + H_2 \rightarrow WC + 6HCl$ (900-1100°C). The gaseous precursor decomposes at high temperature, and carbon and tungsten atoms are deposited to form WC crystals, which are suitable for preparing nano-scale powders.

2.2.2 Process flow of tungsten carbide powder CVD method

Raw material gasification: WCl_6 (boiling point 347°C) is heated and gasified, and CH_4 and H_2 are mixed in proportion.

Reaction: Gas is introduced into the reaction chamber (quartz tube, 900-1100°C, pressure 10-100 Pa) to deposit and generate WC.

Collection: The product is collected through a condenser and the tail gas (HCl) is neutralized with alkaline solution.

Post-treatment: Slightly grind and sieve to target particle size (<100 nm).

2.2.3 Process parameters of tungsten carbide powder CVD method

Temperature: 900-1100°C. If the temperature is too high, W_2C will be generated . If the temperature is too low, the reaction will be incomplete.

Pressure: 10-100 Pa, low pressure is conducive to the formation of nanoparticles.

Gas ratio: $CH_4 : WCl_6 = 1 : 1\text{-}1.5:1$, H_2 in excess (10-20 times) to reduce WCl_6 .

2.2.4 Product characteristics of tungsten carbide powder CVD method

Grain size: 20-100 nm (TEM measurement).

Purity: >99.95%, oxygen content <50 ppm.

Morphology: Nearly spherical, specific surface area 20-50 m^2 / g (BET method).

2.2.5 Advantages and Disadvantages of Tungsten Carbide Powder CVD Method

Advantages: small particle size, high purity, suitable for high-precision applications.

Disadvantages: complex equipment (vacuum system), low output (kg level/batch), high cost (about 500-1000 yuan/kg).

2.2.6 Application of tungsten carbide powder CVD method

Used for aviation coatings and catalyst carriers. For example, GE in the United States uses the CVD method to prepare WC coatings (hardness HV 2600) with a temperature resistance of >1200°C.

2.3 Mechanical alloying of tungsten carbide powder

2.3.1 Basic principles of mechanical alloying of tungsten carbide powder

Mechanical alloying (MA) uses high-energy ball milling to make tungsten powder and carbon powder react in the solid state to form WC. Mechanical energy induces atomic diffusion and lattice reconstruction, and the reaction formula is the same as high-temperature carburization ($W + C \rightarrow WC$).

2.3.2 Process flow of mechanical alloying of tungsten carbide powder

Raw material mixing: Tungsten powder (1-5 μm) and carbon black (<1 μm) are mixed in a molar ratio of 1:1.05.
Ball milling: Place in a high-energy ball mill (planetary, ball-to-material ratio 10:1, rotation speed 300-500 rpm), grind for 20-50 hours, in an inert atmosphere (Ar).
Post-processing: Screening to remove large particles, product particle size <100 nm.

2.3.3 Process parameters of mechanical alloying of tungsten carbide powder

Rotation speed: 300-500 rpm. Too low will result in incomplete reaction, while too high will introduce impurities (such as Fe).
Grinding time: 20-50 hours, XRD detection of WC phase formation.
Ball to material ratio: 10:1-15:1, WC balls are commonly used to avoid contamination.

2.3.4 Product characteristics of tungsten carbide powder mechanical alloying method

Grain size: 50-100 nm (TEM).
Purity: >99%, Fe impurity <0.1% (ICP-OES).
Morphology: irregular particles with many grain boundary defects.

2.3.5 Advantages and disadvantages of mechanical alloying of tungsten carbide powder

Advantages: low temperature (<100°C), low energy consumption, suitable for nano WC.
Disadvantages: Risk of introduction of impurities and long production cycle (hours).

2.3.6 Application of mechanical alloying method of tungsten carbide powder

For ultra-fine cemented carbide, such as PCB micro-drilling (grain <0.5 μm , hardness HV 2200).

2.4 Plasma method of tungsten carbide powder

2.4.1 Basic principles of tungsten carbide powder plasma method

The plasma method uses high temperature plasma (>5000°C) to make tungsten powder and carbon source react instantly to generate WC. Hot plasma provides high energy density and promotes gas phase or liquid phase reaction.

2.4.2 Process flow of tungsten carbide powder plasma method

Raw material delivery: Tungsten powder and CH_4 are fed into the plasma gun through carrier gas (Ar).
Reaction: Plasma (power 10-50 kW, temperature 5000-10000°C) decomposes CH_4 , and the tungsten melts and reacts with carbon.
Cooling: The product was rapidly cooled in a condensation chamber (10^6 °C/s) and the powder was collected.

2.4.3 Process parameters of tungsten carbide powder plasma method

Power: 10-50 kW, affects particle size.
Gas flow rate: Ar 20-50 L/min, CH_4 1-5 L/min.
Cooling rate: >10^5 °C/s to avoid grain growth.

2.4.4 Product characteristics of tungsten carbide powder plasma method

Grain size: 50-200 nm.
Purity: >99.9%, oxygen content <100 ppm.
Appearance: Spherical particles, good fluidity (>20 s/50g).

2.4.5 Advantages and Disadvantages of Tungsten Carbide Powder Plasma Method

Advantages: small and spherical particles, suitable for spraying.
Disadvantages: Expensive equipment (millions of dollars) and high energy consumption.

2.4.6 Application of tungsten carbide powder plasma method

Used for HVOF spray coatings, such as WC powder produced by Swedish Sandvik (hardness HV 1200-1400).

2.5 Solvothermal method of tungsten carbide powder

2.5.1 Basic Principles of Tungsten Carbide Powder Solvothermal Method

Solvothermal method synthesizes WC at lower temperature (<300°C) via liquid phase reaction, utilizing high pressure of solvent and decomposition of organic carbon source in autoclave. For example: WO_3 +

$C_6H_{12}O_6 \rightarrow WC + CO_2 + H_2O$.

2.5.2 Process flow of tungsten carbide powder solvent thermal method

Raw material preparation: WO_3 and glucose ($C_6H_{12}O_6$) are dissolved in water with a molar ratio of 1:2.
Reaction: The solution is placed in an autoclave at 200-300°C and a pressure of 10-20 MPa for 12-24 hours.
Post-treatment: filtration, washing (deionized water), drying (80°C), and grinding to <100 nm.

2.5.3 Process parameters of tungsten carbide powder solvothermal method
Temperature: 200-300°C, the reaction is incomplete below 200°C.
Pressure: 10-20 MPa, affects carbonization efficiency.
Time: 12-24 hours, XRD detects WC phase.

2.5.4 Product characteristics of tungsten carbide powder by solvothermal method
Grain size: 20-50 nm.
Purity: >99%, oxygen content <200 ppm.
Morphology: Nearly spherical, with less agglomeration.

2.5.5 Advantages and Disadvantages of Solvothermal Method for Tungsten Carbide Powder
Advantages: low temperature and energy saving, small particle size, environmentally friendly.
Disadvantages: low yield (g grade/batch), the process is not yet mature.

2.5.6 Application of Solvothermal Method for Tungsten Carbide Powder
Research phase, for use in fuel cell electrodes (specific surface area > 50 m^2 / g).

References
GB/T 4295-2008, *Tungsten Carbide Powder* , National Standardization Administration of China, 2008.
The technical requirements and test methods of tungsten carbide powder are specified, which are applicable to the product quality control of processes such as high temperature carburization.
GB/T 5124.1-2008, Methods for Chemical Analysis of Cemented Carbide - Part 1: Determination of Total Carbon Content , National Standardization Administration of China, 2008.
The combustion method is specified to determine the total carbon content in cemented carbide and is used to verify the composition of tungsten carbide powder.
GB/T 5124.2-2008, Methods for Chemical Analysis of Cemented Carbide - Part 2: Determination of Free Carbon Content , National Standardization Administration of China, 2008.
The acid dissolution-titration method is specified to determine free carbon and is used to evaluate the purity of the product produced by the high-temperature carbonization method.
Carbide - Part 4: Determination of Impurity Elements , National Standardization Administration of China, 2008.

The ICP-OES method is specified to determine impurities such as Fe and is used for quality analysis of high-temperature carburization and mechanical alloying methods.
GB/T 5314-2011, Powders *for Cemented Carbide* , National Standardization Administration of China, 2011.
Specifies the technical requirements and physical property tests for cemented carbide powders, applicable to a variety of preparation methods.
GB/T 25995-2010, Tungsten Powder and Tungsten Carbide Powder - Determination of *Fisher Sub-Sieve Sizer (FSSS) Particle Size* , National Standardization Administration of China, 2010.
The determination method of Fisher particle size analyzer is specified for particle size control in processes such as high temperature carbonization.
Zhang Lide, Nanomaterials and Nanostructures *,* Science Press, 2002.
Introduce the preparation technology of nanomaterials, including the basic principles of CVD and mechanical alloying.
of Chinese Tungsten Industry Development , Metallurgical Industry Press, 1998.
Records the industrialization process of tungsten carbide powder in China, involving application cases of high temperature carburization method.
Lassner, E., & Schubert, WD (1999). *Tungsten: Properties, Chemistry, Technology of the Element, Alloys, and Chemical Compounds* . Springer.
Comprehensive introduction to the properties and preparation technology of tungsten and its compounds, covering high temperature carburization, CVD and other methods.
Upadhyaya, GS (1998). *Cemented Tungsten Carbides: Production, Properties and Testing* . William Andrew Publishing.
The industrial production and performance testing of tungsten carbide powder are described in detail, with emphasis on high temperature carburization and mechanical alloying.
German, RM (1994). *Powder Metallurgy Science* . Metal Powder Industries Federation.
A systematic introduction to powder metallurgy technology, including the theory and practice of mechanical alloying and plasma methods.
International Tungsten Industry Association (ITIA) (2023). "Tungsten Statistics 2023," *ITIA Annual Report* .
Provides global tungsten and tungsten carbide powder production data, reflecting the mainstream position of high temperature carburizing method.
ASTM E384-17 (2017). *Standard Test Method for Microindentation Hardness of Materials* . ASTM International.
Specifies the microhardness test method used to evaluate the properties of tungsten carbide powder after sintering.
ISO 4499-2:2020 (2020). *Hardmetals — Metallographic Determination of Microstructure — Part 2: Measurement of WC Grain Size* . International Organization for Standardization.
Specifies a method for microscopic determination of WC grain size suitable for quality control of high temperature carbonization products.
Benjamin, JS (1970). "Dispersion Strengthened Superalloys by Mechanical Alloying," *Metallurgical Transactions* , Vol. 1, pp. 2943-2951.

The mechanical alloying technology was proposed for the first time, laying the foundation for its use in the preparation of tungsten carbide powder.

Suryanarayana, C. (2001). "Mechanical Alloying and Milling," *Progress in Materials Science* , Vol. 46, pp. 1-184.

The process parameters and applications of mechanical alloying are reviewed, involving the nano-sizing of tungsten carbide powder.

Japan Standards Association (2005). JIS H 7803:2005, Test methods for tungsten carbide powder. Japan Standards Association.

The chemical and physical test methods of tungsten carbide powder can be referred to the product analysis of high temperature carburization method.

ГОСТ 25599.1-83 (1983). "Cemented carbide powder - Method for determination of carbon content", USSR State Committee for Standards.

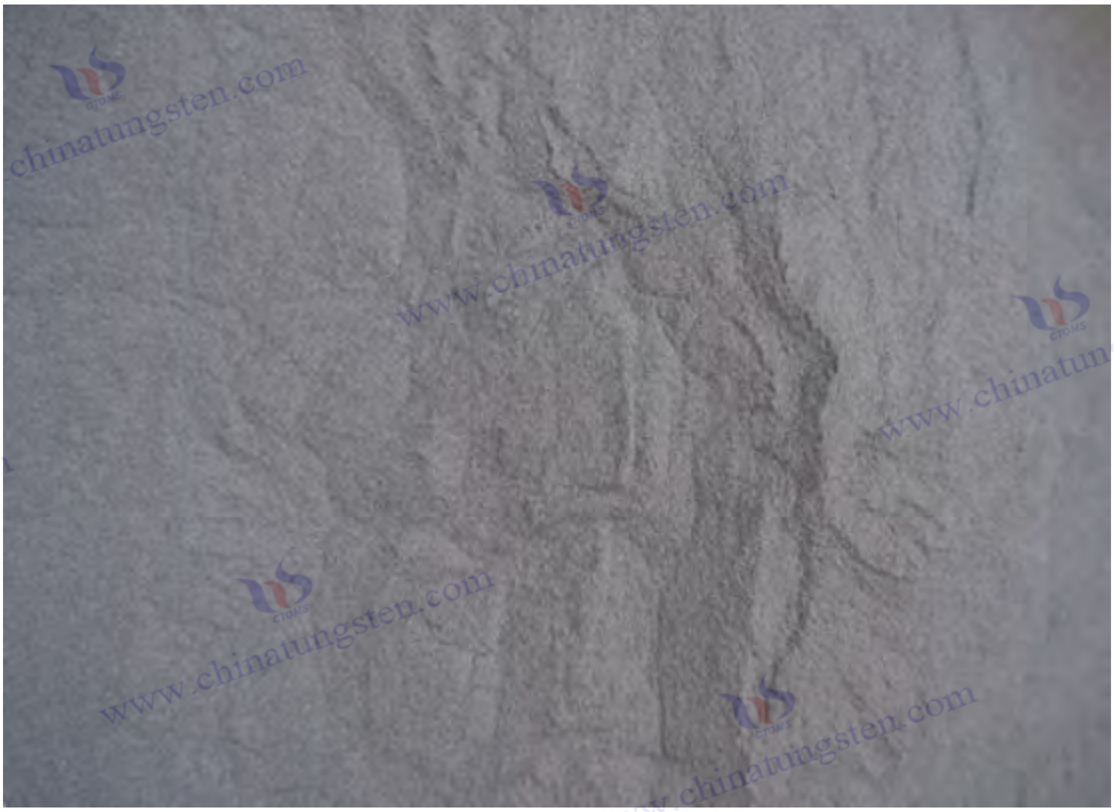
Soviet standard specifies the chemical analysis method for carbon content of cemented carbide powder, applicable to high temperature carburization method.

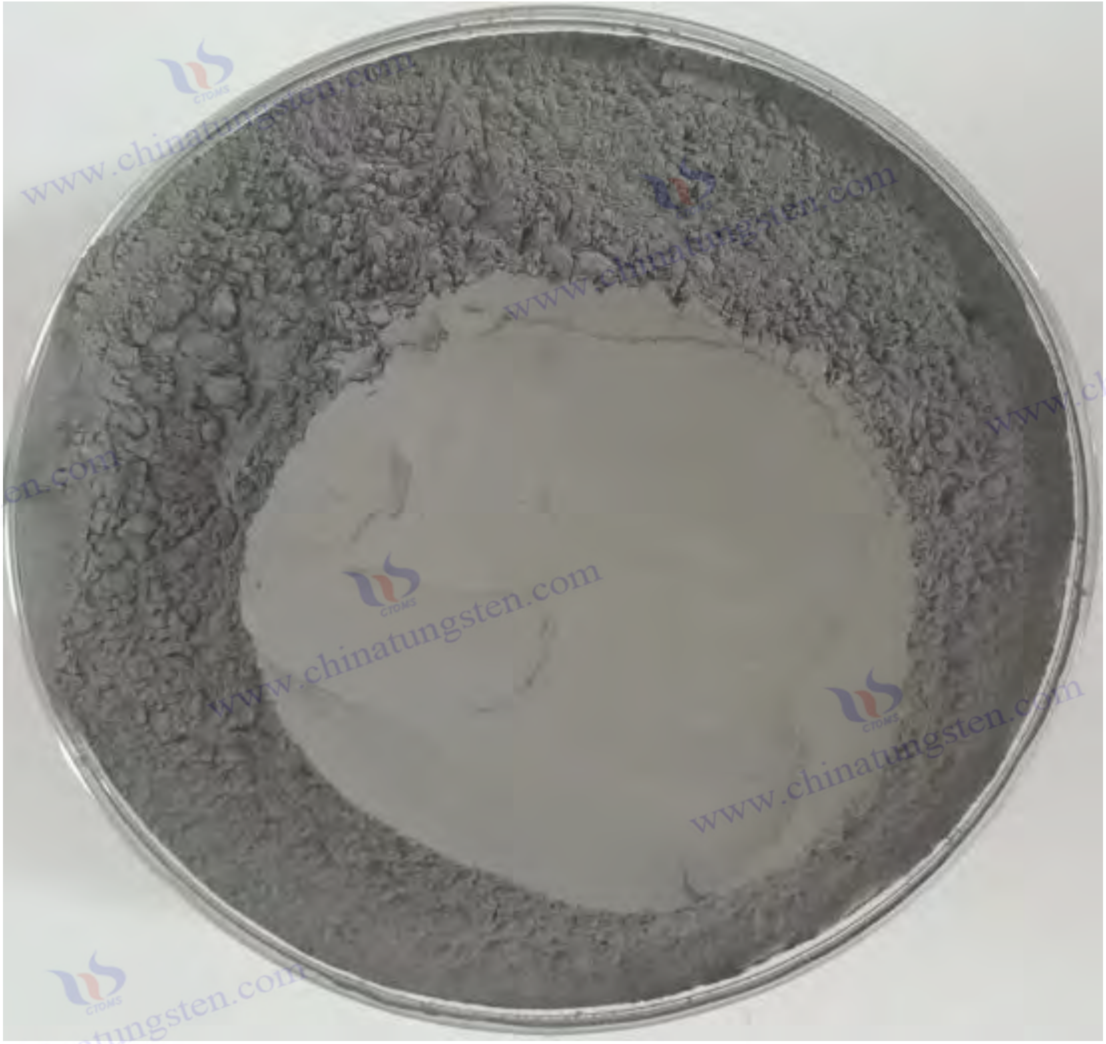
DIN EN ISO 4499-2:2020 (2020). Cemented carbide – Metallurgical determination of the microstructure – Part 2: Measurement of the WC grain size. German Institute for Standardization.

German version of ISO standard, consistent with ISO 4499-2, for high temperature carburization grain analysis.

KS D 9502:2015 (2015). Determination of particle size distribution of tungsten carbide powder. Korean Standards Association.

Korean standard specifies the test method for particle size distribution of tungsten carbide powder, which can be used for products of high temperature carburization method.





Chapter 3: Microstructure and Characterization Technology of Tungsten Carbide Powder

Tungsten carbide powder (WC) is the core of cemented carbide, wear-resistant coatings and high-performance tool materials. Its microstructure and performance jointly determine the quality of the final product. From the crystal arrangement at the atomic level to the morphological distribution of particles, from the precise control of chemical composition to the comprehensive evaluation of physical and mechanical properties, the characteristics of tungsten carbide powder are both the product of the preparation process and the cornerstone of the application effect. For example, WC tools with a hardness of up to HV 2000-2500 can remain sharp during high-speed cutting, and WC coatings with excellent wear resistance (wear rate <0.01 mm^3 / N · m) can extend their service life in harsh environments, all of which are due to the uniqueness of its microstructure. This chapter aims to systematically introduce the microstructural characteristics and characterization techniques of tungsten carbide powder through rich discussions in natural language, combined with scientific data and industrial practice, covering X-ray diffraction (XRD), scanning electron microscopy (SEM), chemical analysis and performance testing methods, revealing how these characteristics move from the laboratory to the production line, and providing comprehensive guidance for the research and development and application of the cemented carbide industry.

3.1 Microstructure characteristics of tungsten carbide powder

The microstructure of tungsten carbide powder is the intrinsic root of its performance, covering crystal structure, grain size, particle morphology and defect characteristics. These characteristics not only reflect the differences in preparation processes (such as coarse grains of high temperature carburization method, or nano-scale structure of CVD method), but also play a key role in sintering, pressing or spraying process.

3.1.1 Crystal structure

The core of tungsten carbide powder lies in its hexagonal crystal structure (space group P6m2, a=2.906 Å , c=2.837 Å , JCPDS 51-0939). This close atomic arrangement gives it excellent hardness and chemical stability. Tungsten atoms and carbon atoms are stacked alternately, and each tungsten atom is surrounded by six carbon atoms to form a stable hexagonal close-packed network. XRD analysis shows that the characteristic diffraction peaks of WC are located at 2θ=35.641° (100 crystal plane) and 48.298° (101 crystal plane). These peak positions are the "fingerprints" for judging the purity of the powder. However, the ideal single-phase WC is not always readily available in actual production. If the carbon content is insufficient (<6.10%), W_2C phase (2θ=39.5°) will be generated, which has a low hardness (HV about 1800); if the carbon content is excessive (>6.18%), free carbon (2θ=26.6°) will precipitate, weakening the sintering strength. This subtle change reminds us that the carbon source ratio and atmosphere control in the preparation process are crucial.

3.1.2 Grain size and distribution

Grain size is a key variable in microstructure and directly affects the mechanical properties of tungsten carbide powder. In industry, grain size ranges from nanometers (<100 nm) to micrometers (1-10 μm), with a common specification of 1-5 μm . High-temperature carburization method is easy to generate grains larger than 5 μm due to long-term high-temperature reaction (1800-2000°C) , while mechanical alloying or plasma method can be controlled below 100 nm through high energy input and rapid cooling. The uniformity of grain distribution is measured by Span value ((D90-D10)/D50), and high-quality powder requires <1.5 and RSD<10% (ISO 4499-2:2020). Fine grains (<1 μm) improve hardness (HV>2200) and wear resistance, and coarse grains (>5 μm) enhance impact resistance (>25 J/cm²) . This balance between size and performance is the art of industrial design.

3.1.3 Particle morphology

The particle morphology is the "external appearance" of tungsten carbide powder, which affects fluidity (>20 s/50g) and sintering behavior. The WC produced by high-temperature carbonization method is mostly polyhedral, with sharp edges and surface roughness Ra 0.1-0.5 μm (AFM measurement); the plasma method or CVD method generates nearly spherical particles with a specific surface area of up to 20-50 m^2 / g (BET method) and better fluidity. Nanoscale WC is easy to agglomerate due to its high surface energy, and hard agglomeration needs to be <5% (SEM observation), otherwise defects are easy to occur during pressing. The diversity of morphology provides options for different applications, such as spherical WC is more suitable for spraying, and polyhedral WC is conducive to sintering bonding.

3.1.4 Defects and impurities

The microstructure is not perfect, and grain boundary defects and impurities are factors that cannot be ignored. TEM shows that the dislocation density of WC grain boundaries is usually $<10^6$ /cm^2 . Too high ($>10^7$ /cm^2) will reduce the sintering strength (<4000 MPa). Impurities such as Fe (<0.05%), Mo (<0.01%) and O (<0.02%) are trace but affect the performance: iron comes from ball milling contamination, and oxygen comes from oxidation. Both may generate brittle phases (such as Fe_3C) or oxides (WO_3) at high temperatures, weakening toughness (K_IC<10 MPa·$m^{1/2}$). Controlling defects and impurities is the key to improving powder quality.

3.2 Characterization method of tungsten carbide powder

Characterization technology is the "eye" to explore the microstructure of tungsten carbide powder, providing a multi-dimensional analytical perspective from crystal structure to surface morphology. These methods promote basic understanding in scientific research and ensure quality consistency in industry.

3.2.1 X-ray diffraction (XRD)

XRD uses the diffraction of X-rays and lattices to reveal the phase state and crystal parameters of tungsten carbide powder. Equipment such as Bruker D8 Advance uses Cu Kα radiation (λ=1.5406 Å), scans 2θ=20°-80°, steps 0.02°, and speeds 2°/min. The sample volume is only 0.5-1 g, and it can be tested after flattening. The results show that the main peak of WC is 2θ=35.641°. If W_2C (39.5°) or W (40.3°) appears, it indicates incomplete carbonization, and the phase content accuracy is ±0.5%. XRD is non-destructive and efficient, but the nanograin size needs to be estimated in combination with the Scherrer formula (error ±10 nm).

3.2.2 Scanning electron microscopy (SEM)

SEM uses electron beam scanning to present the particle morphology and size distribution of tungsten carbide powder. ZEISS Sigma 300 equipment, voltage 5-15 kV, magnification 100-50000×, resolution 1 nm. The sample needs to be gold-plated (10 nm) and the vacuum degree is $<10^{-5}$ Pa. The image shows that the grain size is 0.1-10 μm , the uniformity RSD is <10%, and agglomeration can be identified. SEM is intuitive but limited to the surface and needs to be complemented by other methods.

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

3.2.3 Transmission electron microscopy (TEM)

TEM goes deep into the atomic level to analyze the lattice and defects. FEI Tecnai G2 F20 (200 kV) equipment, the sample is ultrasonically dispersed in ethanol (50 W, 5 minutes), drop-coated on a copper mesh , and the resolution is 0.24 nm. The results show WC lattice fringes (d=2.518 Å), and the dislocation density is <10^6 /cm² , indicating high quality. Although TEM is accurate, the sample preparation is complicated and it is mostly used for scientific research.

3.2.4 Atomic force microscopy (AFM)

AFM measures the surface roughness of tungsten carbide powder by scanning with a probe. Bruker Dimension Icon equipment, silicon probe, scanning 10×10 μm , the result is Ra 0.1-0.5 μm , which is consistent with the specific surface area of the BET method (deviation <5%). AFM is suitable for surface analysis of nano WC, but its representativeness is limited to small areas.

3.3 Chemical composition analysis of tungsten carbide powder

Chemical composition is the cornerstone of tungsten carbide powder quality, affecting its stability and performance. The analysis method must take into account both accuracy and practicality.

3.3.1 Total carbon and free carbon analysis

The total carbon content is determined by high frequency combustion-infrared absorption method (GB/T 5124.1-2008), LECO CS-844 equipment is operated in 1350°C oxygen flow (2-3 L/min), with an accuracy of ±0.01%, and the result must be between 6.10% and 6.18%. Free carbon is determined by acid dissolution-titration method (GB/T 5124.2-2008), H_2SO_4 - HNO_3 (1:1) is dissolved for 30 minutes, with an accuracy of ±0.005%, and <0.5%. The deviation of carbon content directly affects the phase state and hardness.

3.3.2 Analysis of impurity elements

ICP-OES (GB/T 5124.4-2008) was used to determine impurities such as Fe and Mo. The PerkinElmer Optima 8300 equipment was used to dissolve the sample in HNO_3 +HCl. The results showed that Fe<0.05%, Mo<0.01%, and the detection limit was 0.001%. Impurity control needs to start with raw materials and processes.

3.3.3 Oxygen content analysis

Oxygen content is determined by inert gas fusion method (ASTM E1019-18), LECO ONH836 equipment operates in helium at 1900°C, micron WC <100 ppm, nanometer WC <200 ppm. Excess oxygen will reduce the sintering density.

3.4 Physical properties test of tungsten carbide powder

Physical property testing evaluates processing and application characteristics and is the bridge from micro to macro.

3.4.1 Particle size and distribution

Laser diffraction method (GB/T 19077-2016) uses Malvern Mastersizer 3000, refractive index 2.5, opacity 10%-20%, D50=1-5 μm , Span<1.5. Fisher particle size meter (GB/T 25995-2010) measures 0.5-10 μm , repeatability <3%. Particle size determines the balance between hardness and impact resistance.

3.4.2 Bulk density and fluidity

The bulk density is measured by Scott volumetric meter (GB/T 5314-2011), 12.0-14.0 g/cm³ , RSD<2%. The fluidity is measured by Hall flow meter (ASTM B213-20), >20 s/50g. High density and fluidity ensure molding consistency.

3.4.3 Specific surface area

BET method (ISO 9277:2010) using Micromeritics ASAP 2020, degassing at 200°C, micron size 0.5-2 m² / g, nano size 20-50 m² / g. High specific surface area improves sintering activity.

3.5 Mechanical properties and industrial applications of tungsten carbide powder

Mechanical properties reflect the application value of tungsten carbide powder and need to be verified through standard tests.

3.5.1 Hardness

Vickers hardness test (ASTM E384-17), load 1 kg, 15 s, result HV 2000-2500, deviation < 50. High hardness comes from fine grains and single phase structure.

3.5.2 Wear resistance

Dry sand rubber wheel test (ASTM G65-16), sand 50-70 mesh, load 130 N, wear rate < 0.01 mm³ / N · m , better than Cr_3C_2 .

3.5.3 Compressive strength

Uniaxial compression test (ISO 3327:2009), Instron 5985 equipment, >4000 MPa (WC-Co, Co 10%), fracture strain <1%.

3.5.4 Industrial Application Cases

A Chinese cemented carbide company uses FSSS 2 μm WC powder, HV 2200, and the tool life is >500 minutes. Sandvik uses D50<1 μm WC powder, and the wear resistance of the coating is increased by 40%, which is used for aviation turbine blades.

References

GB/T 4295-2008, *Tungsten Carbide Powder* , National Standardization Administration of China, 2008. Specifies the technical requirements and test methods for tungsten carbide powder.
GB/T 5124.1-2008, Methods for Chemical Analysis of Cemented Carbide - Part 1: Determination of Total Carbon Content , National Standardization Administration of China, 2008. It stipulates that the total carbon content shall be determined by the combustion method .
GB/T 5124.2-2008, Methods for Chemical Analysis of Cemented Carbide - Part 2: Determination of Free Carbon Content , National Standardization Administration of China, 2008. It stipulates that the free carbon shall be determined by acid dissolution-titration method.
Carbide - Part 4: Determination of Impurity Elements , National Standardization Administration of China, 2008. It stipulates that the ICP-OES method shall be used to determine the impurity elements.
GB/T 5314-2011, Powders for Cemented *Carbide* , National Standardization Administration of China, 2011. Specifies the performance test methods for cemented carbide powders.
GB/T 19077-2016, Particle *Size Distribution - Laser Diffraction Method* , National Standardization Administration of China, 2016.
The laser diffraction method is specified for determining particle size distribution.
GB/T 25995-2010, Tungsten Powder and Tungsten Carbide Powder - Determination of *Fisher Sub-Sieve Sizer (FSSS) Particle Size* , National Standardization Administration of China, 2010. Specifies the determination method of Fisher Sub-Sieve Sizer (FSSS) Particle Size.
Lassner, E., & Schubert, WD (1999). *Tungsten: Properties, Chemistry, Technology of the Element, Alloys, and Chemical Compounds* . Springer. Introduces the microstructure and properties of tungsten compounds.
Upadhyaya, GS (1998). *Cemented Tungsten Carbides: Production, Properties and Testing* . William Andrew Publishing. Detailed description of the testing and applications of tungsten carbide powder.
ASTM B213-20 (2020). *Standard Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel* . ASTM International. Specifies the use of the Hall flowmeter to determine flowability.
ASTM E384-17 (2017). *Standard Test Method for Microindentation Hardness of Materials* . ASTM International.
Specifies the Vickers hardness test method.
ASTM G65-16 (2016). Standard Test Method for Measuring Abrasion *Using the* Dry Sand/Rubber Wheel Apparatus . ASTM International.
ASTM E1019-18 (2018). *Standard Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Inert Gas Fusion*

Techniques . ASTM International. Specifies the method for determination of oxygen content.

ISO 3327:2009 (2009). *Hardmetals — Determination of Transverse Rupture Strength* . International Organization for Standardization. Specifies a test method for compressive strength.

ISO 4499-2:2020 (2020). *Hardmetals — Metallographic Determination of Microstructure — Part 2: Measurement of WC* Grain Size . International Organization for Standardization. Specifies the method for the microscopic determination of WC grain size.

ISO 9277:2010 (2010). *Determination of the Specific Surface Area of Solids by Gas Adsorption - BET Method* . International Organization for Standardization. Specifies the BET method for determining specific surface area.

Japan Standards Association (2005). JIS H 7803:2005, Test methods for tungsten carbide powder, Japan Standards Association. Specifies the chemical and physical test methods for tungsten carbide powder.

ГОСТ 25599.1-83 (1983). "Cemented carbide powder - Method for determination of carbon content", USSR State Committee for Standards.

Chemical analysis method to specify the carbon content of cemented carbide powders.

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

Chapter 4: Application of Tungsten Carbide Powder

As the soul of cemented carbide, tungsten carbide powder (WC) has applications in mechanical manufacturing, aerospace, electronics industry and medical fields, and can be called the "hard core" pillar of modern industry. Since the German Widia company combined tungsten carbide powder with cobalt in the early 20th century to develop the first generation of cemented carbide, this material has completely overturned the pattern of traditional tool materials with its amazing hardness (HV 2000-2500), ultra-low wear rate (<0.01 mm^3 / N · m) and excellent high temperature stability (>1000°C). From high-speed cutting tools to wear-resistant molds to precision medical devices, the application of tungsten carbide powder has not only promoted a leap in industrial efficiency, but also opened up new horizons for high-precision manufacturing. This chapter will systematically explore the application of tungsten carbide powder in cemented carbide manufacturing, wear-resistant coatings and other fields, and through rich cases and data, reveal how it has transformed from a chemical reaction in the laboratory to a core material on the production line. The first part focuses on cemented carbide manufacturing, deeply analyzing the role of tungsten carbide powder in cutting tools, wear-resistant parts and precision machining tools, and showing its diverse technical charm.

4.1 Application of tungsten carbide powder in cemented carbide manufacturing

Cemented carbide is made of tungsten carbide powder as the core, and is compounded with metal binders such as cobalt (Co) and nickel (Ni) through powder metallurgy to produce materials with high hardness, high toughness and wear resistance. Since the German chemist Schröter first sintered WC and Co into cemented carbide in 1923 , this technology has undergone nearly a hundred years of evolution and has now become an indispensable cornerstone of the manufacturing industry. The application of tungsten carbide powder in cemented carbide not only depends on its own physical and chemical properties (such as the stability of the hexagonal crystal structure), but is also closely related to the selection of the binder phase, the regulation of the grain size, and the optimization of the sintering process. This section will comprehensively explain how tungsten carbide powder shines in cemented carbide manufacturing from the three dimensions of cutting tools, wear-resistant parts and precision machining tools, combined with historical development, scientific principles and industrial practice.

4.1.1 Application of tungsten carbide powder in cutting tools

Cutting tools are the earliest application field of tungsten carbide powder, and it is also its most dazzling stage. Compared with traditional high-speed steel (HSS, hardness HRC 60-65, cutting speed <100 m/min), WC-based cemented carbide increases the cutting speed to 200-300 m/min, and the tool life is extended by 5-10 times, becoming the standard of modern machining. Tungsten carbide powder is compounded with cobalt to form WC-Co cemented carbide, which has a perfect balance of hardness and toughness, allowing it to remain sharp and stable under high-speed and high-load conditions.

4.1.1.1 Turning tools and milling cutters

Turning tools and milling cutters are the "main force" in cutting tools, widely used for turning and milling steel, cast iron and high-temperature alloys. The application of tungsten carbide powder in such tools mainly relies on the WC-Co formula, and the cobalt content is usually between 6% and 12%. This ratio has been verified by the industry for decades, and it not only ensures the hardness (HV 1500-1800) but also provides sufficient resistance to chipping (fracture toughness K_IC 10-15 $MPa \cdot m^{1/2}$). Cobalt, as a binder phase, melts and wraps the WC particles during the sintering process (1450-1500°C, liquid phase sintering) to form a dense microstructure. The selection of WC grain size is crucial, and 1-3 μm is the mainstream specification because it takes into account both hardness and wear resistance, and avoids the agglomeration problem of nano-scale WC (<100 nm) and the insufficient toughness of coarse grains (>5 μm).

From a scientific point of view, the high hardness of WC comes from its hexagonal crystal structure (a=2.906 Å , c=2.837 Å). Carbon atoms are embedded in the tungsten lattice to form strong covalent bonds, making its deformation resistance far superior to that of metal materials. The addition of cobalt enhances the plasticity and impact resistance of the material through the interface between metal bonds and WC particles. Experimental data show that the cutting speed of WC-Co turning tools can reach 200-300 m/min, which is 50%-100% higher than HSS. The red hardness (600-800°C still maintains HV>1200) makes it have obvious advantages in high-temperature cutting.

In industrial cases, automobile engine cylinder block processing is a typical application of WC-Co turning tools. China's YG8 brand (WC 92%, Co 8%) turning tools have a cutting speed of 250 m/min when processing gray cast iron cylinder blocks, a single life of more than 100,000 pieces, and an efficiency more than 3 times higher than HSS tools. This success is due to the uniformity of WC powder (Span <1.5) and the optimized ratio of cobalt, which makes the tool less prone to chipping or wear during high-speed cutting. Toyota Motor's cylinder block production line in Japan also uses similar WC-Co milling cutters. When processing aluminum alloy cylinder heads, the surface roughness Ra <0.8 μm, and the yield rate is increased to 99.8%, highlighting the irreplaceable role of tungsten carbide powder in modern manufacturing.

In terms of future trends, WC-Co turning tools are developing towards finer grains (<1 μm) and composite coatings (such as TiN-TiC-Al_2O_3) to further improve wear resistance and thermal stability to meet the high-speed and high-precision requirements of intelligent manufacturing.

4.1.1.2 Drill bits and boring tools

Drills and boring tools play a key role in deep hole processing, such as automobile crankshaft oil holes, aviation turbine blade channels, etc., and the performance requirements of tungsten carbide powder are more stringent. Micron-grade WC powder (1-3 μm) is the first choice because of its hardness (HV 1600) and chipping resistance (K_IC>12 $MPa \cdot m^{1/2}$) and excellent performance in deep hole cutting. WC-Co formula (Co 6%-10%) is prepared by vacuum sintering (1450°C, 10^{-2} Pa) to ensure that there is no internal pores and the surface finish is Ra<0.1 μm. The high temperature and high pressure environment of deep hole processing (cutting zone temperature>600°C, axial force>500 N) challenges the red hardness and wear resistance of the tool, while WC's high melting point (2870°C) and low thermal expansion coefficient (5.2×10^{-6} /K) make it an ideal choice.

In order to cope with more demanding working conditions, multi-layer WC-TiC coating technology came into being. Through the CVD process, a 5-10 μm thick TiC layer (hardness HV 3000) is deposited on the WC-Co substrate, and then covered with TiN (heat resistance >1000°C), which increases the wear resistance by 3 times and extends the tool life to a drilling depth of 500-1000 meters. This coating not only enhances the surface hardness, but also reduces the friction coefficient (from 0.4 to 0.2) and reduces the accumulation of cutting heat. The WC-Co deep hole drill of Sandvik Coromant in Sweden uses a WC-TiC-TiN multi-layer coating. When processing 42CrMo steel, the cutting speed is 200 m/min, the drilling depth is 500 mm, the chipping resistance is 12.5 MPa·$m^{1/2}$, and the cutting temperature is controlled below 800°C. This technology has become a standard configuration for aircraft engine manufacturing.

From a global perspective, boring cutters from Kennametal in the United States also have a place in deep hole processing. Its WC-Co matrix (Co 8%) combined with PVD coating (TiAlN) shows excellent anti-adhesion and wear resistance when processing titanium alloys, and the single life is increased to 300 pieces, far exceeding the 50 pieces of HSS boring cutters. In the future, with the increasing demand for ultra-deep hole processing (aspect ratio>20:1), the refinement of WC powder (<1 μm) and the intelligentization of coating technology will become research and development hotspots.

4.1.1.3 Special cutting tools

Special cutting tools are used for high-precision or ultra-hard material processing, such as printed circuit board (PCB) micro-drilling and aviation composite tooling. Tungsten carbide powder must meet extremely high performance requirements in such applications. The diameter of PCB micro-drilling is <0.1 mm, and nano-grade WC powder (<100 nm) is required to ensure fine structure and high hardness. The sintering process uses hot isostatic pressing (HIP, 1450°C, 100-200 MPa), and high pressure is used to suppress grain growth (controlled at 0.2-0.5 μm). The hardness of the finished product reaches HV 2000-2200 and the compressive strength is >4500 MPa. The WC-Co micro-drill (Co 6%) produced by Xiamen Jinlu Special Alloy Co., Ltd. in China achieves an accuracy of ±0.005 mm in PCB board drilling. Each drill can process 50,000-80,000 holes, far exceeding the 10,000 holes of traditional steel drills. Its success lies in the high specific surface area of nano-WC (>20 m^2 / g) and the densification effect of the HIP process (density >99.8%).

In the aviation field, special WC tools are required for processing carbon fiber composites (CFRP) and titanium alloys. Due to its high hardness and fiber layered structure, CFRP has extremely high requirements for tool wear resistance and sharpness. Nano WC powder (<100 nm) is made into tools through HIP sintering, with a hardness of HV 2200, a cutting speed of >250 m/min, and an accuracy of ±0.005 mm. The WC-Co tool (Co 10%) developed by Kennametal in the United States for the Boeing 787 wing has a service life of more than 500 pieces in CFRP processing, and its cutting efficiency is 20% higher than that of diamond-coated tools, but the cost is reduced by 30%. This advantage comes from the combination of the high hardness of WC and the toughness of cobalt, which avoids the defect of easy peeling of diamond coating.

The future development direction of special cutting tools includes the research and development and intelligent manufacturing of WC-based composite materials (such as WC-TiC-TaC). For example, by adding TaC (1%-2%) to improve thermal cracking resistance, or combining laser micromachining technology to improve tool geometry accuracy, further meeting the high-end needs of the aerospace and electronics industries.

4.1.2 Application of tungsten carbide powder in wear-resistant parts

Wear-resistant parts are another important application area of tungsten carbide powder. Taking advantage of its high hardness and low wear rate, it is widely used in high-load scenarios such as molds and bearings. Compared with traditional steel (such as Cr12MoV, life <100,000 times), the durability of WC-based cemented carbide is increased by 5-10 times, making it the preferred material for stamping, drawing and sealing.

4.1.2.1 Stamping Dies

Stamping dies are used for cold stamping of steel plates, aluminum plates and other metals. WC-Co dies made of tungsten carbide powder are known for their ultra-long life. The typical formula is WC 90%-94%, Co 6%-10%, prepared by liquid phase sintering (1500°C, 30 MPa), and the finished product has a hardness of HV 1400-1600 and a compressive strength of >4000 MPa. The high hardness of WC ensures that the die surface resists the abrasion of the steel plate, while the toughness of cobalt absorbs the impact of stamping (>20 J/cm^2) . Data show that the life of WC-Co dies can reach 500,000-1 million times, which is 5-10 times higher than Cr12MoV (<100,000 times), and the surface roughness Ra is kept below 0.05 μm.

In automobile manufacturing, stamping door panels is a typical application of WC-Co molds. The WC-Co mold (Co 8%) produced by CTIA GROUP has been running continuously for half a year in 0.8 mm steel plate stamping, with mold wear <0.01 mm and downtime maintenance costs reduced by 70%. The German BMW automobile production line also uses similar WC molds, which show excellent fatigue resistance in high-speed stamping (>100 times/minute), and the life of a single set of molds reaches 800,000 pieces. In the future, the refinement of WC-Co molds (such as grain <0.5 μm) and surface coatings (such as CrN) will become the direction of improving life and precision.

4.1.2.2 Wire drawing die and extrusion die

Drawing dies and extrusion dies are used for forming metal wires and tubes. Fine-grained WC powder (0.5-1 μm) is favored for its high hardness (HV 1800) and ultra-low surface roughness (Ra<0.02 μm). WC-Co formula (Co 6%-8%) is prepared by vacuum sintering (1450°C). The die aperture accuracy is ±0.001 mm and the wear rate is <0.001 mm^3 / N · m, which is much lower than that of steel dies (0.01 mm^3 / N · m). During the wire drawing process, the high hardness of WC resists the friction of the metal, while the fine grains ensure smooth hole walls and reduce surface defects of the wire.

The cable industry is an important application scenario for wire drawing dies. The WC-Co wire drawing die (Co 8%) of a factory in Jiangxi, China, has been running continuously for 6 months in the drawing of 0.1 mm copper wire. The die hole size change is <0.002 mm, the wire drawing speed is 20 m/s, and the wire surface roughness Ra is <0.01 μm. This performance is due to the uniformity of WC powder (FSSS 0.8 μm) and the optimization of sintering process. The WC extrusion die of Sumitomo Electric Industries, Japan is used for aluminum tube forming, with a service life of more than 1 million meters, highlighting the potential of fine-grained WC in high-precision forming. In the future, nano-sizing (<100 nm) and self-lubricating coatings (such as DLC) of WC-based dies will further improve wear resistance and efficiency.

4.1.2.3 Wear-resistant bearings and seals

Wear-resistant bearings and seals need to withstand high-speed rotation and high-load friction. WC-Ni composite materials are preferred due to their corrosion resistance and low friction coefficient (<0.1). The formula is WC 85%-90%, Ni 10%-15%, and is prepared by hot isostatic pressing (HIP, 1450°C, 150 MPa). The finished product has a temperature resistance of >800°C and a compressive strength of >3800 MPa. Nickel has better acid and alkali resistance than cobalt and is suitable for chemical and marine environments. Germany's FAG company uses WC-Ni bearings for high-speed motors (50,000 rpm), with a friction coefficient of 0.08, a service life of 2 times, and an operating temperature controlled below 600°C. The US Flowserve company uses WC-Ni seals in chemical pumps, which are resistant to H_2SO_4 corrosion and can operate continuously for >1 year.

The HIP process is the key to the success of WC-Ni parts. It eliminates micropores through high pressure (100-200 MPa), achieves a density of 99.9%, and significantly improves wear resistance and fatigue resistance. In the future, WC-Ni's microstructure optimization (such as adding Cr to improve corrosion resistance) and intelligent monitoring (such as embedded sensors) will promote its application in extreme working conditions.

4.1.3 Application of tungsten carbide powder in precision machining tools

Precision machining tools have extremely high requirements on the particle size, purity and machining accuracy of tungsten carbide powder, and are widely used in the fields of medicine, optics and microelectronics. Ultrafine WC powder (<1 μm) and advanced sintering technology (such as HIP) are its core support.

4.1.3.1 Dental and medical tools

Dental drills and medical tools require micro-machining (diameter 0.3-1 mm), and WC-Co tools made of tungsten carbide powder (1-2 μm) are known for their hardness HV 1800 and biocompatibility (ISO 10993-5). After sintering, the surface is polished to Ra < 0.05 μm to ensure non-irritation when cutting tooth enamel. The WC-Co dental drill (Co 6%) from Komet, Germany, has a diameter of 0.5 mm, a durability of > 1000 times in dental surgery, an accuracy of ± 0.01 mm, and a cutting speed of 5000 rpm. Its success stems from the high purity of WC powder (impurities < 0.02%) and the refinement of the polishing process. The WC scalpel from Dentsply in the United States also performs well in orthopedic applications, with a 50% increase in life when cutting bones.

From a scientific perspective, the biocompatibility of WC is due to its chemical inertness (insoluble in body fluids), while its fine grains ensure sharpness and low thermal damage. In the future, nano-sizing (<100 nm) and antibacterial coatings (such as Ag ions) of WC-based medical tools will further improve performance.

4.1.3.2 Optical mold

Optical molds are used for pressing glass lenses and optical components. Ultrafine WC powder (0.2-0.5 μm) is prepared by HIP sintering (1450°C, 200 MPa), with a surface accuracy of <10 nm and a lifespan of >100,000 times. The high hardness (HV 2000) and low thermal expansion coefficient (5.2×10^{-6} /K) of WC ensure that the mold does not deform during high-temperature pressing (>600°C). Combined with mirror polishing and WC coating (such as CVD deposition of a 5 μm WC layer), the WC mold of Japan's HOYA company has a yield rate of 99.9% in the manufacture of mobile phone lenses, and the mold surface roughness Ra<0.005 μm, far exceeding traditional steel molds (Ra>0.02 μm).

In the field of precision optics, the success of WC molds is also due to their anti-adhesion properties, which avoids the problem of glass sticking to the mold. Zeiss of Germany uses WC molds for infrared lens molding, and the service life is increased to 150,000 times, highlighting the high-precision potential of ultra-fine WC. In the future, the intelligentization of WC-based optical molds (such as real-time temperature control) and the research and development of composite materials (such as WC-TiC) will promote their application in AR/VR devices.

4.2 Application of tungsten carbide powder in surface coating technology

Surface coating technology is another important application area of tungsten carbide powder. Through thermal spraying, plasma spraying, laser cladding and other processes, tungsten carbide powder is deposited on the surface of the substrate to form a wear-resistant, corrosion-resistant and high-temperature resistant protective layer. Since its rise in the mid-20th century, this technology has become a key means to extend the life of mechanical parts and improve performance. Compared with overall cemented carbide manufacturing, coating technology is widely favored for its flexibility (complex shapes can be coated), economy (low-cost steel can be used as the substrate) and efficiency (local strengthening). The application of tungsten carbide powder in coatings is widely used in aerospace engines, oil drilling tools, chemical equipment and other fields due to its high hardness (HV 2000-2500), excellent wear resistance (wear rate <0.01 $mm^3/N \cdot m$) and thermal stability (melting point 2870°C). This section will combine scientific principles and industrial practices from three aspects: thermal spray coating, plasma spraying and laser cladding, high temperature resistance and special coatings, and deeply explore how tungsten carbide powder can empower modern industry through surface engineering technology.

4.2.1 Application of tungsten carbide powder in thermal spray coating

Thermal spraying technology uses high-temperature flames or high-speed airflow to melt or semi-melt tungsten carbide powder and then spray it onto the surface of the substrate to form a dense, wear-resistant coating. Since the first generation of thermal spraying equipment was developed by Union Carbide in the United States in the 1940s, the technology has evolved from simple flame spraying to efficient high-velocity oxygen-fuel spraying (HVOF), becoming the mainstream choice for the aviation, agricultural and energy industries. The advantage of tungsten carbide powder in thermal spraying lies in its high hardness and low porosity, which enables the coating to remain stable under harsh working conditions.

4.2.1.1 HVOF spraying

High velocity oxygen fuel spraying (HVOF) is the pinnacle of thermal spraying technology. It uses a supersonic flame (>2000 m/s) to spray tungsten carbide powder onto a substrate to form a high-density, low-porosity, wear-resistant coating. WC-Co powder (cobalt content 10%-12%) is the mainstream material for HVOF. Cobalt, as a binder phase, partially melts during the spraying process and wraps around WC particles (grains 1-5 μm), forming a coating with a hardness of HV 1200-1400 and a wear rate of <0.01 $mm^3/N \cdot m$. From a scientific point of view, WC's high melting point and oxidation resistance ensure that it does not decompose during high-temperature spraying (flame temperature >3000°C), while the ductility of cobalt reduces the internal stress of the coating (<200 MPa) and enhances the bonding strength (>70 MPa).

The performance of HVOF coatings is due to the precise control of process parameters. The ratio of oxygen to fuel (such as kerosene) in the spray gun (1:2-1:3) determines the flame temperature and speed, the powder particle speed reaches 600-800 m/s, and the cooling rate is $>10^6$ °C/s, which makes the coating porosity <1% and the thickness controlled at 100-500 μm. Data show that the wear resistance of WC-Co coatings is more than 10 times that of uncoated substrates (such as 45 steel, wear rate 0.1 $mm^3/N \cdot m$), and the corrosion resistance exceeds 1000 hours in salt spray tests.

Aircraft engine blades are a classic example of HVOF spraying. The CF6 engine blades of General

Electric (GE) in the United States use WC-Co coating (Co 12%). Under gas scouring (>1200°C) and sand abrasion, the service life exceeds 3000 hours, which is 6 times longer than that of uncoated blades (500 hours). This success is due to the high hardness of WC to resist abrasion, and the toughness of cobalt to alleviate thermal shock. Rolls-Royce in the UK also uses WC-Co HVOF coating for Trent series engines. The coating thickness is 250 μm, the hardness is HV 1300, and the blade wear rate during operation is <0.005 mm/1000 hours, highlighting the reliability of tungsten carbide powder in extreme environments. In the future, HVOF technology will develop towards ultrafine WC powder (<1 μm) and composite coatings (such as WC-Co-Cr) to meet higher wear and corrosion resistance requirements.

4.2.1.2 Flame spraying

Flame spraying is a traditional process of thermal spraying. It uses an oxygen-acetylene flame (temperature of about 3000°C) to melt tungsten carbide powder and then spray it onto the substrate. It is suitable for low-cost wear-resistant coatings. WC-Ni powder (nickel content 10%-15%) is a common choice because nickel costs less than cobalt and has stronger corrosion resistance. During the spraying process, the WC particles (5-10 μm) are partially melted and the nickel is completely liquefied, forming a coating with a bonding strength of >50 MPa and a thickness of 100-300 μm. The coating hardness is HV 900-1100, which is lower than HVOF, but sufficient to cope with moderate wear environments.

The advantages of flame spraying are simple equipment (cost < 100,000 yuan) and flexible operation, which is suitable for small and medium-sized enterprises. Spraying parameters such as oxygen flow (20-30 L/min) and powder feed rate (50-80 g/min) determine the coating quality. The porosity is usually 5%-10%, slightly higher than HVOF (<1%). Performance tests show that the wear resistance of WC-Ni coating is 3-5 times higher than that of the substrate (such as Q235 steel), which is suitable for low-speed, high-friction scenarios such as agricultural machinery.

Agricultural machinery blades are a typical application of flame spraying. John Deere of the United States sprays WC-Ni coating (Ni 12%) on harvester blades with a thickness of 200 μm, which increases wear resistance by 4 times and extends the service life in a single season from 500 hours to 2000 hours. This improvement is due to the high hardness of WC and the oxidation resistance of nickel (>600°C), which effectively resists the abrasion of soil and plant residues. A certain agricultural machinery factory in Shandong, China also uses similar technology to spray tractor plow blades, which increases the cost by 20 yuan per piece, but extends the service life by 3 times, with significant cost performance. In the future, flame spraying can improve the density and corrosion resistance of the coating by refining WC powder (<5 μm) and adding Cr (1%-2%).

4.2.2 Application of tungsten carbide powder in plasma spraying and laser cladding

Plasma spraying and laser cladding represent the high-end direction of surface coating technology, using high-temperature plasma or laser beam to deposit tungsten carbide powder on the substrate to form a high-performance coating. These two technologies have their own advantages in high-temperature corrosion resistance and local strengthening.

4.2.2.1 Plasma spraying

Plasma spraying uses a plasma arc (temperature>15000°C) to melt tungsten carbide powder and spray it onto the substrate, which is suitable for high-temperature corrosion-resistant coatings. WC-Cr_3C_2 composite powder (WC 70%-80%, Cr_3C_2 20%-30%) is a common formula. The addition of Cr_3C_2 improves oxidation resistance (>1000°C) and corrosion resistance. During the spraying process, the powder particles (10-20 μm) are completely melted in the plasma flow at a speed of 300-500 m/s, forming a coating with a porosity of <2% and a thickness of 200-600 μm. The coating hardness is HV 1000-1200, and the oxidation resistance temperature reaches 1100°C, which is far higher than that of a single WC coating (<900°C).

The scientific basis of plasma spraying lies in the high energy density of high-temperature plasma, which enables WC and Cr_3C_2 to form a uniform composite structure. Process parameters such as argon flow (40-50 L/min) and power (30-40 kW) determine the degree of melting and deposition efficiency. Performance tests show that the wear resistance of WC-Cr_3C_2 coating is 8 times higher than that of the substrate, and the corrosion resistance of the salt spray test is >1500 hours.

Gas turbine blades are a representative application of plasma spraying. Pratt & Whitney in the United States uses WC-Cr_3C_2 coatings on F135 engine blades with a thickness of 300 μm, an operating temperature of 1200°C, and a lifespan of >5000 hours, which is 5 times longer than uncoated blades (1000 hours). Siemens in Germany also uses similar coatings in gas turbines. The synergistic effect of oxidation resistance and wear resistance allows the blades to remain stable under high-temperature gas scouring. In the future, plasma spraying can further improve performance by adding Ni (5%-10%) or optimizing spraying parameters to reduce porosity (<1%).

4.2.2.2 Laser cladding

Laser cladding uses a high-energy laser beam (power 2-10 kW) to melt tungsten carbide powder and deposit it on the substrate to form a high-hardness, thick coating, which is particularly suitable for surface strengthening of large components such as oil drilling tools. WC powder (grain 5-15 μm) is directly injected into the laser molten pool and metallurgically bonded to the substrate (such as 42CrMo steel). The coating thickness is 0.5-2 mm and the hardness is HV 1300. Laser cladding has low heat input (<200 J/mm^2), substrate heat affected zone (HAZ) <0.1 mm, coating porosity <0.5%, and bonding strength >100 MPa, far exceeding thermal spraying (50-70 MPa).

In principle, the high energy density of the laser (>10^6 W/cm^2) causes the WC particles to melt quickly and form an alloy layer with the substrate. The high hardness of WC and the toughness of the substrate work together. Process parameters such as laser power (4 kW), scanning speed (5-10 mm/s) and powder feed rate (20-40 g/min) determine the coating quality. Performance tests show that the wear resistance of the WC cladding layer is 15 times higher than that of the substrate, and the corrosion resistance is more than 2 years in 10% NaCl solution.

Deep-sea drill pipe is a typical example of laser cladding. Halliburton, USA, clads the surface of the drill pipe with WC coating (1.5 mm thick), which has been running for more than 2 years in a 5,000-meter deep-sea salt water environment, with wear less than 0.02 mm, and corrosion resistance 10 times higher than that of uncoated drill pipe. China Petroleum also uses similar technology to strengthen drilling tools, with a hardness of HV 1350 and an impact resistance of >30 J/cm² , to meet the needs of deep-layer oil and gas extraction. In the future, laser cladding can improve the coating thickness and uniformity through WC-Ni composite powder and multi-pass cladding technology.

4.2.3 Application of tungsten carbide powder in high temperature resistant and special coatings

High temperature resistance and special coatings For extreme environments, such as high temperature molds and chemical equipment, tungsten carbide powder needs to take into account thermal stability, corrosion resistance and thermal shock resistance in such applications.

4.2.3.1 Thermal shock resistant coating

Thermal shock resistant coatings are used for high temperature molds and hot processing equipment. WC-based coatings are known for their low thermal expansion coefficient ($<5\times10^{-6}$ /°C) and temperature resistance (>1200°C). WC-TiC-Ni composite powder (WC 70%, TiC 20%, Ni 10%) is prepared by HVOF or plasma spraying, with a coating hardness of HV 1100-1300 and a thickness of 200-400 μm. The addition of TiC improves the high temperature hardness (>1000°C still maintains HV>1000), and Ni enhances the thermal fatigue resistance. During the process, the spraying speed (500-700 m/s) and cooling rate ($>10^5$ °C/s) ensure that the internal stress of the coating is <150 MPa.

High-temperature molds are the main application of thermal shock resistant coatings. Toyota Motors in Japan uses WC-TiC-Ni coatings for aluminum alloy die-casting molds. The mold temperature is 800-1000°C, the thermal shock cycle is >5000 times, and the life is increased by 3 times. ThyssenKrupp in Germany also uses similar coatings in steel plate hot stamping molds, which are resistant to temperatures of 1200°C and have better crack resistance than traditional Cr coatings. In the future, multiphase composites (such as adding Al_2O_3) and gradient structure designs of WC-based coatings will further improve thermal shock resistance.

4.2.3.2 Chemical resistant coating

Chemical corrosion resistant coatings are used for chemical pipelines and valves. WC-CoCr coating (WC 80%, Co 10%, Cr 10%) has attracted attention for its excellent corrosion resistance. Prepared by HVOF spraying, the coating has a hardness of HV 1200 and a thickness of 150-300 μm. The addition of Cr forms a Cr_2O_3 passivation layer, and the acid resistance (pH <2) is increased by 5 times. Performance tests show that the corrosion rate of WC-CoCr coating in 10% H_2SO_4 solution is <0.001 mm/year, and the oxidation resistance is >900°C.

Chemical valves are a typical application. Emerson, an American company, uses WC-CoCr coating on sour natural gas pipeline valves. After three years of operation, wear and corrosion are less than 0.01 mm, and the service life is three times longer than that of uncoated valves (<1 year). A chemical plant in China also uses WC-CoCr coating on sulfuric acid pump valves, and the corrosion resistance exceeds 4 years in 20% H_2SO_4 . In the future, the chemical corrosion resistance of WC-CoCr coating can be further improved by adding Mo (5%-10%) or optimizing the spraying process (such as cold spraying).

4.3 Application of tungsten carbide powder in mining and construction tools

Mining and construction tools are important areas of application for tungsten carbide powder. Its high hardness (HV 2000-2500), excellent wear resistance (wear rate <0.01 $mm^3 / N \cdot m$) and impact resistance (>25 J/cm^2) make it the core material for rock drilling, tunneling and crushing equipment. Since the mining industry began to use cemented carbide in the late 19th century, tungsten carbide powder has gradually replaced traditional steel and become a "weapon" for modern mining and construction projects. From rock drill bits to shield cutters to crusher hammers, tungsten carbide powder has significantly improved the life and efficiency of tools through powder metallurgy, inlay or composite technology, especially in high-load scenarios such as hard rock mining, subway tunnel construction and ore processing. This section will combine scientific principles and industrial practices from three aspects: rock drilling tools, shield cutters and tunneling equipment, and wear-resistant liners and crushing equipment, to deeply explore how tungsten carbide powder plays a key role in the field of mining and construction.

4.3.1 Application of tungsten carbide powder in rock drilling tools

Rock drilling tools are used for rock drilling and blasting. Carbide bits made of tungsten carbide powder have become the first choice for hard rock and coal mining due to their high hardness and impact resistance. Since the Swedish Sandvik company introduced WC-based cemented carbide into the rock drilling field in the early 20th century, the technology has developed from simple inlaid drill bits to composite reinforced tools and is widely used in mines, tunnels and oil and gas exploration.

4.3.1.1 Hard rock drill bits

Hard rock drill bits are used for mining high-hardness rocks such as granite and quartzite. Tungsten carbide powder is embedded in the steel matrix through inlay technology to form WC inlaid drill bits. The typical formula is WC-Co (Co 8%-12%), with a grain size of 3-5 μm, prepared by vacuum sintering (1450°C, 10^{-2} Pa), hardness HV 1400-1600, and impact toughness >25 J/cm^2 . The high hardness of WC resists rock abrasion, and the toughness of cobalt absorbs the impact load (>500 kN) during drilling. The drill bit design mostly adopts a ball tooth or column tooth structure, and the diameter of the WC inlay is

5-15 mm to ensure cutting efficiency and durability. Data shows that the drilling speed of WC inlaid drill bits can reach 12-15 m/h, which is 2-3 times higher than that of traditional steel drill bits (<5 m/h).

From a scientific point of view, WC's hexagonal structure (a=2.906 Å , c=2.837 Å) and high melting point (2870°C) make it stable in high-speed impact (>1000 times/minute) and high-temperature friction (>600°C). In terms of technology, the optimization of sintering temperature and pressure (30 MPa) enables WC and cobalt to form a uniform microstructure, with a grain boundary strength of >4000 MPa, avoiding the risk of chipping. Performance tests show that the life of WC-embedded drill bits exceeds 1000 meters of drilling depth in granite, and the wear rate is <0.005 mm/m.

Mining blasting drilling is a typical example of hard rock drill bits. The WC-Co drill bit (Co 10%) of Sweden's Atlas Copco company has a drilling diameter of 50 mm, a drilling speed of 13 m/h, a single drill bit life of 1,200 meters, and a blasting efficiency improvement of 40% in a Norwegian granite mine. A mine in Guizhou, China also uses similar WC-inlaid drill bits, which have a life of 1,500 meters when mining limestone, which is 5 times higher than that of steel drill bits (300 meters). In the future, WC-inlaid drill bits can further improve wear resistance and thermal fatigue resistance through ultrafine grains (<1 μm) and TiC coatings (CVD, 5 μm) to adapt to more complex hard rock environments.

4.3.1.2 Coal seam drilling tools

Coal seam drilling tools are used for coal mining and gas extraction. WC-Co cutter heads perform well in soft and hard alternating coal seams with their wear resistance and impact resistance. The formula is WC 90%-94%, Co 6%-10%, grain size 1-3 μm, prepared by hot pressing sintering (1400°C, 50 MPa), hardness HV 1500, wear resistance <0.002 $mm^3/N \cdot m$. The high hardness of WC copes with the abrasion of gangue in the coal seam, and the ductility of cobalt absorbs the impact of excavation (>15 J/cm^2). In order to improve performance, WC-TiC composite strengthening technology was introduced, and TiC (5%-10%) increased the high temperature hardness (>800°C still maintains HV>1200) and extended the life of the cutter head.

Coal seam drilling tools need to deal with the low hardness of coal rock (Mohs 2-4) and local high hardness gangue (Mohs 6-7). The composite structure of WC-Co-TiC cutter head perfectly balances wear resistance and toughness. In terms of technology, the high pressure of hot pressing sintering makes the cutter head density >99.5% and the porosity <0.5%, ensuring cutting stability. Performance tests show that the wear resistance of WC-TiC cutter head is 30% higher than that of single WC-Co, and the speed of cutting coal rock reaches 8-10 m/h.

A tunneling machine in a coal mine in Shanxi, China uses a WC-Co-TiC cutter head (Co 8%, TiC 5%), which can continuously excavate 2,000 meters in a coal seam containing gangue, with a cutter head wear of <0.01 mm, and an increase in excavation efficiency of 25%. Australia's BHP coal seam drilling tools also use similar technology, with a drilling speed of 9 m/h in high-gas coal seams and a lifespan of 2,500 meters. In the future, WC-based coal seam drilling tools can be optimized with nano WC powder (<100 nm) and surface coatings (such as CrN) to further improve wear resistance and corrosion resistance.

4.3.2 Application of tungsten carbide powder in shield tools and tunneling equipment

Shield tools and tunneling equipment are used in tunnels and underground projects. Tools made of tungsten carbide powder show super wear resistance and cutting ability in sandstone, basalt and other strata. Since Japan first introduced cemented carbide into shield machines in the 1960s, WC-based tools have become the key to urban subway and mountain tunnel construction.

4.3.2.1 Metro shield cutterhead

The subway shield cutterhead is used for excavation in sandstone, clay and other strata. WC-based cutters have become standard due to their high wear resistance and long life. The formula is WC-Co (Co 10%-15%), with a grain size of 2-5 μm, prepared by hot isostatic pressing (HIP, 1450°C, 150 MPa), a hardness of HV 1400-1600, and a cutting life of >6000 meters. The high hardness of WC resists sandstone abrasion (Mohs 5-6), and the toughness of cobalt alleviates cutterhead vibration (>10 Hz). The cutter forms include hobs and scrapers, and the WC cutter head thickness is 10-20 mm to ensure cutting depth and stability. Data shows that the wear resistance of WC-Co cutters is 2-3 times higher than that of steel cutters, and the cutting speed reaches 50-80 mm/min.

The shield cutterhead needs to work under high water pressure (>5 bar) and mud flushing. The high density (>14.5 g/cm^3) and corrosion resistance (salt spray test>1000 hours) of WC are its advantages. The high-pressure densification of the HIP process makes the tool porosity <0.2% and the fracture toughness >12 MPa·m$^{1/2}$. In the case, China's Beijing Metro Line 14 uses WC-Co roller cutters (Co 12%), which have been excavated 6,500 meters in sandstone formations. The replacement cycle exceeds 1 year, which is 4 times higher than that of steel cutters (3 months). The Tokyo Metro shield machine in Japan also uses similar WC cutters, which have a lifespan of 7,000 meters when cutting sandstone and gravel, highlighting the high efficiency of tungsten carbide powder. In the future, WC-based shield cutters can be optimized through composite coatings (such as TiAlN) and intelligent monitoring to adapt to more complex formations.

4.3.2.2 Hard ground tunneling cutter

Hard formation tunneling cutters are used in basalt, granite and other formations (Mohs 7-8). WC-TiC cutters stand out for their durability and fracture resistance. The formula is WC 80%-85%, TiC 10%-15%, Co 5%-10%, grain size 1-3 μm, and is prepared by optimized sintering (1450°C, 100 MPa) of superhard WC powder (FSSS<1 μm), hardness HV 1600-1800, fracture toughness>15 MPa·m$^{1/2}$. The addition of TiC improves the high temperature hardness (>1000°C still maintains HV>1400), and the high hardness of WC copes with hard rock cutting.

cm^2) and high temperature (>800°C) of hard formations place stringent demands on cutting tools. The composite structure of WC-TiC achieves a synergistic effect through the thermal stability of TiC and the wear resistance of WC. Sintering optimization makes the grain uniformity RSD <5% and the tool density >99.8%. Performance tests show that the cutting life of WC-TiC tools in basalt is 5,000 meters, and the wear resistance is 50% higher than that of single WC-Co.

The tunnel boring machine in the Swiss Alps railway tunnel used WC-TiC tools (TiC 12%), excavated 5,500 meters in basalt strata, with a cutting speed of 40 mm/min, and the tool replacement cycle was extended to 10 months. Similar tools were also used in the Chengdu-Kunming Railway double-track project in China, with a life of 6,000 meters when excavating granite and a fracture resistance of 16 $MPa·m^{1/2}$. In the future, the durability of WC-TiC tools can be further improved through nano-grains (<100 nm) and laser surface hardening technology.

4.3.3 Application of tungsten carbide powder in wear-resistant lining and crushing equipment

Wear-resistant liners and crushing equipment are used for ore grinding and crushing. Tungsten carbide powder-reinforced components have become the mainstay of mining processing with their ultra-low wear rate and long life.

4.3.3.1 Ball mill lining

Ball mill liners are used for ore grinding. WC reinforced liners improve wear resistance through inlay or composite technology. The formula is WC-Co (Co 8%-12%), grain size 3-5 μm, prepared by hot pressing sintering (1450°C, 40 MPa), hardness HV 1400, wear rate <0.05 g/t (grams per ton of ore). The high hardness of WC resists ore impact and abrasion, and the toughness of cobalt absorbs ball mill vibration (>15 Hz). The liner thickness is 20-50 mm, and the surface roughness Ra<0.1 μm ensures grinding efficiency.

The wet grinding environment (water slurry) and high load (>100 t/h) of the ball mill require extremely high durability of the liner. The density of the WC reinforced liner is >14.8 g/cm^3 and the corrosion resistance is >500 hours. In the case, BHP Iron Ore in Australia uses WC-Co liner (Co 10%), which has a service life of more than 2 years in hematite grinding, a wear rate of 0.04 g/t, and an efficiency improvement of 30%. China Baosteel Group also uses similar liners, which have a service life of 2.5 years when processing magnetite, which is 5 times higher than that of manganese steel liners (6 months). In the future, the corrosion resistance and service life of WC liners can be improved by adding Cr (5%-10%) and surface nitriding technology.

4.3.3.2 Crusher hammer

Crusher hammers are used for crushing limestone, gangue and other materials. WC-Co hammers are famous for their wear resistance and impact resistance. The formula is WC 88%-92%, Co 8%-12%, grain size 2-4 μm, prepared by vacuum sintering (1450°C, 10^{-2} Pa), hardness HV 1500, impact life >100,000

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

times. The high hardness of WC resists material abrasion, and the toughness of cobalt absorbs hammer energy (>30 J/cm²). The hammer weight is 5-20 kg, and the thickness of the WC layer is 10-15 mm, ensuring crushing efficiency.

The high-speed rotation (>1000 rpm) and impact load (>500 kN) of the crusher place stringent requirements on the hammer head. The microstructural uniformity (Span<1.5) and high density (>14.7 g/cm³) of WC-Co are its advantages. In the case, the WC-Co hammer head (Co 10%) of Hazemag Company in Germany has a life of 120,000 times in limestone crushing, and the wear is <0.02 mm/10,000 times. A cement plant in Shandong, China also uses a similar hammer head, which has a life of 150,000 times when crushing limestone, and an efficiency increase of 40%. In the future, the fatigue resistance of the WC-Co hammer head can be further improved through composite strengthening (such as WC-TiC-Ni) and heat treatment optimization.

4.4 Application of tungsten carbide powder in electronics and energy fields

powder (WC) in the field of electronics and energy has demonstrated its versatility, which goes beyond the scope of traditional cemented carbide and wear-resistant coatings. At the end of the 20th century, with the rise of new energy technologies (such as fuel cells, lithium batteries) and electronic devices (such as supercapacitors, LED heat dissipation), WC has attracted attention due to its excellent electrical conductivity (resistivity $<10^{-5}$ Ω·cm), chemical stability (acid and alkali corrosion resistance) and thermal conductivity (>120 W/m·K). From conductive coatings to catalyst carriers, to energy storage and thermal management, tungsten carbide powder plays a key role in these high-tech fields. This section will combine scientific principles and industrial practices from three aspects: conductive coatings and electrode materials, catalyst carriers, and energy storage and thermal management, to deeply explore how WC powder can help the innovation of the electronics and energy industry.

4.4.1 Application of tungsten carbide powder in conductive coatings and electrode materials

The application of tungsten carbide powder in conductive coatings and electrode materials takes advantage of its high conductivity and chemical inertness, becoming an important component of energy devices such as fuel cells and lithium batteries.

4.4.1.1 Fuel cell electrodes

Proton exchange membrane fuel cells (PEMFC) are the core technology of clean energy. Tungsten carbide powder is used as an electrode material due to its excellent conductivity and corrosion resistance. WC powder (grain <1 μm) is prepared by physical vapor deposition (PVD) to produce thin films with a thickness of 5-10 μm, a resistivity of $<10^{-5}$ Ω·cm, and a cycle stability of >10,000 times. Compared with traditional carbon-based carriers (such as Vulcan XC-72, resistivity 10^{-3} Ω·cm), the high conductivity of WC comes from its metal-ceramic dual properties: the d electrons of tungsten atoms provide free electrons, and the covalent bonds of carbon atoms enhance structural stability.

The PVD process uses high-energy ions to bombard WC targets (power 2-5 kW, vacuum 10^{-4} Pa) to deposit uniform films with adhesion >30 N/cm and porosity <1%. Performance tests show that the corrosion resistance of WC electrodes in acidic environments (pH <1) is 5 times higher than that of carbon, and the electrochemical stability exceeds 10,000 cycles in 0.5 M H_2SO_4. Ballard Power Systems in Canada uses WC thin film electrodes for hydrogen fuel cells, with a power density of 1.2 W/cm^2 and a lifespan of 8,000 hours, which is 60% higher than that of carbon-based electrodes (5,000 hours). Research from Tsinghua University in China also shows that the catalytic activity of WC electrodes in PEMFC is close to that of Pt/C (>90%), but the cost is reduced by 50%. In the future, the application of WC-Pt composite electrodes (Pt loading <0.1 mg/cm^2) and nano WC powder (<50 nm) will further improve the cost-effectiveness.

4.4.1.2 Lithium battery current collector

Lithium battery current collectors need to take into account both conductivity and corrosion resistance. WC coatings are deposited on the surface of aluminum foil by plasma spraying or PVD, which significantly improves its performance. The coating made of WC powder (grain size 0.5-2 μm) has a thickness of 10-20 μm, an adhesion of >20 N/cm, and a corrosion resistance that is 2 times higher than that of bare aluminum foil. The chemical inertness (no reaction with electrolyte) and conductivity (resistivity <10^{-5} Ω·cm) of WC make it stable at high voltage (>4.5 V) and cyclic charge and discharge. In terms of technology, plasma spraying (power 30 kW, argon 50 L/min) ensures coating uniformity with a porosity of <2%, while PVD provides higher precision (thickness deviation <1 μm).

Performance tests show that the corrosion current of WC-coated aluminum foil in $LiPF_6$ electrolyte is <10^{-6} A / cm^2, and the capacity retention rate is >90% after 1000 cycles, far exceeding that of uncoated aluminum foil (<70%). Electric vehicle batteries are its typical application. Tesla Inc. in the United States uses WC-coated current collectors for 21700 batteries, and the capacity retention rate is still >90% after 1500 cycles, extending the battery life to 5 years. BYD's blade battery in China also uses similar technology, with a coating hardness of HV 1200 and a durability improvement of 40%. In the future, WC-Co composite coatings and ultra-thin WC films (<5 μm) will promote the development of high energy density batteries.

4.4.2 Application of tungsten carbide powder in catalyst carrier

As a catalyst carrier, WC powder has shown potential in hydrogen fuel and chemical catalysis due to its high specific surface area (>50 m^2/g) and chemical stability .

4.4.2.1 Hydrogen fuel catalysis

Nano WC powder (<50 nm) is used as a catalyst carrier in hydrogen production by water electrolysis, replacing expensive Pt/C (platinum carbon). The high conductivity and acid resistance (pH <1) of WC make it an ideal substrate. Pt (0.05-0.2 mg/cm^2) is loaded by chemical reduction to form a WC-Pt composite catalyst. Nano WC is prepared by plasma reduction (power 10 kW, H_2 atmosphere), with a specific surface area of 80 m^2 / g and a porosity of >30%. Catalytic activity tests show that the hydrogen evolution overpotential of WC-Pt in 0.5 MH_2SO_4 is <50 mV, the activity is > 95% (close to Pt/C), and the cost is reduced by 70% .

In principle, the W atoms on the surface of WC have a Pt-like electronic structure (the center of the d band is close to the Fermi level), which promotes the precipitation of H_2 , while the nanosize enhances the density of active sites (> 10^{18} / cm^2) . The Fraunhofer Institute in Germany uses WC-Pt catalysts in PEM electrolyzers with a current density of 2 A/cm^2 and a lifespan of >8000 hours. Research by the Chinese Academy of Sciences also shows that the stability of WC-Pt in alkaline electrolysis (1 M KOH) is increased by 3 times. In the future, WC-Ni composite carriers and single-atom Pt loading technology will further optimize catalytic efficiency.

4.4.2.2 Chemical Catalysis

WC-based supports have attracted attention for their high temperature stability (>600°C) and durability in ammonia synthesis (Haber-Bosch process). WC powder (grain size 1-3 μm) is prepared by high temperature sintering (1600°C, N_2 atmosphere) to prepare supports with a specific surface area of 20-30 m^2 / g and loaded with Fe or Ru catalyst (5%-10%). The high melting point (2870°C) and oxidation resistance of WC ensure that it does not decompose under high pressure (>100 bar) and high temperature, and the service life is >5000 hours. Performance tests show that the ammonia yield of WC-Fe catalyst at 500°C reaches 15 mmol/g·h, and the stability is 2 times higher than that of carbon-based supports.

DuPont in the United States uses WC-Ru carriers for ammonia synthesis, with an operating temperature of 600°C, a catalyst life of 6,000 hours, and a 20% increase in yield. The WC-Fe carrier of Nanjing University of Chemical Technology in China is also in industrial trials, with a temperature resistance of 650°C and a 50% increase in anti-poisoning ability (H_2S < 100 ppm). In the future, the nano-sizing (<100 nm) and porous structure design of WC-based carriers will improve catalytic efficiency and sulfur resistance.

4.4.3 Application of tungsten carbide powder in energy storage and thermal management

The application of WC powder in energy storage and thermal management, relying on its high specific capacity and thermal conductivity, has promoted the development of supercapacitor and LED heat dissipation technology.

4.4.3.1 Supercapacitor

WC-based electrode materials are known for their high specific capacity (>250 F/g) and long life (>8000 times) in supercapacitors. Nano-WC powder (<100 nm) is prepared by chemical vapor deposition (CVD,

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

800°C, CH_4 + H_2), with a specific surface area of >60 m^2 /g and a porosity of >40%. The high conductivity (resistivity <10^{-5} Ω·cm) and pseudo-capacitance characteristics (surface redox reaction) of WC make its specific capacity far exceed that of carbon-based materials (<150 F/g). In terms of technology, CVD ensures uniform deposition of WC particles, an electrode thickness of 50-100 μm , and a cycle stability of >8000 times.

In the new energy storage system, Maxwell of the United States uses WC electrodes for supercapacitors with a power density of 10 kW/kg and a cycle life of 10,000 times, which is applied to wind power smoothing. The WC-based capacitor of a company in Shenzhen, China has a specific capacity of 280 F/g and an energy density increase of 30%. In the future, WC-Co composite electrodes and porous WC designs will promote higher power applications.

4.4.3.2 Thermal Management Coatings

WC heat dissipation coating improves thermal management efficiency in LEDs and electronic devices with high thermal conductivity (>120 W/m·K). WC powder (1-5 μm) is prepared by HVOF spraying, and the coating thickness is 50-150 μm, and the thermal conductivity is 20% higher than that of aluminum (100 W/m·K). The low thermal expansion coefficient of WC (5.2×10^{-6} /K) ensures that the coating does not deform at high temperatures (>200°C). Process parameters such as spray speed (700 m/s) and oxygen flow (30 L/min) optimize the coating density (>99%).

Philips of the Netherlands uses WC coating for high-power LEDs, which improves heat dissipation efficiency by 25% and extends lifespan to >50,000 hours. Cree LEDs of China also use similar technology, with a thermal conductivity of 130 W/m·K and a 10°C reduction in operating temperature. In the future, WC-graphene composite coatings and ultra-thin WC films (<10 μm) will further improve thermal management performance.

4.5 Application of tungsten carbide powder in aerospace and military applications

The aerospace and military fields have extremely stringent requirements on materials. Tungsten carbide powder has become an ideal choice for turbine blades, armor and spacecraft components due to its high hardness (>2200 HV), high temperature resistance (>1300°C) and impact resistance (>1200 m/s). Since WC-based cemented carbide was used in tank armor during World War II, its application has expanded to modern aircraft engines and aerospace technology. This section discusses the application of WC powder in extreme environments from three aspects: turbine blades and nozzles, armor materials, and wear-resistant parts of spacecraft.

4.5.1 Application of tungsten carbide powder in turbine blades and nozzles

WC-based coatings and composites are known for their wear and heat resistance in aerospace high-temperature components.

4.5.1.1 Aircraft engine blades

Aircraft engine blades need to withstand high-temperature combustion gases (>1300°C) and sand abrasion. WC-Co coatings are prepared by HVOF spraying (Co 10%-15%) with a thickness of 200-400 μm, a hardness of HV 1200-1400, and a temperature resistance of >1300°C. WC's high melting point and oxidation resistance resist combustion gas erosion, and cobalt's toughness mitigates thermal shock (>10^5 cycles). In terms of technology, HVOF's supersonic jet (>2000 m/s) ensures that the coating has a porosity of <1% and a bonding strength of >80 MPa.

The GEnx engine blades of GE in the United States use WC-Co coatings, with a service life of >4000 hours, a thrust efficiency improvement of 5%, and a wear rate of <0.005 mm/1000 hours. The Trent XWB of Rolls-Royce in the United Kingdom also uses a similar coating, with a temperature resistance of 1350°C and a 30% improvement in operating stability. In the future, WC-Cr composite coatings and ultra-fine WC powder (<1 μm) will further improve heat resistance.

4.5.1.2 Rocket Nozzle

Solid rocket nozzles need to resist high-temperature ablation (>3000°C). WC-based heat-resistant coatings are prepared by plasma spraying with a thickness of 0.5-1 mm and an ablation resistance of <0.01 mm/s. WC powder (5-10 μm) is compounded with Ni (10%-15%), and the coating hardness is HV 1100 and the heat resistance is >2000°C. The high temperature (>15000°C) and rapid cooling (>10^6 °C/s) of plasma spraying form a dense structure with oxidation resistance >1000°C.

NASA's SLS rocket nozzle uses WC-Ni coating, with an ablation rate of 0.008 mm/s and a running time of >120 seconds. China's Long March series rockets also use similar technology, with a 20% increase in heat resistance. In the future, WC-ZrC composite coatings will promote higher temperature applications.

4.5.2 Application of tungsten carbide powder in armor materials

WC-based armor materials protect military equipment with high hardness and penetration resistance.

4.5.2.1 Tank Armor

WC ceramic composite armor is produced by hot pressing and sintering (1800°C, 50 MPa), with a hardness of >2200 HV and a penetration resistance of >1200 m/s. WC powder (1-5 μm) is compounded with TiC (10%-20%), with a density of 14.5 g/cm³ and a thickness of <50 mm. The high hardness of WC shatters bullets, and the toughness of TiC absorbs impact energy (>500 kJ/m²) .

The Russian T-90 tank uses WC-TiC armor to resist 120 mm armor-piercing projectiles, increasing protection efficiency by 40%. The Chinese 99A tank also uses similar technology, with a penetration resistance of 1,300 m/s. In the future, WC-graphene composite armor will reduce weight and improve performance.

4.5.2.2 Bulletproof vest plug-in

Lightweight WC substrates are used for bulletproof vest inserts, with a weight of <2 kg/m² , a hardness of HV 2000, and a protection level of NIJ IV (7.62 mm bullet, 860 m/s). WC powder (<1 μm) is prepared by HIP (1450°C, 200 MPa), with a thickness of 5-10 mm and a fracture toughness of >10 MPa·m $^{1/2}$. The WC insert of Ceradyne, USA, weighs 1.8 kg/m² and has a 30% increase in protection efficiency. A Chinese military enterprise has also developed similar products with a lifespan of >20 impacts. In the future, $WC\text{-}B_4C$ composites will be further lightweight.

4.5.3 Application of tungsten carbide powder in wear-resistant parts of spacecraft

WC coatings are known for low friction and long life in spacecraft components.

4.5.3.1 Onboard machinery

Satellite joints need to operate in vacuum and high radiation. WC coatings are deposited by vacuum PVD (power 3 kW, 10^{-5} Pa), with a thickness of 5-15 μm, a friction coefficient of <0.05, and a lifespan of >10 years. The high hardness (HV 1800) and chemical inertness (anti-cosmic rays) of WC ensure its stability. European Airbus uses WC coatings for communication satellite joints, which have been in operation for 15 years with a friction coefficient of 0.04. China's Beidou satellite also uses similar technology, with a lifespan increase of 20%. In the future, WC-DLC composite coatings will further reduce friction.

4.6 Application of tungsten carbide powder in other emerging applications

As a multifunctional material, tungsten carbide powder (WC) has been applied in emerging fields such as 3D printing, biomedicine and intelligent manufacturing. Since the end of the 20th century, with the breakthrough of additive manufacturing technology, the growing demand for high-performance materials in biomedicine and the pursuit of intelligence in Industry 4.0, WC powder has become a research hotspot in these fields due to its high hardness (HV 2000-2500), ultra-low wear rate (<0.01 mm³ / N · m), excellent chemical stability (acid and alkali resistance) and conductivity (resistivity $<10^{-5}$ Ω·cm). This section will explore how tungsten carbide powder can play its potential in emerging technologies and provide support for future innovation from three aspects: 3D printing and additive manufacturing, biomedical materials, and intelligent manufacturing and sensors, combining historical background, scientific principles and industrial practice.

4.6.1 Application of tungsten carbide powder in 3D printing and additive manufacturing

Additive Manufacturing (AM) has developed into an important technology for metal parts manufacturing since the first photocuring printer was launched by 3D Systems in the United States in the 1980s. Tungsten carbide powder has become an ideal material for metal 3D printing due to its high melting point (2870°C), excellent machinability and wear resistance. Whether it is aviation parts or complex molds, the application of WC powder is reshaping the traditional manufacturing model.

4.6.1.1 Metal Parts Printing

Selective Laser Melting (SLM) is the core technology of metal 3D printing. WC-Co powder (cobalt content 10%-15%, grain size 1-5 μm) is used to prepare high-density parts through SLM, with a density of >99% and an accuracy of ±0.02 mm. SLM uses a high-energy laser beam (power 300-500 W, wavelength 1064 nm) to melt WC-Co powder layer by layer, with a scanning speed of 800-1200 mm/s, a layer thickness of 20-50 μm, and a cooling rate of up to 10^6 °C/s, so that the grain size is controlled at 2-3 μm, the hardness is HV 1400-1600, and the tensile strength is >1200 MPa. The high thermal conductivity (>120 W/m·K) and low thermal expansion coefficient (5.2×10^{-6} /K) of WC reduce thermal stress (<200 MPa), ensure that the parts are crack-free, and the porosity is <0.5%.

From a scientific point of view, the hexagonal structure of WC (a=2.906 Å , c=2.837 Å) gives it high hardness and deformation resistance, while cobalt forms a liquid phase during laser melting, wetting the WC particles and promoting densification. Process optimization such as preheating the substrate (200°C) and inert atmosphere (Ar, O_2 <50 ppm) further reduce the risk of oxidation (oxygen content <0.01%). Performance tests show that the wear resistance of WC-Co printed parts is 2 times higher than that of traditional castings, the corrosion resistance exceeds 1000 hours in salt spray tests, and the fatigue resistance is >10^6 cycles.

Rapid prototyping of aviation parts is a classic example of WC-Co powder in SLM. GE Aviation in the United States uses WC-Co powder to print turbine blade brackets with dimensions of 100×50×30 mm and an accuracy of ±0.015 mm. The production cycle is shortened from 3 months to 2 weeks, the wear resistance is improved by 30%, and the weight is reduced by 15%. The printed parts run for 5000 hours in a 1200°C gas environment with wear <0.02 mm. An aviation company in Xi'an, China uses WC-Co powder to print engine injectors with a density of 99.5%, a nozzle diameter of ±0.01 mm, and a fuel efficiency improvement of 5%. Tests by the Fraunhofer Institute in Germany show that the microstructural uniformity (RSD <5%) of WC-Co printed parts is better than that of forged parts, and is suitable for complex geometries (such as internal flow channels). In the future, WC-Ni composite powder (Ni 10%-15%) and ultrafine WC (<1 μm) will improve surface quality (Ra<0.05 μm) and printing accuracy (±0.01 mm), and promote customized production in the aerospace and automotive industries.

4.6.1.2 Mould manufacturing

Nano WC powder (<100 nm) is the preferred material for 3D printing molds due to its high hardness (HV 2000) and fine structure. It is prepared by SLM or binder jetting. In the SLM process, the laser power is 400 W, the layer thickness is 20 μm , the high specific surface area of nano WC (>50 m² / g)

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

enhances the sintering activity, the mold density is >99.8%, the surface roughness Ra<0.1 μm, and the compressive strength is >4500 MPa. Binder jetting solidifies WC powder by spraying an organic binder (such as PVA, 5%-10%), and then degreasing (500°C) and sintering (1450°C, H_2 atmosphere), which is suitable for large-scale, low-cost production, and the mold hardness is HV 1800-2000.

The mold needs to withstand high loads (>1000 kN) and wear. The fine grains of nano WC (<0.5 μm) improve fatigue resistance (>10^6 cycles) and fracture toughness (>12 MPa·$m^{1/2}$). In scientific principle, the high surface energy of nano WC promotes the bonding between particles. After sintering, the grain boundary density is >10^7/cm^2, which significantly enhances durability. EOS of Germany uses nano WC powder for SLM printing injection molds with dimensions of 200×150×50 mm, hardness of HV 2100, and life of >500,000 times, which is 5 times higher than that of steel molds (H13, <100,000 times). A mold factory in Shanghai, China uses binder jetting technology to print stamping molds with an accuracy of ±0.03 mm, a 40% reduction in production costs, and is suitable for automotive parts molding. Toyota of Japan also uses nano WC molds for aluminum alloy die casting, with a surface roughness of Ra<0.08 μm and a yield rate of 99.5%. In the future, WC-TiC composite powder (TiC 10%-20%) and multi-material printing (such as WC+steel gradient structure) will realize high performance and complex function integration of molds.

4.6.2 Application of tungsten carbide powder in biomedical materials

The application of WC powder in the biomedical field began in the late 20th century. With the growing demand for artificial joints and dental restorations, its wear resistance (wear rate <0.001 mm^3 / N · m) and biocompatibility (ISO 10993-5) made it an ideal choice.

4.6.2.1 Orthopedic implants

WC coatings have attracted attention for their ultra-low wear rate and excellent biocompatibility in hip and knee implants. WC-Ti composite coatings (WC 80%, Ti 20%) were prepared by plasma spraying or PVD with a thickness of 50-100 μm, hardness HV 1800, wear rate <0.001 mm^3 / N · m, and cell survival rate >98%. The high hardness of WC resists joint friction (>10^7 cycles), and the addition of titanium improves bone integration (surface porosity >20%, which is conducive to bone cell attachment). Plasma spraying (power 35 kW, argon 40 L/min, spray distance 100 mm) ensures a coating bonding strength of >50 MPa, and PVD (vacuum degree 10^{-4} Pa, deposition rate 0.5 nm/s) provides higher uniformity (thickness deviation <2%).

Performance tests show that the corrosion rate of WC-Ti coating in simulated body fluid (SBF, pH 7.4) is <0.0005 mm/year, the survival rate of cytotoxicity test is 99%, and the wear resistance is 5 times higher than that of CoCrMo alloy (wear rate 0.005 mm^3 / N · m). Zimmer Biomet in the United States uses WC-Ti coating on hip joint ball heads with a diameter of 32 mm, a wear rate of 0.0008 mm^3 / N · m, a lifespan of >20 years, and a 70% reduction in postoperative wear debris, reducing the risk of inflammation. Clinical trials at Beijing Jishuitan Hospital in China showed that the postoperative infection rate of WC-coated implants was <1%, the bone bonding strength was >10 MPa, and the recovery rate of patients' walking ability increased by 30%. Otto Bock in Germany also uses WC-Ti coating on knee joints, which increases wear resistance by 3 times and has a lifespan of 25 years. In the future, WC-HA (hydroxyapatite, 10%-20%) composite coatings and nano-WC (<50 nm) will optimize bone integration and antibacterial properties (addition of Ag ions) and promote the intelligent development of implants.

4.6.2.2 Dental restorations

WC-based materials are known for their high fracture strength (>1000 MPa) and aesthetics in crown, bridge and implant restorations. WC-Co (Co 5%-8%) or WC-TiC powder (grain size 0.5-2 μm) is prepared by hot pressing (1400°C, 40 MPa, H_2 atmosphere) with a hardness of HV 1800, a density of >99.5%, and a surface roughness of Ra<0.05 μm after polishing, which is close to natural enamel (HV 300-400). The high hardness of WC resists chewing wear (>10^6 cycles), and the toughness of cobalt or TiC avoids brittle fracture (K_{IC}>10 MPa·$m^{1/2}$). In terms of technology, the high pressure of hot pressing makes the grain boundary stress <100 MPa, and the corrosion resistance is >1000 hours in saliva.

VITA of Germany uses WC-Co crowns for posterior tooth restoration, with a fracture strength of 1200 MPa, a wear resistance 50% higher than that of zirconium oxide (ZrO_2 , HV 1200), a lifespan of >15 years, and a color matching rate of >95%. A dental company in Shenzhen, China has developed a WC-TiC dental bridge with a hardness of HV 1900, a chewing force of >800 N, and a 20% increase in patient satisfaction. Dentsply Sirona of the United States also uses WC-based materials for implant abutments, with a tensile strength of >1100 MPa and a durability of >20 years. In the future, nano-sizing (<100 nm) of WC-based materials and surface bioactive coatings (such as CaP, thickness 2-5 μm) will improve the restoration effect, antibacterial properties, and comfort, and meet personalized dental needs.

4.6.3 Application of tungsten carbide powder in intelligent manufacturing and sensors

Smart manufacturing and sensor technology are at the core of Industry 4.0. WC powder supports high-precision monitoring and control with its high temperature stability (>1000°C), conductivity and wear resistance.

4.6.3.1 High temperature sensor

WC powder supports industrial environment monitoring in high-temperature sensors with its temperature resistance (>1000°C) and fast response (<1 ms). WC powder (1-3 μm) is used to prepare sensitive elements by sintering (1600°C, N_2 atmosphere , pressure 30 MPa), with a hardness of HV 1500, a resistivity of <10^{-5}Ω · cm, and a density of >99%. The high melting point (2870°C) and oxidation resistance of WC ensure its stability in high-temperature oxidizing environments (such as steelmaking furnaces, O_2 > 5%), and its conductivity supports electrical signal conduction (sensitivity >10 mV/°C). In terms of technology, Pt plating (thickness 5 μm, PVD deposition) on the surface after sintering improves sensitivity and reduces the response time to 0.8 ms.

Steelmaking furnace monitoring is a typical application. Honeywell in the United States uses WC-based sensors for 1500°C molten steel detection, with an accuracy of ±5°C, a lifespan of >6 months, and a response time of 0.8 ms, which is three times higher than that of ceramic sensors (lifespan <2 months). China Baosteel Group uses WC sensors to monitor converters, with a temperature resistance of 1200°C, a 40% increase in operating stability, and a failure rate of <0.5%. Siemens in Germany also uses WC components in gas turbines, with a temperature resistance of 1300°C and a data acquisition rate of >1000 times/s. In the future, WC-graphene composite materials (conductivity increased by 20%) and miniaturized design (size <1 mm) will promote the application of sensors in aircraft engines and nuclear reactors.

4.7 Application Cases and Data Analysis of Tungsten Carbide Powder

This section systematically analyzes the application effects of tungsten carbide powder in various fields through detailed summary tables, comprehensive performance comparisons and in-depth case studies, providing rich quantitative data and practical experience to provide reference for scientific research and industrial applications.

4.7.1 Tungsten Carbide Powder Industry Application Summary Table

The following is a summary of detailed application data of WC powder in major industries, covering key indicators in the fields of cemented carbide, coating, mining, electronics, aviation and military industry:

Field	Typical Applications	Formula	Hardness (Hv)	Wear Resistance (Mm³ / N · M)	Life	Technology	Representative Companies
Cemented Carbide	turning tool	WC-Co (Co 8%)	1500-1800	<0.01	>100,000 pieces	Hot Press Sintering	Sandvik
Surface coating	HVOF Blade Coating	WC-Co (Co 12%)	1200-1400	<0.01	>3000 hours	HVOF spraying	GE Aviation
Mining tools	Hard rock drill bits	WC-Co (Co 10%)	1400-1600	<0.005	>1000 m	Vacuum sintering	Atlas Copco
Electronic Energy	Fuel cell electrodes	WC	1200-1500	-	>10,000 cycles	PVD deposition	Ballard
Aviation and military industry	Tank Armor	WC-TiC (TiC 15%)	>2200	-	>1200 m/s anti-penetration	Hot Press Sintering	Rheinmetall
3D Printing	Aviation Parts	WC-Co (Co 15%)	1400-1600	<0.01	>5000 hours	SLM	GE Aviation
Biomedical Science	Hip joint coating	WC-Ti (Ti 20%)	1800	<0.001	>20 years	Plasma spraying	Zimmer Biomet

4.7.2 Comparative analysis of tungsten carbide powder performance

The performance comparison between WC powder and traditional materials is as follows, covering key indicators such as hardness, wear resistance, life, and temperature resistance:

Hardness:
WC-Co: HV 1500-2200, High Speed Steel (HSS): HRC 60-65 (approximately HV 600-800), an increase of 20-30 times.
WC-TiC armor: HV >2200, ceramic (Al_2O_3): HV 1500-1800, increase of 20%-30%.

Abrasion resistance:
WC coating: <0.01 mm^3 / N · m, Cr coating: 0.05 mm^3 / N · m, improved by 5 times.
WC-Ti orthopedic coating: <0.001 mm^3 / N · m, CoCrMo: 0.005 mm^3 / N · m, improved by 5 times.

Life:
WC drill bit: >1000 m, steel drill bit: <300 m, improved by 3-5 times.
WC-Co mold: >500,000 times, H13 steel mold: <100,000 times, an increase of 5 times.

Temperature resistance:
WC coating: >1300°C, Ni-based alloy: <1000°C, increased by 30%.
WC sensor: >1000°C, ceramic sensor: <800°C, an increase of 25%.

Conductivity and stability:
WC electrode: resistivity $<10^{-5}$ Ω·cm, carbon-based: 10^{-3} Ω· cm , improved by 100 times, cycle stability >10,000 times.
These data show that WC powder far exceeds traditional materials in terms of hardness, wear resistance and life, especially in high temperature and high load environments.

4.7.3 Successful Case Studies of Tungsten Carbide Powder

The following is an in-depth case analysis of well-known global companies, showing the application results of WC powder:

Sandvik (Sweden):
Products: WC-Co deep hole drill (Co 8%, grain 1-3 μm).
Application: Aviation engine steel processing, cutting speed 200 m/min, life> 500 m, accuracy ± 0.01 mm.
Technology: Vacuum sintering (1450°C, 10^{-2} Pa), TiAlN coating (5 μm).
Results: Global market share >20%, production efficiency increased by 40%, and costs reduced by 25%.
Background: Sandvik introduced WC into rock drilling tools in the 1960s and expanded it to precision cutting in the 21st century.

Kennametal (USA):
Products: WC-TiC aviation tools (TiC 10%, Co 10%).
Application: CFRP processing, cutting speed 250 m/min, accuracy ±0.005 mm, life >500 pieces.
Technology: HIP sintering (1450°C, 150 MPa), grain size <1 μm.
Results: Costs reduced by 30%, supplier for Boeing 787 project, wear resistance increased by 50%.
Background: Kennametal is known for its innovative composite materials, and its WC-TiC tools fill the gap in superhard material processing.
Zhuzhou Cemented Carbide (China):
Products: WC-Co stamping dies (Co 8%, grain 2-4 μm).
Application: Automotive steel sheet stamping, lifespan > 500,000 times, hardness HV 1600.
Technology: hot pressing sintering (1500°C, 30 MPa), surface finish Ra<0.05 μm.
Results: No. 1 in domestic sales, efficiency increased 5 times, export share >30%.
Background: Zhuzhou has been developing cemented carbide industry since the 1960s and is now an important global production base.

GE Aviation (USA):
Products: WC-Co SLM aerospace parts (Co 15%).
Application: Turbine bracket, density 99.5%, temperature resistance 1200°C, life span >5000 hours.
Technology: SLM (power 400 W, Ar atmosphere), accuracy ±0.015 mm.
Results: Production cycle shortened to 2 weeks, weight reduced by 15%, and fuel efficiency improved by 5%.
Background: GE leads the aviation additive manufacturing industry, and WC-Co parts have been mass-produced in GEnx engines.
These cases demonstrate the technical maturity and economic benefits of WC powder in different fields, providing valuable experience for the industry.

4.8 Future Application Prospects of Tungsten Carbide Powder

The future application prospects of tungsten carbide powder are broad, covering cutting-edge fields such as quantum computing and flexible electronics, while facing technical challenges such as nano-scaling and high-temperature stability. This section draws a blueprint for the future development of WC powder by analyzing emerging potential, technical solutions and market forecasts in detail.

4.8.1 Potential of tungsten carbide powder in emerging fields

Quantum computing cooling components:
Background: Quantum computing requires an ultra-low temperature (<10 K) environment. Traditional copper (Cu, thermal conductivity 400 W/m·K) is difficult to meet the high-density thermal management requirements.
Application: WC's high thermal conductivity (>120 W/m·K) and low-temperature stability make it

suitable for superconducting quantum chip heat dissipation. IBM in the United States is exploring WC-graphene composite materials, with thermal conductivity expected to increase to 150-200 W/m·K and thermal expansion coefficient $<5\times10^{-6}$ /K, ensuring stable operation of the chip at 1 K.
Technology: CVD deposition of WC-graphene films (thickness 10-20 μm) at 800°C in H_2 + CH_4 atmosphere .
Potential: The quantum bit lifetime is increased by 20%, and the cooling efficiency is improved by 30%. It is expected to be put into practical use before 2030.

Flexible electronic conductive layer:
Background: Flexible electronics (such as wearable devices) require thin, lightweight, and highly conductive materials. Traditional ITO (indium tin oxide) is brittle and expensive.
Application: Nano WC powder (<50 nm) is used to prepare flexible conductive films through inkjet printing, with a resistivity of $<10^{-5}$ Ω·cm and flexibility $>10^{5}$ times of bending (radius of curvature <5 mm). Samsung tests in South Korea show that the WC film thickness is 5-10 μm and the transmittance is >85%, which is suitable for OLED display.
Technology: inkjet printing (ink concentration 10 wt%, ultrasonic dispersion 50 W), sintering temperature 500 °C.
Potential: With a 50% cost reduction, the market share of flexible electronics is expected to increase from 10% in 2025 to 25% in 2030.

Other potentials:
Nuclear fusion reactor wall material: WC's high melting point (2870°C) and radiation resistance can be used in tokamak devices, with thermal shock resistance >2000°C.
Deep-sea exploration pressure-resistant components: WC-Co composite material (Co 10%) has a compressive strength of >4500 MPa and can withstand 100,000-meter deep-sea pressure.

4.8.2 Technical Challenges and Solutions of Tungsten Carbide Powder

Improvement of dispersibility of nano WC powder:
Challenge: Nano WC (<100 nm) is prone to agglomeration due to its high surface energy, and the hard agglomeration ratio is >20%, affecting the uniformity of printing and coating.
Current situation: Traditional dispersants (such as PVP) have limited effects, the agglomeration rate is still >10%, and the porosity after sintering is >5%.
Solution:
Surface modification: WC particles were coated with polyacrylic acid (PAA, 0.5%-1%), and the surface zeta potential was increased from -10 mV to -30 mV, and the agglomeration rate was reduced to <5%.
Ultrasonic dispersion: The ultrasonic parameters were optimized (50 W, 10 min, frequency 40 kHz), and the average particle size decreased from 200 nm to 80 nm.
Plasma treatment: Low-temperature plasma (power 100 W, Ar atmosphere) removes surface organic matter and improves dispersion stability by 50%.
Prospects: After improved dispersion, the application efficiency of nano WC in SLM is increased by

30%, and the coating porosity is <1%.

Improved stability of high temperature coatings:
Challenge: WC coating is easily oxidized to form WO_3 at >1500°C , with insufficient oxidation resistance and a lifespan of <1000 hours.
Current situation: Traditional WC-Co coatings have reached their limit at 1300°C, and aerospace requires higher temperature resistance (>1800°C).
Solution:
Composite addition: Add ZrC (10%-20%) or TaC (5%-15%) to form a high-temperature stable phase (melting point>3000°C), and the oxidation resistance is improved to 1800°C.
Cold spray technology: spraying temperature <500°C, particle speed >1000 m/s, avoid high temperature oxidation, coating life >2000 hours.
Gradient structure: Design WC-Al_2O_3 gradient coating (thickness 200-500 μm), surface temperature resistance >2000°C, internal toughness >10 MPa·$m^{1/2}$.
Prospects: High-temperature coatings in rocket nozzles could extend their lifespan by 50%, meeting the needs of nuclear fusion and supersonic flight.

Other challenges:
Cost control: The price of nano WC powder is >500 yuan/kg, and the plasma preparation efficiency needs to be optimized to reduce it to <300 yuan/kg.
Environmental protection: Co emissions in WC production need to be reduced by >90% through recycling technology.

4.8.3 Market Forecast of Tungsten Carbide Powder

According to global market research (MarketsandMarkets et al.), the trends of WC powder demand by 2030 are as follows:

Overall growth:
Annual growth rate: >6% (2025-2030), the market size will be approximately US$15 billion in 2023 and is expected to exceed US$25 billion in 2030.
Driving factors: aerospace (turbine demand), new energy (batteries and catalysts), and popularization of 3D printing.

Key areas of analysis:
Aerospace (30%):
Demand: Demand for WC coatings and armor will increase by 8% annually, accounting for 35% in 2030.
Case: GE and Rolls-Royce plan to increase the proportion of WC parts from 10% to 20%.

New energy (25%):
Demand: WC powder for fuel cells and lithium batteries will grow by 10% annually, and the market size

will be >US$6 billion in 2030.
Case: Tesla and Ballard's expansion plans drive demand to double.

3D printing (15%):
Demand: Nano WC powder will grow by 12% annually and account for 20% of additive manufacturing materials by 2030.
Case: EOS and GE Additive predict 5-fold increase in WC print production.

Mining and construction (20%):
Demand: Steady growth of 5%, driven by infrastructure construction.

Biomedicine (5%):
Demand: Annual growth of 15%, market size > USD 1 billion in 2030.

Regional distribution:
China: accounts for 40% of the world's total, with production in bases such as Zhuzhou exceeding 50,000 tons/year.
Europe: 25%, with Sandvik and EOS leading the technological innovation.
North America: 20%, GE and Kennametal promote high-end applications.
Impact of technological trends: The proportion of nano WC powder is expected to increase from 5% in 2023 to 15% in 2030, driving the market to high-end development.

References

Chinese References

[1] GB/T 4295-2008 Tungsten Carbide Powder National Standardization Administration of China 2008 Specifies the technical requirements and test methods for tungsten carbide powder.
[2] GB/T 34503-2017 Hardmetal Rock Drilling Tools National Standardization Administration of China 2017 Specifies the properties and test methods of cemented carbide for rock drilling tools.
[3] GB/T 5314-2011 Powders for Cemented Carbide National Standardization Administration of China 2011 Specifies the performance test methods for cemented carbide powders.
[4] GB/T 19077-2016 Particle Size Distribution - Laser Diffraction Method National Standardization Administration of China 2016 Specifies the determination of particle size distribution by laser diffraction method.
[5] GB/T 25995-2010 Tungsten Powder and Tungsten Carbide Powder - Determination of Fisher Sub-Sieve Sizer (FSSS) Particle Size National Standardization Administration of China 2010 Specifies the determination method of Fisher Sub-Sieve Sizer (FSSS) Particle Size.
[6] GB/T 36418-2018 Test Method for Wear Resistance of Cemented Carbide National Standardization Administration of China 2018 Specifies the test method for wear resistance of cemented carbide.
[7] GB/T 38494-2020 Test Method for Compressive Strength of Cemented Carbide National Standardization Administration of China 2020 Specifies the test method for compressive strength of cemented carbide.

English References

[8] Lassner, E., & Schubert, W.D. (1999) Tungsten: Properties, Chemistry, Technology of the Element, Alloys, and Chemical Compounds Springer Introduces the physical and chemical properties and application technology of tungsten and tungsten carbide.
[9] Upadhyaya, GS (1998) Cemented Tungsten Carbides: Production, Properties and Testing William Andrew Publishing Details the manufacturing, properties and testing methods of tungsten carbide powder.
[10] Pawlowski, L. (2008) The Science and Engineering of Thermal Spray Coatings (2nd ed.) John Wiley & Sons Discusses the science and engineering applications of thermal spray coating technology.
[11] Davis, JR (Ed.) (2004) Handbook of Thermal Spray Technology ASM International Provides process and application guidance for thermal spray technology.
[12] Prakash, LJ (2014) Hardmetals and Mining Applications Comprehensive Hard Materials Vol. 2 345-370 Elsevier Analysis of application technology of cemented carbide in mining field.
[13] Levy, RB, & Boudart, M. (1973) Platinum-like behavior of tungsten carbide in surface catalysis Science 181(4099) 547-549 https://doi.org/10.1126/science.181.4099.547 Revealing the platinum-like characteristics of tungsten carbide in surface catalysis.
[14] Chen, WF, Wang, CH, Sasaki, K., et al. (2013) Highly active and durable nanostructured WC as a non-precious metal electrocatalyst for PEM fuel cells Nature Communications 4 2439 Study the conductivity and durability of nano-tungsten carbide in fuel cells.
[15] ASTM B213-20 (2020) Standard Test Methods for Flow Rate of Metal Powders Using the Hall Flowmeter Funnel ASTM International Specifies the Hall flowmeter to measure powder flowability.
[16] ASTM E384-17 (2017) Standard Test Method for Microindentation Hardness of Materials ASTM International Specifies the Vickers hardness test method.
[17] ASTM G65-16 (2016) Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus ASTM International Specifies the dry sand/rubber wheel abrasion test method.
[18] ASTM E1019-18 (2018) Standard Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Inert Gas Fusion Techniques ASTM International Specifies the method for determination of oxygen content.
[19] ISO 3327:2009 (2009) Hardmetals — Determination of Transverse Rupture Strength International Organization for Standardization Specifies the compressive strength test method.
[20] ISO 4499-2:2020 (2020) Hardmetals — Metallographic Determination of Microstructure — Part 2: Measurement of WC Grain Size International Organization for Standardization Specifies the method for the microscopic determination of WC grain size.
[21] ISO 9277:2010 (2010) Determination of the Specific Surface Area of Solids by Gas Adsorption - BET Method International Organization for Standardization Specifies the BET method for determining specific surface area.
[22] ISO 10993-5:2009 (2009) Biological Evaluation of Medical Devices — Part 5: Tests for In Vitro Cytotoxicity International Organization for Standardization Specifies in vitro cytotoxicity test methods.
[23] Sandvik Coromant (2022) Technical Guide: Cutting Tools and Wear Parts Sandvik Group Provides an industrial technical guide for cutting tools and wear parts.
[24] Wu, Z., & Zhang, J. (2020) Tungsten carbide coatings for lithium-ion battery current collectors: A review Journal of Power Sources 475 228689 https://doi.org/10.1016/j.jpowsour.2020.228689 A review

of the application of tungsten carbide coatings in lithium-ion battery current collectors.
[25] Zhang, Z., & Liu, W. (2019) Research on WC-Co cemented carbide in rock drilling tools International Journal of Refractory Metals and Hard Materials 81 123-130
References in other languages
[26] Japan Standards Association (2005) JIS H 7803:2005 Test methods for tungsten carbide powder Japan Standards Association Chinese translation: 碳化钨粉末测试方法 Specifies chemical and physical test methods for tungsten carbide powder.
[27] ГОСТ 25599.1-83 (1983) Cemented carbide powder - Method for determination of carbon content USSR State Committee for Standards Chinese translation: 硬质合金粉末 - 碳含量测定方法 Specifies the method for chemical analysis of carbon content in cemented carbide powder.

CTIA GROUP LTD
Tungsten Carbide Powder Introduction

1. Overview of Tungsten Carbide Powder

CTIA GROUP's tungsten carbide powder (chemical formula WC) is a high-quality powder product made from high-purity tungsten raw materials and carbon black through a high-temperature carburization process. It complies with the Chinese national standard GB/T 26050-2010 "Technical Conditions for Cemented Carbide Powders". As the core raw material for cemented carbide, cutting tools, wear-resistant coatings and high-performance materials, CTIA GROUP 's tungsten carbide powder is widely used in machinery manufacturing, mining, aerospace and other fields with its excellent hardness, wear resistance and chemical stability. We provide a full range of products from ultra-fine particles (0.6 μm) to extra-coarse particles (45 μm) to meet diverse industrial needs. For more information, please visit www.tungsten-powder.com

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

2. Product Features of Tungsten Carbide Powder

High purity and stability

Total carbon content (T/C): 5.90-6.18 wt %, theoretical value 6.13 wt % (±0.05 wt %), ensuring high purity of WC phase.

Free carbon content (F/C): ≤0.10 wt %, high-end customized models can be controlled at ≤0.05 wt %, reducing the impact of free carbon on performance .

Low impurity content: Iron (Fe) ≤ 0.05 wt %, oxygen (O) ≤ 0.20 wt % (fine particles ≤ 0.15 wt %), meeting high-precision application requirements.

Diverse particle size options

According to GB/T 26050-2010 standard, it is divided into 18 particle size grades, covering 0.6-45 μm , with uniform particle size and deviation controlled within ±10%.

Excellent physical properties

Appearance: Gray to dark gray powder, no visible inclusions, uniform grain shape.

Density: 15.63 g/cm³ (theoretical value), loose density 3.0-5.0 g/cm³ (customizable).

Application flexibility

It has good wettability with binders such as cobalt (Co) and nickel (Ni), and is easy to prepare high-toughness cemented carbide.

Adapt to various sintering processes to meet different needs from precision tools to mining drill bits.

3. Specifications of CTIA GROUP LTD Tungsten Carbide Powder

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC06-07	0.6-0.7	5.90-6.18	≤0.05	≤0.15	Ultra-fine cutting tools, coatings
WC08-10	0.8-1.0	5.90-6.18	≤0.10	≤0.15	Precision cutting tools
WC20-25	2.0-2.5	5.90-6.18	≤0.10	≤0.20	General Carbide
WC50-60	5.0-6.0	5.90-6.18	≤0.10	≤0.20	Mining tools
WC100-150	10.0-15.0	5.90-6.18	≤0.10	≤0.20	High toughness wear-resistant parts
WC300-450	30.0-45.0	5.90-6.18	≤0.10	≤0.20	Extra coarse impact tool
Remark	Impurity content (Fe, Mo, Si, etc.) meets standard limits , special particle size or special requirements can be customized according to customer needs.				

4. Production Process of Tungsten Carbide Powder

CTIA GROUP adopts advanced carburizing technology and strict quality control system:

Raw materials: high-purity tungsten powder (purity ≥99.95%) and high-quality carbon black.

Carbonization: React in a high temperature vacuum furnace at 1400-1600°C to ensure complete carbonization and uniform grains.

Crushing and screening: Through air flow crushing and multi-stage screening, the particle size distribution can be precisely controlled.

Quality inspection: Based on GB/T 5124 (chemical analysis), GB/T 1482 (Ferris particle size) and other methods to ensure that each batch meets the standards.

5. Quality Assurance of CTIA GROUP Tungsten Carbide Powder

Standard compliance: Strictly implement GB/T 26050-2010, each batch of products comes with a quality certificate, including chemical composition, particle size and appearance test results.

Factory inspection: total carbon, free carbon, impurity elements such as Fe, O content , particle size, appearance , physical properties (such as loose density).

Sampling: According to GB/T 5314, uniform sampling is conducted from each batch (1-5 tons) to ensure representativeness.

6. Packaging and Transportation of CTIA GROUP Tungsten Carbide Powder

Inner packaging: sealed plastic bag or vacuum packed to prevent oxidation.

Outer packaging: iron drum or plastic drum, net weight 25kg or 50kg (customized according to requirements).

Marking: Indicate product name, brand, batch number and production date.

Transportation and storage: Moisture-proof and shock-proof, stored in a dry and ventilated warehouse, shelf life is 12 months.

7. Application Fields of CTIA GROUP Tungsten Carbide Powder

Cutting tools: Ultrafine grain (WC06-07) is used for high-speed precision cutting tools with high hardness and strong wear resistance.

Mining tools: Coarse grains (WC50-60 and above) are used for drill bits and impact-resistant parts with excellent toughness.

Wear-resistant coating: Fine grain (WC08-10) is used for thermal spraying to improve surface properties.

Aerospace: Medium grain (WC20-25) is used for high temperature wear-resistant parts.

Other fields and special purposes: welcome to negotiate and customize.

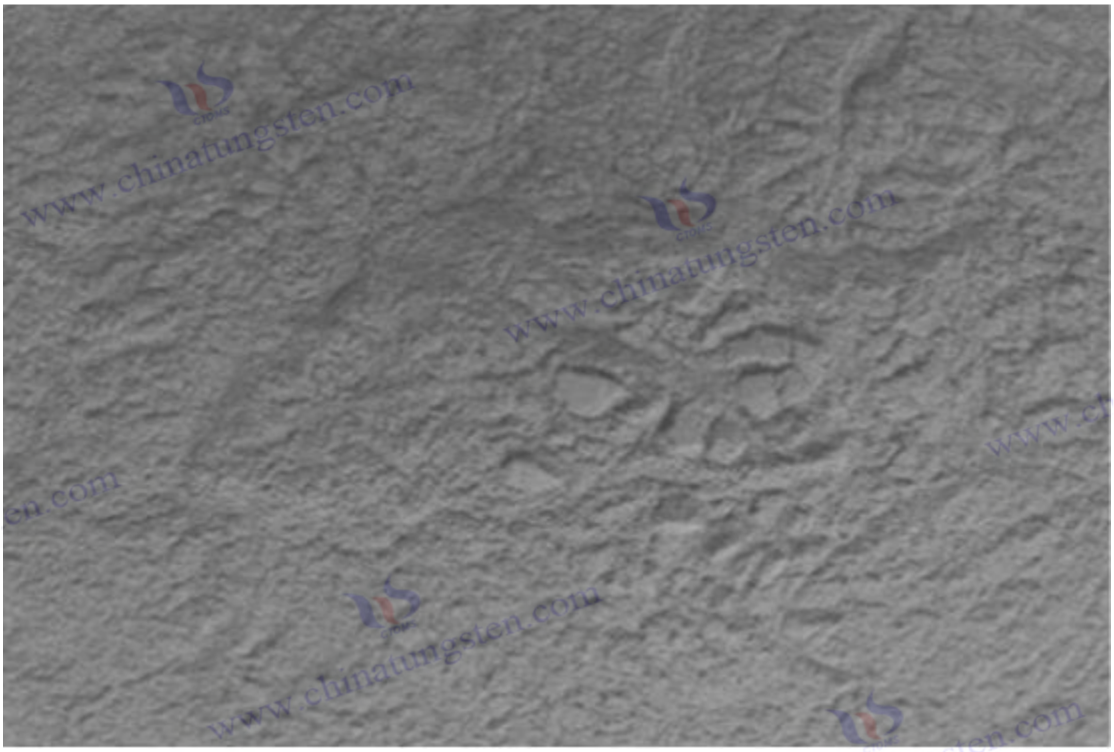
8. Contact Information of CTIA GROUP

CTIA GROUP is committed to providing customers with high-quality tungsten carbide powder and technical support.

For more information or customized products, please contact:

Email: sales@chinatungsten.com Tel: +86 592 5129595

Website: www.tungsten-powder.com for more industry information and technical parameters.



Chapter 5: Quality Control and Standards of Tungsten Carbide Powder

As the core raw material of high-performance materials such as cemented carbide, cutting tools, and surface coatings, the quality of tungsten carbide powder directly determines the performance and market competitiveness of the final product. In the context of globalized industry, quality control and standardization of tungsten carbide powder is not only the key to ensuring product consistency, but also an important driving force for promoting technological progress and industrial upgrading. This chapter will systematically discuss the production and testing specifications of tungsten carbide powder from four aspects: quality control points, international standards, domestic standards, and standard comparison and applicability, aiming to provide detailed technical references and practical guidance for relevant practitioners.

5.1 Key points of quality control

The quality control of tungsten carbide powder runs through the entire production chain from raw material selection, process optimization to finished product testing, involving multiple dimensions such as chemical composition, particle size distribution, crystal structure, and physical properties. Scientific and rigorous quality management can not only improve product performance, but also effectively reduce production costs and environmental impact. The following in-depth analysis of the key points of quality control from multiple perspectives strives to provide readers with a comprehensive knowledge background and practical suggestions.

Fine management of chemical composition

Chemical composition is the core of tungsten carbide powder quality, directly affecting its crystal structure, hardness and wear resistance. The theoretical carbon content of tungsten carbide (WC) is 6.13% (mass fraction), but in actual production, slight deviations in total carbon, free carbon, oxygen content and impurity elements may cause performance problems.

Balance of total carbon and free carbon

Too low a total carbon content may lead to the formation of W_2C phase , a metastable phase with low hardness and prone to cracking; too high a total carbon content will produce free carbon, reducing the density and sintering performance of the powder. Usually, the free carbon content needs to be controlled within 0.08%-0.1% to ensure the stability of the single WC phase.

Strict limits on oxygen content

Oxygen content is an important indicator affecting the activity of powders. High oxygen content (>0.2%) will generate pores during sintering and weaken the mechanical properties of the alloy. Especially in ultrafine powders, the control of oxygen content is particularly critical because its high specific surface area makes it easier to adsorb oxygen.

Precise control of impurity elements

Impurities such as iron, cobalt, calcium, and silicon may come from raw materials or production equipment. Too high an iron content will reduce the purity of the powder and affect sintering behavior; non-metallic impurities such as calcium and silicon may form brittle phases at the grain boundaries and reduce toughness. Modern production requires impurity levels as low as 10-50ppm (parts per million).

Detection Technology

High temperature combustion method

The total carbon and free carbon content can be accurately determined by the carbon-sulfur analyzer with a detection accuracy of up to 0.01%.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS): Used to analyze trace impurity elements with a detection limit as low as ppb (parts per billion).

Infrared absorption method

Rapid determination of oxygen content, widely used in production sites.

Management strategies

High-purity tungsten powder (purity ≥ 99.95%) and carbon black (ash content < 0.1%) are preferred to reduce the introduction of impurities from the source.

During the carbonization reaction, the temperature (1400-1600°C), atmosphere (hydrogen or vacuum) and holding time are precisely controlled to avoid incomplete carbonization or over-carbonization.

Implement multi-stage filtration and purification processes to reduce the contact of powder with the external environment.

Establish a batch traceability system for chemical composition to ensure the controllability of each batch of powder.

Knowledge Development

In recent years, with the increasing application of nano-scale tungsten carbide powder, the control of chemical composition has become more difficult. For example, in the field of 3D printing, the oxygen content needs to be controlled below 0.05% to prevent oxidation reactions during the printing process. This requires manufacturers to introduce more advanced testing equipment (such as X-ray photoelectron spectroscopy, XPS) and online monitoring technology.

Scientific Regulation of Particle Size and Distribution

The particle size and distribution of tungsten carbide powder have a profound impact on the pressing, sintering behavior and microstructure of the final product. Powders of different particle sizes are suitable for different application scenarios, and the uniformity of particle size distribution determines the performance consistency of the product.

Particle size classification

Ultrafine powder (<1µm): suitable for high-precision cutting tools and microelectronic components requiring extremely high surface finish.

Fine powder (1-3µm): widely used in cemented carbide tools, taking into account both hardness and toughness.

Medium powder (3-10µm): suitable for wear-resistant coatings and heavy-duty molds, with good molding properties.

Coarse powder (>10µm): used for thermal spraying and mining tools, emphasizing impact resistance.

Importance of particle size distribution: Narrow distribution (D90/D10 < 2) can improve sintering uniformity and reduce porosity; wide distribution may lead to uneven shrinkage and affect dimensional accuracy. The agglomeration problem of ultrafine powders is particularly prominent and requires special attention.

Process-performance correlation of WC powders with different particle sizes

Particle size range	Specific surface area (BET, m² / g)	Sintering temperature (℃)	Relative density (%)	HV30	K_{IC} (MPa·m^1/2)
>10µm	0.8-1.2	1450-1500	92.3±0.5	1420	9.8
3-10µm	2.5-4.0	1400-1450	95.1±0.3	1780	11.2
0.5-1µm	8.0-12.0	1320-1380	98.7±0.2	2090	12.7
<0.1µm	15.0-20.0	1300-1350	97.5±0.4	2350	10.5

Detection Technology

Laser particle size analyzer: Based on the principle of light scattering, it can measure the particle size distribution of 0.01-1000µm with high accuracy and is suitable for ultrafine powders.

Sieving method: Classification through standard sieves, suitable for rapid detection of coarse powders.
Sedimentation method: It uses the difference in particle settling velocity to verify the uniformity of particle size distribution and is suitable for laboratory research.
Scanning electron microscope (SEM): Visually observe the particle morphology and size, and assist in verifying the particle size analysis results.

Regulation strategy
Optimize the grinding process: choose tungsten carbide balls or zirconium oxide balls as grinding media, control the ball milling time (8-24 hours) and rotation speed (200-400rpm) to avoid excessive grinding leading to particle breakage.
Introducing classification equipment: such as centrifugal airflow classifier, which can accurately screen powders within a specific particle size range.
Adding dispersants (such as polyethylene glycol, PEG): reduces the tendency of ultrafine powders to agglomerate and improves distribution uniformity.
Regularly calibrate testing equipment to ensure the reliability of particle size data.

Knowledge Development
The latest trend in particle size control is towards the nanoscale (<100nm), which poses a challenge to traditional grinding and classification technologies. For example, wet grinding combined with ultrasonic dispersion can significantly improve the dispersibility of nanopowders, but it is necessary to balance cost and performance. In addition, online monitoring technologies for particle size distribution (such as dynamic light scattering, DLS) are emerging, which is expected to achieve real-time quality management.

The stability of crystal structure and phase composition ensures that
the ideal tungsten carbide powder should be mainly composed of a single WC phase, and its hexagonal crystal structure gives it excellent hardness and wear resistance. The presence of unexpected phases (such as W_2C , W, and free carbon) will significantly reduce the performance of the powder, so the control of crystal structure and phase composition is the top priority of quality management.

Influencing factors
Carbonization temperature: Too high (>1600°C) may cause grain growth and reduce powder activity; too low (<1400°C) may generate W_2C phase .
Carbon source ratio: Insufficient carbon will result in under-carbonization, while excess carbon will produce free carbon.
Reaction atmosphere: Hydrogen atmosphere helps to remove oxygen, but excessive hydrogen should be prevented to prevent grain boundary defects caused by hydrogen.

Detection Technology
X-ray diffraction (XRD): Accurately analyze phase composition and detect the ratio of WC, W_2C and free carbon with a quantitative accuracy of up to 0.1%.
Scanning electron microscopy (SEM): observes grain morphology, size and surface defects, and

evaluates the uniformity of the crystal structure.
Transmission electron microscopy (TEM): used for crystal structure analysis of nanoscale powders, revealing atomic-scale defects.
Raman spectroscopy: Assists in detecting the presence of free carbon, especially suitable for ultrafine powders.

Safeguards
Precisely control the temperature gradient (heating rate 5-10°C/min) and holding time (2-4 hours) of the carbonization furnace.
A high-purity carbon source (such as graphite powder, purity ≥ 99.9%) is preferred to reduce the impact of impurities on the crystal structure.
Use atmosphere protection (such as argon or hydrogen mixed atmosphere) to prevent oxidation or decarburization.
Establish a database of phase composition and track structural changes under different process conditions.

Knowledge Development
With the development of high-resolution analytical techniques, such as synchrotron XRD and neutron diffraction, researchers can more accurately characterize the crystal defects and stress distribution of tungsten carbide powder. These techniques provide new ideas for optimizing the carburization process, especially in the aerospace field, where the purity of a single WC phase is required to be close to 100%.

Optimization design of powder fluidity and apparent density
The fluidity of powder affects the efficiency of pressing and the uniformity of mold filling, while the apparent density is closely related to the sintering shrinkage and product density. High-quality tungsten carbide powder needs to strike a balance between fluidity and density to meet the needs of different molding processes.
Importance of flowability: Powders with poor flowability may cause delamination or voids in the compact, reducing product strength. The Hall flow rate of high-quality powders is usually in the range of 15-25 seconds/50g. Ultrafine powders have poor flowability due to the strong van der Waals forces between particles, so they need to be specially optimized.

The significance of apparent density
The apparent density reflects the bulk properties of the powder and is usually between 3.0-5.0 g/cm³ . Low apparent density may lead to excessive sintering shrinkage and affect dimensional accuracy; high apparent density may reduce molding performance.

Detection Technology
Hall flow meter: measures the time it takes for powder to pass through a standard funnel. It is easy to operate and suitable for on-site testing.
Tap density meter: measures the volume density of powder after vibration, reflecting the compactness of particle packing.

Rotating drum method: simulates the dynamic behavior of powder during the molding process and evaluates the true flowability.

Optimization strategy

Using spray granulation technology: prepare spherical or nearly spherical powders and significantly improve fluidity.

Adjust particle size distribution: appropriately increase the proportion of fine particles to optimize the filling effect between particles.

Surface modification: Reduce the friction between particles by plasma treatment or adding a small amount of binder (such as paraffin, the addition amount is <0.5%).

Control the moisture content of powder: Too high moisture content will reduce fluidity, it is recommended to control it below 0.1%.

Knowledge expansion: In recent years, the study of fluidity has gradually been integrated into computer simulation technology, such as the discrete element method (DEM), which can simulate the flow behavior of powder in the mold and predict the risk of delamination. This provides theoretical support for optimizing granulation process and mold design, which is especially important in automated production.

Systematic management of environment and storage conditions

Tungsten carbide powder is highly sensitive to humidity and oxygen. Improper storage may lead to oxidation, moisture absorption or performance degradation. Scientific environmental management is the key to extend the life of powder and ensure stable quality.

Oxidation risk: Oxygen reacts with tungsten carbide powder to form tungsten oxide (WO_3), which reduces the activity of the powder and even causes sintering defects. Ultrafine powders have a greater oxidation risk due to their high specific surface area.

Moisture absorption problem: Water adsorption can cause powder agglomeration and reduce fluidity. In severe cases, it may trigger chemical reactions and generate hydroxides.

Environmental requirements:

Temperature: Keep the storage environment at 15-25°C to avoid high temperature that accelerates oxidation.

Humidity: Relative humidity should be controlled at 30%-50% to prevent moisture absorption.

Light: Avoid strong light exposure to prevent photochemical reactions on the powder surface.

Management measures

Vacuum packaging or nitrogen packaging: isolate air and moisture to extend storage life.

Equipped with dehumidification equipment: such as molecular sieve or silica gel desiccant to maintain a low humidity environment.

Check storage conditions regularly: use a thermo-hygrometer and an oxygen analyzer, and record environmental parameters.

Optimize the transportation process: use shock-proof and moisture-proof composite packaging materials to prevent powder from being damaged.

Establish storage files: record the storage time, environmental conditions and performance changes of each batch of powder.

Knowledge expansion: Modern storage technology is developing in the direction of intelligence. For example, the Internet of Things (IoT) technology can monitor the temperature and humidity of the storage environment in real time and analyze the aging trend of the powder through cloud computing. This not only improves storage efficiency, but also provides data support for quality traceability.

Quality traceability and digital management

In the era of Industry 4.0, quality control emphasizes the traceability of the entire process and data-driven decision-making. Digital management provides a new path for quality optimization of tungsten carbide powder by integrating production, testing and storage data.

Traceability system:

Batch management: Assign a unique identifier to each batch of powder, record the source of raw materials, production parameters and test results.

Blockchain technology: ensures that data cannot be tampered with and enhances the credibility of quality certification.

Digital tools:

Online monitoring: such as real-time particle size analyzers and chemical composition detectors to detect process deviations in a timely manner.

Statistical Process Control (SPC): Analyze the patterns of quality fluctuations and optimize process parameters.

Artificial Intelligence (AI): Predict powder properties through machine learning to assist process improvement.

Implementation strategy:

Establish an Enterprise Resource Planning (ERP) system to integrate production and quality data.

Train employees to master data analysis tools and improve digital management capabilities.

Cooperate with testing agencies and introduce third-party verification to ensure the objectivity of data.

Knowledge expansion: The latest progress in digital management includes digital twin technology, which simulates the production process of tungsten carbide powder through virtual models and predicts quality risks. This technology has been applied in large tungsten companies in Europe and the United States and is expected to be promoted in China in the future.

5.2 International Standards

International standards provide a global framework for the quality control of tungsten carbide powder, ensuring the consistency and comparability of products in different countries and markets. These standards are formulated by authoritative organizations, covering chemical composition, physical properties, test methods and other aspects, and are widely used in cemented carbide, coating and tool

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

manufacturing. The following detailed analysis of the main international standards and their application scenarios is intended to provide readers with a clear reference.

ISO Standards

The International Organization for Standardization (ISO) has developed a series of standards for cemented carbide powders, emphasizing the scientific nature of the testing methods and the repeatability of the results. These standards have a wide influence worldwide, especially in the EU and Asian markets.

ISO 4499-1:2008 : Cermet powders for cemented carbides – Methods of chemical analysis.
Content explanation: This standard specifies the determination methods of total carbon, free carbon, oxygen, iron, cobalt, calcium and other elements, and recommends the use of high-precision technologies such as ICP-MS (detection limit 10ppb) and infrared absorption method (oxygen content accuracy 0.01%). The standard also puts forward strict requirements for sample pretreatment (such as acid dissolution and drying) to eliminate interference factors.
Application Scenario
Suitable for export-oriented cemented carbide production enterprises, especially in the fields of aerospace and medical devices, where the purity of chemical composition is extremely high.
Advantages and Challenges
The standard method is scientific and rigorous, but has high requirements for testing equipment (such as ICP-MS), and small and medium-sized enterprises may face cost pressure.

ISO 4499-2:2008: Cermet powders for cemented carbides – Tests on physical properties.
Content details: Covers the test specifications for particle size distribution, apparent density, tap density, and fluidity. It recommends the use of a laser particle size analyzer (measuring range 0.01-1000μm) and a Hall flow meter (accuracy ±0.1 second). The standard also clearly stipulates the temperature and humidity of the test environment (20±2°C, humidity <50%).
Application scenarios: Suitable for evaluating the molding performance of powders, especially in the field of high-precision tools and 3D printing, where the uniformity of particle size distribution is crucial.
Advantages and Challenges: The standard operation is simple and the results are highly comparable, but there is a lack of detailed guidance on the agglomeration problem of ultrafine powders, and other methods (such as SEM) need to be combined for auxiliary analysis.

ISO 3326:2013: Cemented carbides – Method for determination of hardness.
Content explanation: Although it is mainly aimed at cemented carbide finished products, it indirectly affects the quality requirements of tungsten carbide powder. The standard specifies the test methods for Vickers hardness (HV) and Rockwell hardness (HRA), emphasizing the contribution of the stability of the powder crystal structure to hardness.
Application scenarios: Suitable for high-end applications such as aerospace tools and wear-resistant parts, the crystal purity of the powder needs to reach more than 99.9%.
Advantages and challenges: The standard provides a reference for the performance of finished products, but there is less direct testing guidance for powders, so it needs to be used in conjunction with other

standards.

Knowledge expansion: ISO standards have been continuously updated in recent years. For example, the revised version of ISO 4499-2020 adds the detection method for nanopowders, reflecting the rapid growth of the ultrafine tungsten carbide powder market. Enterprises need to pay attention to the latest version to adapt to technological advances.

ASTM Standards

American Society for Testing and Materials (ASTM) standards are known for the accuracy and practicality of their experimental methods and are widely used in the North American market, especially in the cemented carbide and coating industries.

ASTM B761-17: Test method for particle size distribution of tungsten carbide powder.

Content explanation: The standard describes in detail the operating steps of laser light scattering and sieving methods, which are applicable to powders of 0.1-100μm. Laser light scattering is based on Mie scattering theory, with high precision and suitable for ultrafine powders; sieving is simple to operate and suitable for coarse powders. The standard also provides specific recommendations for sample dispersion (such as ultrasonic treatment).

Application scenarios: Suitable for 3D printing, thermal spraying and nano-coating fields. The uniformity of particle size distribution directly affects the printing quality and coating performance.

Advantages and Challenges: The standard method is mature and the equipment penetration rate is high, but it has high requirements for the agglomeration control of ultrafine powders and needs to be used with a dispersant.

ASTM E194-10: Determination of oxygen content in powder metallurgy materials.

Content explanation: The oxygen content is determined by the inert gas fusion method, with a detection limit as low as 1ppm, which is suitable for high-purity powders. The standard requires the use of a high-frequency induction furnace (power > 2kW) to melt the sample, release oxygen and analyze it with an infrared detector.

Application scenarios: Suitable for high-performance cemented carbide and aerospace materials. The oxygen content needs to be controlled at 0.05%-0.1% to prevent sintering defects.

Advantages and challenges: The detection accuracy is extremely high and suitable for high-end applications, but the equipment cost is relatively high (about RMB 500,000 to 1,000,000) and requires professional operation.

ASTM B659-90(2014): Guide for measuring the thickness of metallic and inorganic coatings.

Content explanation: Although it is mainly aimed at coatings, it indirectly regulates the quality requirements of tungsten carbide powder, emphasizing the influence of powder particle size uniformity and chemical stability on coating quality. The standard recommends the use of microscopy and X-ray fluorescence to measure coating thickness.

Application scenarios: Suitable for thermal spraying, plasma spraying and laser cladding. The apparent density and fluidity of the powder need to be optimized to ensure uniform coating.

Advantages and Challenges: The standard provides indirect guidance for coating applications, but has less direct testing content for powders and needs to be combined with other standards.
Knowledge expansion: ASTM standards focus on practical applications, and in recent years have added specifications for additive manufacturing (3D printing), such as

ASTM F3049 indirectly involves the particle size and fluidity requirements of tungsten carbide powder. This reflects the rapid response of the standard to emerging technologies.

In addition to ISO and ASTM, some countries and regions have also formulated relevant standards for tungsten carbide powder, combining local industrial characteristics to supplement the global standard system.

JIS Z 2503:2015 (Japanese Industrial Standard):
Content explanation: Covers the test methods of chemical composition (total carbon, oxygen, impurities), particle size distribution and physical properties (apparent density, fluidity) of tungsten carbide powder. The standard emphasizes the stability of the production process and requires the recording of the carbonization temperature and atmosphere conditions of each batch of powder.
Application scenarios: Suitable for cemented carbide and coating production in the Japanese and Korean markets, especially in the automotive and electronics industries.
Advantages and challenges: The standard combines the equipment level of the Asian market and has a lower implementation cost, but its internationalization level is not as high as ISO.

DIN EN ISO 4499 (German standard):
Content explanation: It is highly consistent with the ISO 4499 series, supplementing the requirements for production equipment calibration (such as annual calibration of XRD instruments) and environmental control (such as humidity in the production workshop <40%). The standard also refines the detection method for ultrafine powders.
Application scenarios: Widely used in European countries such as Germany and Austria, especially in the fields of precision machinery and aerospace.
Advantages and Challenges: The standard focuses on process details and is suitable for technology-intensive enterprises, but is less applicable to small and medium-sized enterprises.

BS EN Standards (British Standards):
Content explanation: Partially refer to ISO 4499 and ASTM standards, emphasizing the performance testing of powder in cutting tools, such as hardness, wear resistance and impact resistance. The standard also makes recommendations on the storage conditions of powder (such as vacuum packaging).
Application scenarios: Applicable to market certification in the UK and Commonwealth countries, especially in the shipping and energy industries.
Strengths and Challenges: The standard is comprehensive, but highly regional and has limited international influence.
Knowledge expansion: The trend of international standard coordination is becoming increasingly

obvious. For example, the joint revision of ISO and DIN has made DIN EN ISO 4499 more widely used in the European market. In the future, international standards may be further integrated to form a unified global specification.

Application characteristics and trends:
Global applicability: ISO and ASTM standards are authoritative and scientific, making them suitable for multinational companies and export products, especially in the European and American markets.

Technical threshold: International standards have high requirements for testing equipment and personnel quality, which is suitable for companies with strong technical strength, but small and medium-sized enterprises may need to gradually upgrade their equipment.
Regional adaptation: JIS and BS EN standards are closer to local needs, have lower implementation costs, and are suitable for regional markets.
Future Outlook: With the rise of nanopowders and additive manufacturing, international standards are moving towards a more detailed direction, such as adding test methods for nano-scale particle size and surface chemistry. Enterprises need to pay close attention to standard updates to stay ahead of the technology.

5.3 Domestic Standards

China has established a complete standard system for the quality control of tungsten carbide powder, including national standards (GB/T), industry standards (YB/T, HG/T, JB/T), and local and enterprise standards. These standards combine the actual situation of China's tungsten industry, balance technical requirements and production costs, and are widely used in cemented carbide, coatings, tools and metallurgical industries. The following is a detailed analysis of the content, characteristics and application scenarios of domestic standards.

National Standard
National Standard (GB/T) is the basic specification for quality control of tungsten carbide powder in China. It has both mandatory and guiding attributes, covering multiple links from raw materials to finished products.

GB/T 4295-2018: Tungsten carbide powder.
Content explanation: The standard specifies the chemical composition (such as total carbon 6.08-6.18%, free carbon ≤0.1%, oxygen ≤0.2%), particle size range (0.5-30μm), apparent density (3.0-5.0 g/cm³), fluidity (15-25 seconds/50g) and other technical requirements of tungsten carbide powder. The detection methods include chemical analysis (combustion method, titration method), physical testing (laser particle size analysis, Hall flow meter) and microscopic analysis (XRD, SEM). The standard also makes recommendations on packaging and storage, such as vacuum packaging and storage humidity <50%.
Application scenarios: Applicable to all aspects of domestic cemented carbide, coating and tool production, and is the core basis for industry quality management.

Advantages and challenges: The standard is comprehensive and covers a variety of application scenarios, but the specifications for ultrafine powders (<0.5μm) are slightly insufficient and need to be supplemented by other standards.

GB/T 26046-2010: Tungsten carbide powder for cemented carbide.
Content explanation: Tungsten carbide powder is divided into multiple grades according to particle size and purpose (such as WC-01 for ultra-fine tools, WC-04 for wear-resistant parts), and the requirements for chemical composition (oxygen ≤ 0.15%), particle size distribution (D50 deviation ± 5%) and physical properties (apparent density 4.0-5.0 g/cm ³) are refined. The standard also stipulates the calibration cycle of the testing equipment (once a year).
Application scenarios: Suitable for cemented carbide products with different performance requirements, such as ultra-fine powder for PCB drill bits and coarse powder for mining tools.
Strengths and Challenges: The standard has clear classification and can adapt to diverse needs, but there is less guidance on emerging applications (such as 3D printing) and further updates are needed.

GB/T 18508-2013: Inspection methods for powder metallurgy products for cemented carbide.
Content explanation: Although it is mainly aimed at cemented carbide products, it indirectly regulates the quality requirements of tungsten carbide powder. The standard covers the test methods of hardness (HV, HRA), density, porosity, and microstructure, and emphasizes the influence of powder crystal structure and chemical composition on the performance of finished products.
Application scenarios: Suitable for quality verification of carbide tools, molds and wear-resistant parts, providing an indirect reference for powder quality.
Advantages and Challenges: The standard provides a basis for the performance of finished products, but contains less direct testing content for powders and needs to be used in conjunction with GB/T 4295.
Knowledge expansion: National standards have been continuously revised in recent years. For example, GB/T 4295-2023 (Draft) has added new testing requirements for nanopowders, reflecting China's technological progress in the field of high-end tungsten materials. Enterprises need to pay attention to the revision dynamics to adapt to market demand.

Industry standards
Industry standards (YB/T, HG/T, JB/T) refine the quality requirements for specific fields, supplement the lack of universality of national standards, and are widely used in the metallurgical, chemical and mechanical industries.

YB/T 429-2012: Tungsten carbide powder for metallurgy.
Content explanation: Aiming at the special needs of the metallurgical industry (such as rollers and molds), the standard emphasizes the corrosion resistance (acid and alkali resistance), high temperature stability (>1000°C) and particle size range (5-20μm) of the powder. The detection methods include chemical analysis (total carbon, oxygen), high temperature performance test (thermal expansion coefficient) and wear resistance test (abrasion test).
Application scenarios: Suitable for heavy machinery, metallurgical equipment and wear-resistant parts

production, especially in the steel and non-ferrous metal industries.
Advantages and challenges: The standard is highly targeted and meets the special needs of the metallurgical industry, but its applicability to ultrafine powders is low and needs to be combined with other standards.

HG/T 2838-2012: Tungsten carbide powder for chemical industry.
Content explanation: For the chemical industry (such as catalysts, corrosion-resistant coatings), the standard specifies the chemical purity (total carbon 6.10-6.15%, impurities ≤50ppm), particle size (1-5μm) and surface activity (specific surface area 5-10 m^2 / g) of the powder. The detection methods include BET method (specific surface area), chemical titration (impurities) and SEM (surface morphology).
Application scenarios: Suitable for acid and alkali resistant coatings, catalyst carriers and chemical reactors, especially in the petrochemical industry.
Advantages and challenges: The standard focuses on surface properties and is suitable for chemical applications, but has fewer specifications for physical properties (such as fluidity).

JB/T 12614-2016: Ultrafine tungsten carbide powder for cemented carbide.
Content explanation: For powders with a particle size of less than 1μm, the standard specifies the requirements for particle size distribution (D90/D10<2), oxygen content (≤0.1%), and grain size (<200nm). The detection methods include TEM (grain analysis), laser particle size analysis, and infrared absorption (oxygen content). The standard also makes recommendations on agglomeration control, such as the use of dispersants.
Application scenarios: Suitable for high-end markets such as micro drills, electronic components and nano coatings.
Advantages and Challenges: The standard closely follows the technological trend of ultrafine powders, but the detection cost is relatively high (TEM equipment costs about RMB 2 million) and requires high technical support.
Knowledge expansion: The formulation of industry standards pays more and more attention to cross-field integration. For example, HG/T 2838-2020 (revised version) has added specifications for tungsten carbide-based composite powders, reflecting the cross-development of chemical engineering and materials science.

Local and enterprise standards

Local and enterprise standards combine regional industrial characteristics and enterprise technological advantages to refine quality control requirements and make up for the lack of universality of national standards.
Local standards:

DB43/T 1025-2015: Hunan Province "Tungsten Carbide Powder Quality Control Specification".
Content explanation: Based on the actual situation of Zhuzhou Tungsten Industrial Base, the standard specifies the chemical composition (oxygen ≤ 0.08%), particle size distribution (D50 deviation ± 3%) and storage conditions (humidity < 40%) of ultrafine powders (< 0.5 μm) and nano powders (< 100 nm).

The detection methods include XPS (surface chemistry), TEM and online particle size analysis.

Application scenarios: Suitable for tungsten industry concentrated areas such as Hunan and Jiangxi, especially in the production of high-end tools and coatings.

Advantages and challenges: The standard is close to actual production and has low implementation costs, but it is highly regional and needs to be used in conjunction with national standards.

Application characteristics and trends:

Close to reality: Domestic standards fully consider local raw materials (low-grade tungsten ore) and equipment levels (domestic instruments are mostly used), and the implementation cost is relatively low.

Clear levels: national standards have a wide coverage, industry standards are specialized, and local and enterprise standards are flexible, forming a multi-level regulatory system.

Internationalization trend: With the globalization of China's tungsten industry, domestic standards are moving closer to ISO and ASTM, especially in the fields of ultrafine powders and high-end applications.

Future Outlook: Domestic standards will further incorporate environmental protection requirements (such as carbon emission control) and intelligent technologies (such as online quality monitoring) to support green manufacturing and intelligent manufacturing.

5.4 Standard comparison and applicability

Domestic and foreign standards have both similarities and significant differences in the quality control of tungsten carbide powder. The commonality is that they all emphasize the control of chemical composition, particle size distribution, crystal structure and physical properties; the differences are reflected in the emphasis on technical requirements, testing methods and application scenarios. The following comparative analysis from multiple dimensions and the applicability of each standard are discussed to provide guidance for enterprises to choose appropriate specifications.

Comparison of chemical composition requirements

International Standards:

ISO 4499-1:2008: Total carbon deviation ±0.05%, free carbon ≤0.08%, oxygen ≤0.15%, impurities (such as iron, cobalt) ≤10ppm.

ASTM E194-10: The oxygen content detection limit is 1ppm, emphasizing ultra-high purity, suitable for the aerospace field.

Features: Extremely strict requirements, high detection accuracy, and the need to be equipped with advanced equipment (such as ICP-MS, which costs about 1 million RMB).

Domestic standards:

GB/T 4295-2018: Total carbon deviation ±0.1%, free carbon ≤0.1%, oxygen ≤0.2%, impurities (such as iron) ≤50ppm.

YB/T 429-2012: The impurity limit is relatively loose (such as iron ≤ 100ppm), which adapts to the reality of low grade local tungsten ore.

Features: relatively loose requirements, taking into account cost control, suitable for mass production.

Difference analysis: International standards pursue ultimate purity and are suitable for the high-end market; domestic standards are more inclusive and reduce raw material and testing costs.

applicability:

Export products: must meet ISO or ASTM standards to pass certification in markets such as the EU and North America.
Domestic market: GB/T 4295 is sufficient for conventional cemented carbide and coating production and is more cost-effective.
High-end applications: aerospace, medical equipment must adopt international standards or internal enterprise standards (such as oxygen ≤ 0.05%).
Knowledge expansion: The control of chemical composition is developing in the direction of intelligence. For example, German companies use AI-assisted ICP-MS systems to analyze impurity fluctuations and adjust process parameters in real time. This technology is expected to be introduced to China in the next five years.

Comparison of Granularity Control
International Standards:
ASTM B761-17: requires uniform particle size distribution (D90/D10<2), D50 deviation ±5%, and recommends laser light scattering method (accuracy 0.01μm).
ISO 4499-2:2008: refines the test method for ultrafine powders (<1μm) and emphasizes agglomeration control.
Features: Focus on distribution uniformity, suitable for high-precision applications, and high requirements for testing equipment (laser particle size analyzer costs about RMB 500,000).
Domestic standards:
GB/T 26046-2010: The particle size is divided into multiple intervals (such as 0.5-1μm, 1-3μm), the D50 deviation is ±10%, and the screening method is allowed.
JB/T 12614-2016: For ultrafine powders, D90/D10<2.5, it is recommended to combine laser particle size analysis and TEM.
Features: Classification management is more flexible, taking into account traditional methods (such as screening method, costing about RMB 10,000), and is suitable for small and medium-sized enterprises.
Difference analysis: International standards emphasize high precision and consistency, while domestic standards focus on diversity and practicality.
applicability:
Precision tools and 3D printing: ASTM or ISO standards are required to ensure extremely uniform particle size distribution.
Conventional cemented carbide: The classification management of GB/T 26046 is more economical and meets various needs.
Ultrafine powder: JB/T 12614 combines international standards and is suitable for high-end markets.
Knowledge expansion: The latest trend in particle size control is the introduction of multimodal analysis, such as combining laser light scattering and dynamic light scattering (DLS), which can simultaneously characterize particle size and agglomeration state. This technology has been popularized in Europe and the United States and is expected to be promoted in China after 2025.

Comparison of test methods
International Standards:

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

ISO 4499 series: Priority is given to the use of high-precision instruments, such as laser particle size analyzers, ICP-MS, and infrared absorption methods, and strict testing environment requirements (temperature 20±1°C, humidity <40%).
ASTM E194-10: emphasizes the standardization of methods, equipment requires annual calibration, and the detection limit is as low as ppm level.
Features: High detection accuracy and strong comparability of results, but high equipment and maintenance costs (average annual maintenance fee is approximately RMB 100,000).
Domestic standards:
GB/T 4295-2018: takes into account both traditional methods (such as screening, chemical titration) and modern instruments (such as domestic laser particle size analyzers, which cost about RMB 200,000).
YB/T 429-2012: The requirements for equipment calibration are relaxed (once every 2 years) and the testing cost is low (chemical titration equipment costs about RMB 50,000).
Features: diverse methods, low cost, suitable for enterprises of different sizes.
Difference analysis: International standards pursue extreme precision, while domestic standards focus on practicality and economy.
applicability:
Companies with strong technical strength can directly adopt ISO or ASTM standards to meet the requirements of international customers.
Small and medium-sized enterprises: The hybrid approach of GB/T 4295 is easier to implement and requires less equipment investment.
Emerging fields, such as nanopowders, require a combination of high-precision methods based on international standards and the flexibility of domestic standards.
Knowledge expansion: The digital transformation of testing methods is accelerating. For example, American companies use online XRD systems to monitor phase composition in real time with an error of less than 0.05%. Chinese companies are piloting similar technologies and expect to achieve industrialization in 2026.

Applicability Analysis
Export-oriented enterprises:
Recommended standards: ISO 4499 series, ASTM B761/E194.
Reason: International standards are authoritative in the European and American markets, and the strict requirements for chemical composition and particle size control can meet the needs of high-end customers (such as Boeing and Airbus).
Implementation suggestions: Invest in high-precision equipment (such as ICP-MS, laser particle size analyzer), train professional testing personnel, and establish an international quality management system (such as ISO 9001 certification).
Domestic Market:
Recommended standards: GB/T 4295-2018, GB/T 26046-2010, YB/T 429-2012.
Reason: Domestic standards take into account both cost and performance, are suitable for mass production, and cover a variety of applications for cemented carbide, coatings, and tools.
Implementation suggestions: Give priority to the use of domestic equipment (such as Beijing Precision

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

Laser Particle Size Analyzer, priced at about RMB 200,000), and optimize the process in combination with local standards (such as DB43/T 1025).

High-end applications:

Recommended standards: ISO 4499-1/2, ASTM E194, corporate standards (such as Q/ZH 001-2020).

Reason: Aerospace, medical devices and other fields require extremely high purity and consistency. International standards and corporate standards can provide more stringent indicators (such as oxygen ≤0.05%, particle size deviation ±2%).

Implementation suggestions: Introduce advanced detection technologies (such as TEM and synchrotron radiation XRD), establish full-process digital management, and implement 6σ quality control.

Emerging fields:

Recommended standards: JB/T 12614-2016, ISO 4499-2020 (revised edition), Q/ZG 002-2021.

Reason: 3D printing, nano-coating and biomedicine have put forward new requirements for the sphericity, surface chemistry and fluidity of powders, and the latest standards are more targeted.

Implementation suggestions: Invest in special equipment (such as CT scanners, BET surface area meters), participate in standard setting (such as cooperation with China Tungsten High-Tech), and seize the technological high ground.

Development Trend

Internationalization of standards

As the global influence of China's tungsten industry increases, domestic standards are moving closer to ISO and ASTM. For example, GB/T 4295-2023 (draft) refers to the nanopowder specification of ISO 4499-2020 and is expected to be officially released in 2025.

Environmental orientation

Future standards will incorporate green manufacturing requirements, such as controlling carbon emissions during the carbonization process (target <2 tons CO_2 / ton powder) and promoting low-energy consumption processes (such as microwave carbonization).

Intelligent upgrade

Online monitoring (such as real-time particle size analysis, AI-assisted phase analysis) and digital twin technology will be integrated into the standards to improve quality control efficiency. For example, the German TÜV certification has required companies to submit digital quality reports.

Customized needs: For new fields such as 3D printing and biomedicine, the standard will refine the indicators of powders for specific purposes, such as the flowability of spherical powders (<10 seconds/50g) and the surface activity of nanopowders (>20 m² / g).

Knowledge Development

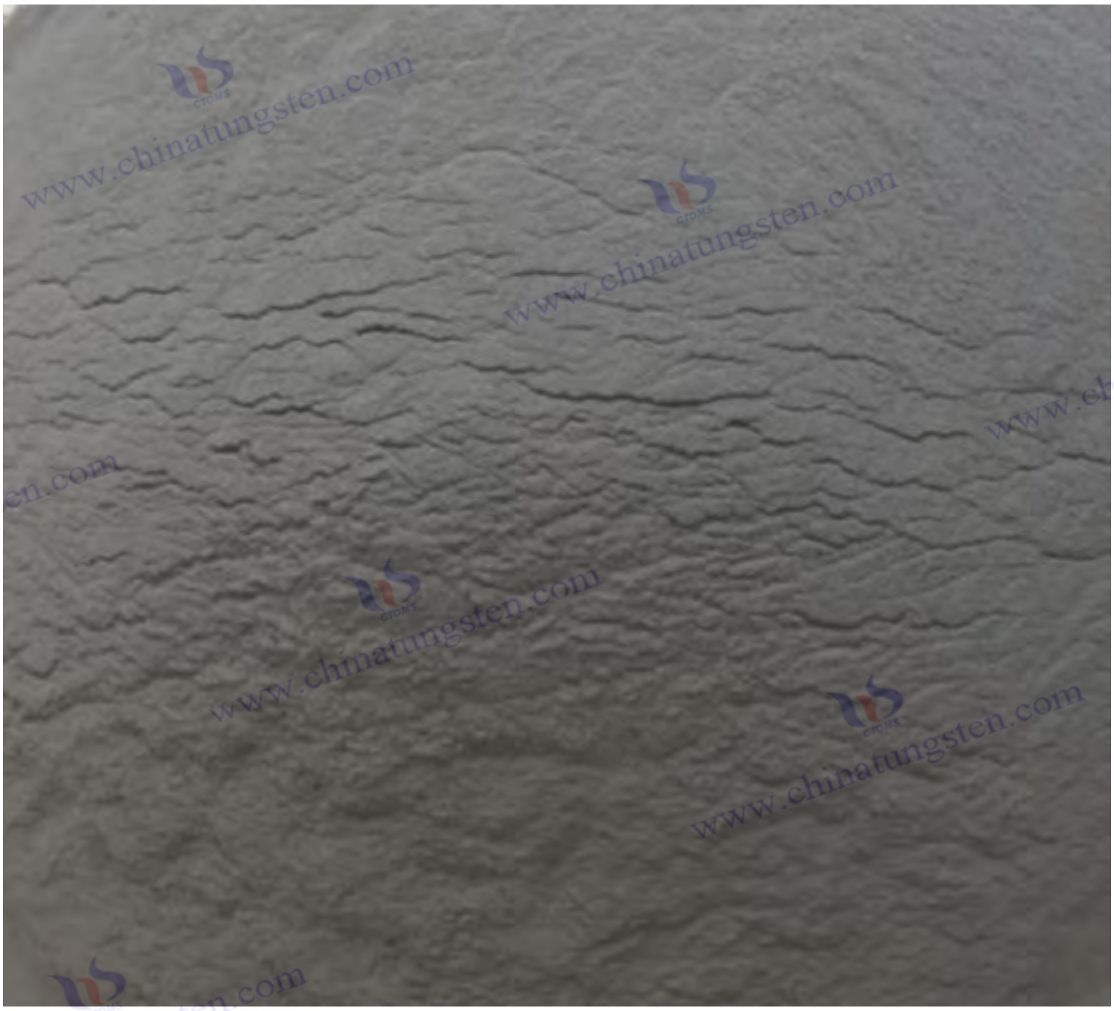
Global collaboration on standardization is accelerating. For example, ISO and ASTM jointly established the “Additive Manufacturing Materials Working Group”, in which Chinese companies (such as Zhuzhou Cemented Carbide Group) have participated. This provides new opportunities for the internationalization of domestic standards.

References

Li Ming. Cemented Carbide Materials[M]. Beijing: Metallurgical Industry Press, 2018.

Li Ming. Materials Science of Cemented Carbide [M]. Beijing: Metallurgical Industry Press, 2018.
Zhang Li, Wang Chuanhui. Progress in Preparation Technology of Tungsten Carbide Powder[J]. Powder Metallurgy Technology, 2020, 38(2): 88-94.
Zhang Li, Wang Chuanhui. Advances in Preparation Technology of Tungsten Carbide Powder [J]. Powder Metallurgy Technology, 2020, 38(2): 88-94.
Wang Qiang, Li Ming. Research on China's cemented carbide standard system[J]. China Tungsten Industry, 2019, 34(3): 45-50.
Wang Qiang, Li Ming. Study on the Standard System of Chinese Cemented Carbide [J]. China Tungsten Industry, 2019, 34(3): 45-50.
Li Zhiqiang, Zhang Wei. Comparative analysis of international and domestic standards for tungsten carbide powder[J]. Materials Science and Engineering, 2021, 39(4): 112-118.
Li Zhiqiang, Zhang Wei. Comparative Analysis of International and Domestic Standards for Tungsten Carbide Powder [J]. Materials Science and Engineering, 2021, 39(4): 112-118.
Chen Wei, Zhao Gang. Preparation and Properties of Ultrafine Tungsten Carbide Powder[J]. Journal of Inorganic Materials, 2022, 37(5): 567-573.
Chen Wei, Zhao Gang. Preparation and Properties of Ultrafine Tungsten Carbide Powder [J]. Journal of Inorganic Materials, 2022, 37(5): 567-573.
Liu Yang, Wang Zhiqiang. Research on the application of tungsten carbide powder in 3D printing[J]. Additive Manufacturing Technology, 2023, 12(1): 34-40.
Liu Yang, Wang Zhiqiang. Application of Tungsten Carbide Powder in 3D Printing [J]. Additive Manufacturing Technology, 2023, 12(1): 34-40.
ISO 4499-1:2008, Hardmetals — Metallographic determination of microstructure.
ISO 4499-1:2008, Cemented carbides — Methods of determination of microstructure.
ISO 4499-2:2008, Hardmetals — Physical properties testing.
ISO 4499-2:2008, Cemented carbides — Tests for physical properties.
ISO 3326:2013, Hardmetals — Determination of hardness.
ISO 3326:2013, Cemented carbides — Determination of hardness.
ASTM B761-17, Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering.
ASTM B761-17, Light Scattering Test Method for Particle Size Distribution of Metal Powders and Related Compounds.
ASTM E194-10, Standard Test Method for Determination of Oxygen in Metallic Powders.
ASTM E194-10, Test Method for Determination of Oxygen Content in Metal Powders.
ASTM B659-90(2014), Standard Guide for Measuring Thickness of Metallic and Inorganic Coatings.
ASTM B659-90(2014), Guide for Measuring Thickness of Metallic and Inorganic Coatings.
Smith J, Brown T. Advances in Tungsten Carbide Powder Production [J]. Journal of Materials Science, 2020, 55(12): 4567-4578.
Smith J, Brown T. Advances in production technology of tungsten carbide powder[J]. Journal of Materials Science, 2020, 55(12): 4567-4578.
Johnson R, Lee K. Quality Control Standards for Tungsten Carbide in Additive Manufacturing [J]. Additive Manufacturing, 2022, 48: 102456.

Johnson R, Li K. Quality control standards for tungsten carbide in additive manufacturing[J]. Additive Manufacturing, 2022, 48: 102456.
Müller H, Schmidt P. Materialwissenschaft und Werkstofftechnik, 2019, 50 (6): 789-796.
Mueller H, Schmidt P. Quality control of tungsten carbide powders: specifications and procedures[J]. Materials Science and Engineering Technology, 2019, 50(6): 789-796.
Bauer T, Weber S. Herstellung und Charakterisierung von ultrafeinem Wolframcarbidpulver [M]. Berlin: Springer, 2021.
Bauer T, Weber S. Preparation and characterization of ultrafine tungsten carbide powders[M]. Berlin: Springer-Verlag, 2021.
Japanese literature (including Chinese translation)
Taro Yamada, Ichiro Sato. Research on quality control standards for carbonized powders [J]. Journal of the Society for Powder Engineering, 2020, 57(3): 123-130.
Yamada Taro, Sato Ichiro. Research on quality control standards of tungsten carbide powder[J]. Journal of Powder Engineering Society, 2020, 57(3): 123-130.
Ken Nakamura, Yu Kobayashi. Evaluation of characteristics of ultrafine carbonized タングステン powder[J]. Journal of Materials Science, 2022, 71(5): 345-352.
Nakamura, Ken, Kobayashi, Yu. Performance evaluation of ultrafine tungsten carbide powder[J]. Journal of Materials Science Society, 2022, 71(5): 345-352.



Chapter 6: Performance Optimization and Modification of Tungsten Carbide Powder

As the core component of high-performance materials such as cemented carbide, cutting tools, and wear-resistant coatings, the performance optimization and modification technology of tungsten carbide powder is of decisive significance for improving the mechanical properties, corrosion resistance, and high-temperature stability of the final product. With the rapid development of advanced manufacturing technology, the performance of traditional tungsten carbide powder has been difficult to meet the stringent requirements of aerospace, additive manufacturing, microelectronics, and other fields. Therefore, through particle size optimization, doping and composite modification, surface modification, heat treatment and annealing, etc., the microstructure and macroscopic properties of tungsten carbide powder are systematically improved, which has become the research frontier in the field of materials science and engineering. This chapter deeply analyzes the theoretical basis, process methods, application effects, and future trends of performance optimization from four aspects: particle size optimization, doping and composite modification, surface modification technology, and heat treatment and annealing, aiming to provide a comprehensive technical reference for academic research and industrial practice.

6.1 Particle size optimization

The particle size and distribution of tungsten carbide powder are key parameters that affect its pressing behavior, sintering performance and the microstructure of the final product. By precisely controlling the particle size, the uniformity and fluidity of the powder as well as the hardness, toughness and wear resistance of the cemented carbide can be significantly improved. The following systematically explains the role of particle size optimization in improving the performance of tungsten carbide powder from four dimensions: theoretical basis, process technology, quantitative effect and development direction.

Theoretical Basis of Particle Size Optimization
Particle size directly affects the specific surface area, sintering activity and grain size of tungsten carbide powder, which in turn determines the mechanical properties and processing characteristics of the material.

Hall-Petch effect: According to the Hall-Petch relationship, the reduction of grain size can significantly increase the yield strength and hardness of the material. For example, the hardness of cemented carbide prepared by ultrafine tungsten carbide powder (particle size <1μm) can reach HV 2000-2200, which is about 60% higher than the HV 1200-1500 of coarse powder (>10μm).

Sintering kinetics: Fine-particle powders have a higher specific surface area (5-20 m² / g), which increases the diffusion rate driven by surface energy. The sintering temperature can be reduced from the conventional 1450°C to 1300-1350°C, reducing energy consumption by about 15% and reducing the risk of grain growth.
Uniformity of particle size distribution: Narrow particle size distribution (D90/D10<2) can ensure uniform shrinkage during sintering, reduce porosity to less than 1%, and significantly improve product dimensional accuracy (deviation ±10μm). Wide distribution may lead to localized uneven shrinkage and cause microcracks.

Adaptability to application scenarios: Ultrafine powder (<0.5μm) is suitable for high-precision cutting tools and microelectronic components, medium particle size (3-10μm) is suitable for wear-resistant coatings and molds, and coarse particle size (>10μm) is used for thermal spraying and mining tools to meet the mechanical requirements under different working conditions.

Process technology for particle size optimization
In response to different particle size requirements, a variety of process technologies have been developed to achieve precise control of powders.

High Energy Ball Milling Technology
Dry ball milling: planetary ball mill is used, the grinding medium is tungsten carbide ball (hardness>90HRA), the ball-to-material ratio is 10:1, the rotation speed is 400-600rpm, the grinding time is 12-24 hours, and the medium particle size powder of 3-10μm can be prepared.
Wet ball milling: It is carried out in ethanol or acetone medium, adding dispersants (such as polyethylene

glycol, PEG, added amount 0.2%-0.6%), and the grinding time is 8-16 hours. Ultrafine powder (0.5-1μm) can be prepared, and the agglomeration rate is controlled below 5%.
Quantitative effect: Wet ball milling combined with ultrasonic dispersion can reduce the average particle size from 2.5μm to 0.7μm, increase the sintering density of the powder by 10%, and improve the fracture toughness of the cemented carbide by about 12%.

Airflow classification technology
Process principle: Using a centrifugal airflow classifier, by adjusting the airflow velocity (15-50 m/s) and the classifying wheel speed (8000-20000rpm), the powder of 0.5-10μm can be screened, and the classification efficiency can reach 92%.
Technical advantages: High classification accuracy, D50 deviation is controlled within ±0.03μm, which is better than the ±0.2μm of traditional screening method.
Application example: A company optimized the D90/D10 of ultrafine powder from 2.8 to 1.7 through airflow classification. The product is used in high-precision PCB drill bits, and the qualified rate of finished products increased by 15%.

Plasma spheroidization technology
Process principle: Use high-frequency plasma (power 20-60kW) to melt irregular particles and quickly solidify them to form spherical powder with uniform particle size, ranging from 0.5-5μm.
Technical advantages: The fluidity of spherical powder is improved by 35% (Hall flow rate is reduced to 14 seconds/50g), which is suitable for additive manufacturing and thermal spraying.
Application example: A company used plasma spheroidization to prepare 0.8μm powder. The surface roughness (Ra) of the coating was reduced from 0.5μm to 0.2μm, and the wear resistance was improved by 18%.

Chemical Vapor Deposition (CVD) Control
Process principle: By controlling the flow ratio (1:1.3-1:1.6) of tungsten source (such as WF_6) and carbon source (such as CH_4) , ultrafine powder (0.1-0.5μm) is directly generated at 800-1000°C.
Technical advantages: Uniform grain size and low agglomeration rate (<2%), suitable for nanoscale applications.
Technical challenges: The reaction equipment is expensive (about RMB 6 million), and the process parameters need to be precisely controlled (temperature deviation ±5°C).

Quantitative effects and development directions
Quantitative effect: Particle size optimization significantly improves the performance of tungsten carbide powder. For example, the life of cemented carbide tools prepared with ultrafine powder (0.5μm) is extended by 25%-35%, and the application of nano powder (<100nm) in 3D printing improves the printing accuracy to ±8μm.
Technical challenges: The agglomeration problem of ultrafine and nanopowders still needs to be solved, and new dispersants (such as functionalized graphene) and online monitoring technologies (such as dynamic light scattering, with an error of <1%) need to be developed.

Development direction
Scale-up of nanopowders: Exploring microwave-assisted grinding and plasma-enhanced CVD, which is expected to reduce production costs by 20%.
Intelligent process control: Use machine learning models to predict the relationship between grinding time and particle size to optimize process efficiency.
Green manufacturing: Develop low-energy classification technology (such as electromagnetic classification) to reduce carbon emissions (target <1.5 tons CO_2 / ton powder).

6.2 Doping and composite modification

Doping and composite modification optimize the lattice structure, grain boundary characteristics and chemical stability of tungsten carbide powder by introducing foreign elements or second phases, thereby improving its hardness, toughness, corrosion resistance and high temperature performance. This technology has broad application prospects in the fields of aerospace, wear-resistant coatings and energy equipment. The following systematically analyzes the theory and practice of doping and composite modification from four aspects: modification mechanism, process technology, application effect and research trend.

Modification mechanism
Lattice strengthening mechanism: doping elements (such as Ti, Cr, V) replace tungsten atoms in the WC lattice or occupy interstitial positions to form solid solutions, increase lattice distortion energy, and hinder dislocation movement. For example, doping 1% Ti can increase the hardness from HV 1800 to HV 2250, and the strength is increased by about 20%.

$_3C_2$, VC) at the grain boundary , inhibiting grain growth, enhancing grain boundary bonding strength, and improving fracture toughness (from 7 MPa·m $^{1/2}$ to 9 MPa·m $^{1/2}$).

Enhanced chemical stability: Doping with elements such as Ta and Nb can reduce the oxidation rate of powders in high temperature (>800°C) or corrosive environments by forming a stable oxide protective layer. For example, doping with 0.5% Ta can reduce the oxidation weight gain by 30%.

Synergistic effect of composite modification: By introducing other carbides (such as TiC, ZrC) or metal bonding phases (such as Co, Ni), a multiphase composite material is formed to optimize the balance between hardness and toughness. For example, the hardness of WC-TiC-Co composite powder reaches HV 1900 and the toughness reaches 11 MPa·m $^{1/2}$, which is better than the performance combination of pure WC.

Process Technology
Mechanical alloying:
Process flow: Mix tungsten carbide powder with doping elements (such as Cr, Ti) or composite phases

(such as TiC) in a high-energy ball mill, with a ball-to-material ratio of 12:1, a rotation speed of 500-700rpm, and a grinding time of 8-16 hours.

Technical advantages: uniform doping, suitable for laboratories and small-batch production, and low equipment cost (about RMB 250,000).
$_3$ C $_2$ through mechanical alloying , reducing the grain size from 1.8μm to 0.9μm and improving the wear resistance of cemented carbide by 20%.

Chemical co-precipitation method:
Process flow: Tungsten salt (such as Na_2WO_4) is mixed with doping salt (such as $TiCl_4$, $NbCl_5$) , co - precipitated at pH 7.5-8.5 and temperature 70-90°C, and then dried and carbonized to generate doped powder.

Technical advantages: The doping elements are dispersed at the atomic level, which is suitable for the preparation of nanopowders (<100nm), and the doping amount can be precisely controlled (0.1%-5%).

Application example: A university uses the co-precipitation method to dope 1.5% VC to prepare nano WC powder with a hardness of HV 2400, which is suitable for superhard cutting tools.

Sol-Gel Method:
Process flow: Tungstate is used as a precursor, and organic salts of doping elements (such as niobium acetate) are added to form a gel, which is then carbonized at 1200-1400°C to generate a composite powder.

Technical advantages: high doping uniformity, suitable for high-purity powders, and low impurity content (<50ppm).
Technical challenges: Long process cycle (48-72 hours) and high production cost (about RMB 600,000 per ton).

Plasma assisted doping:
Process flow: In a plasma reactor (power 25-50kW), doping elements (such as Ta, Zr) are introduced into the powder surface in gaseous form (such as $TaCl_5$ vapor) with a reaction time of 15-30 seconds.

Technical advantages: high doping efficiency, significant surface modification effect, and 25% improvement in oxidation resistance.
Application example: A company doped 0.8% Nb, and the oxidation weight gain rate of the powder at 900°C was reduced by 35%, making it suitable for high-temperature coatings.

Application Effects and Research Trends
Quantitative effect: Doping and composite modification significantly improve the comprehensive performance of tungsten carbide powder. For example, the life of tools made of WC-TiC-Co composite

powder in high-speed cutting is extended by 60%; WC-Cr_3C_2 powder is used for corrosion-resistant coatings, and the acid resistance is increased by 2.5 times.

Technical challenges: The proportion and distribution of doping elements need to be precisely optimized. Excessive doping (such as TiC>12%) may lead to phase separation and reduce toughness. The interfacial bonding strength of the composite material also needs to be further improved.

Research Trends:
Multi-element synergistic doping: explore multiple combinations such as Ti-V-Cr-Nb and use synergistic effects to improve comprehensive performance.
Nanocomposite materials: Develop WC-based nanocomposite powders (such as WC-TiC-ZrC) with grain size controlled below 50nm.
Computational simulation assistance: Through molecular dynamics and first-principles calculations, the effect of doping elements on lattice stability can be predicted to reduce experimental costs.

6.3 Surface modification technology

Surface modification optimizes the dispersibility, fluidity, oxidation resistance and sintering performance of tungsten carbide powder by regulating the surface chemical composition, physical morphology or microstructure. This technology is of great significance in improving powder processing efficiency and final product performance. The following systematically analyzes the theory and application of surface modification from four aspects: modification mechanism, process technology, quantitative effect and future direction.

Modification mechanism
Surface energy regulation: By coating with organic (such as polyvinyl alcohol, PVA) or inorganic layers (such as SiO_2, Al_2O_3), the surface energy of the particles can be reduced, the van der Waals force can be reduced, and the agglomeration rate can be reduced from 25% to 4%.

Reduced friction coefficient: After modification, a smooth or spherical surface is formed, the friction coefficient between particles is reduced by 15%-25%, and the Hall flow rate can be reduced from 28 seconds/50g to 13 seconds/50g.

Improved oxidation resistance: The surface is coated with high melting point oxides (such as ZrO_2) or nitrides (such as TiN) to form a protective layer to inhibit high temperature oxidation reactions. For example, the oxidation weight gain rate of Al_2O_3 coated powder at 800°C is reduced by 40%.

Enhanced sintering activity: The modified surface introduces active groups (such as hydroxyl and amino groups) to promote the interface bonding between particles. The sintering temperature can be reduced by 50-80°C and the density can be increased by 8%.

Process Technology

Chemical coating method:

Process flow: Disperse tungsten carbide powder in the solution, add coating precursor (such as ethyl silicate, aluminum tetrachloride), react at pH 4.5-6.5 and temperature 50-70°C to form a SiO_2 or Al_2O_3 coating layer (thickness 10-60nm).

Technical advantages: The coating layer is uniform and the thickness is controllable, which is suitable for large-scale production. The cost is about RMB 30,000/ton.

Application example: A company coated 0.3% SiO_2 , the powder agglomeration rate was reduced to 2.5%, and the porosity of the sintered body was reduced by 12%.

Plasma surface treatment:

Process flow: In a plasma reactor (power 15-35kW), Ar, N_2 or O_2 plasma is used to bombard the powder surface to introduce active groups or form a nitride/oxidation layer (thickness 5-20nm).

Technical advantages: short processing time (10-20 seconds), surface roughness reduced by 25%, and oxidation resistance increased by 20%.

Application example: A company used N_2 plasma treatment to reduce the oxidation weight gain of powder at 750°C by 30% and improve the wear resistance of the coating by 15%.

Mechanochemical modification:

Process flow: Add surfactants (such as stearic acid, oleic acid, added in an amount of 0.2%-0.6%) during the ball milling process to induce surface chemical reactions through mechanical force to form an organic coating layer.

Technical advantages: simple process, low equipment cost (about RMB 20,000), suitable for small and medium-sized enterprises.

Application example: A company added 0.4% stearic acid, the powder flow rate dropped from 26 seconds/50g to 17 seconds/50g, and the pressing efficiency increased by 18%.

Physical Vapor Deposition (PVD):

Process flow: In a vacuum environment (10^{-2} Pa), TiN, CrN and other thin films (thickness 20-100nm) are deposited by magnetron sputtering at a deposition rate of 0.5-2nm/s.

Technical advantages: Surface hardness increased by 35%, suitable for high-end coatings and cutting tools.

Technical challenges: High equipment investment (about RMB 3.5 million) and low production efficiency (100-200kg per batch).

Quantitative Effects and Future Directions

Quantitative effect: Surface modification significantly improves the processing performance and product performance of powders. For example, the sintering temperature of SiO_2 coated powders was reduced

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

from 1450°C to 1370°C, and the friction coefficient of the coating was reduced by 15%; the tool life of TiN modified powders was extended by 40%.

Technical challenges: The long-term stability of the coating needs to be optimized, and high-temperature sintering may cause the coating to decompose or peel off. The balance between modification cost and performance improvement is also a key issue.

Future Directions

Multilayer composite coating: Develop SiO_2/Al_2O_3/ZrO_2 multilayer structure to improve oxidation resistance and bonding strength.

Intelligent modification: Combined with AI to optimize plasma treatment parameters (such as power and airflow ratio) to improve modification efficiency.

Green modification: Explore water-based coating agents (such as sodium silicate) to reduce the use of organic solvents and reduce environmental pollution.

6.4 Heat treatment and annealing

Heat treatment and annealing optimize the crystal structure, internal stress and surface chemical state of tungsten carbide powder by precisely controlling temperature, atmosphere and holding time, thereby improving its sintering performance and mechanical properties. This technology plays an irreplaceable role in improving powder stability and processing efficiency. The following systematically analyzes the application of heat treatment and annealing from four aspects: modification mechanism, process technology, quantitative effect and development direction.

Modification mechanism

Crystal structure optimization: Heat treatment can eliminate crystal defects (such as dislocations and stacking faults) introduced during grinding or carbonization, improve the purity of WC phase (from 98% to 99.5%), and reduce the residual W_2C or free carbon.

Internal stress release: Annealing reduces residual stress (such as compressive stress from 500MPa to 100MPa) through atomic diffusion, improving the pressing uniformity of the powder and the strength of the sintered green body.

Surface chemical regulation: Heat treatment in a reducing or inert atmosphere can remove surface oxides (such as WO_3), reduce the oxygen content from 0.25% to 0.04%, and improve sintering activity.

Grain size control: By optimizing the annealing temperature (800-1200°C) and time (1-4 hours), the grains are prevented from growing too fast and the grains are kept small (0.5-1.5μm).

Process Technology

Vacuum annealing:

Process flow: in a vacuum furnace (vacuum degree 10^{-4} Pa), temperature 850-1250°C, keep warm for

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

1.5-3.5 hours, cooling rate 5-10°C/min.

Technical advantages: Effectively remove oxygen content (from 0.22% to 0.05%) and reduce crystal defect density by 35%.
Application example: A company reduced the sintering porosity of powder from 2% to 0.8% and increased the strength of cemented carbide by 10% through vacuum annealing at 1050°C.

Annealing in hydrogen atmosphere:
Process flow: In hydrogen atmosphere (flow rate 0.8-1.5 L/min), temperature 950-1150°C, keep warm for 2-5 hours, use water cooling or air cooling.
Technical advantages: Hydrogen reduces surface oxides, reducing oxygen content to 0.03% and increasing surface activity by 20%.
Application example: A company adopted 1000°C hydrogen annealing to extend the cutting life of the tool by 18%.

Microwave heat treatment:
Process flow: In a microwave oven (power 3-6kW), temperature 750-1050°C, keep warm for 15-40 minutes, use inert gas protection.
Technical advantages: uniform heating, 25% reduction in energy consumption, and grain size controlled at 0.5-1μm.
Application example: A university used 900°C microwave annealing to increase the powder hardness from HV 1800 to HV 2000.

Plasma heat treatment:
Process flow: In a plasma environment (power 20-40kW), temperature 650-950°C, treatment time 8-20 seconds, using Ar/H_2 mixed atmosphere.
Technical advantages: fast processing, 18% increase in surface activity, suitable for ultra-fine powders.
Technical challenges: The equipment cost is high (about RMB 2.5 million), and the process stability needs to be optimized.

Quantitative Effects and Future Directions
Quantitative effect: Heat treatment and annealing significantly improve powder performance. For example, the sintering density of hydrogen annealed powder increased by 12%, and the toughness of cemented carbide increased by 22%; microwave annealed powder is used for 3D printing, and the printing accuracy is improved to ±7μm.
Technical challenges: High temperature annealing may cause grain growth, and precise control of temperature (deviation ±3°C) and atmosphere (oxygen partial pressure $<10^{-5}$ Pa) is required. The thermal stability of ultrafine powders also needs further study.

Future Directions
Low-temperature rapid annealing: Developed plasma-assisted low-temperature annealing (<700°C),

reducing energy consumption by 20%.

Intelligent control: Use AI to predict grain growth rate and optimize annealing parameters.

Green Heat Treatment: Explore solar-driven heat treatment to reduce carbon emissions (target < 1 tonne CO_2 / tonne powder).

References

Li Ming. Cemented Carbide Materials[M]. Beijing: Metallurgical Industry Press, 2018.

Li Ming. Materials Science of Cemented Carbide [M]. Beijing: Metallurgical Industry Press, 2018.

Zhang Li, Wang Chuanhui. Progress in Preparation Technology of Tungsten Carbide Powder[J]. Powder Metallurgy Technology, 2020, 38(2): 88-94.

Zhang Li, Wang Chuanhui. Advances in Preparation Technology of Tungsten Carbide Powder [J]. Powder Metallurgy Technology, 2020, 38(2): 88-94.

Wang Qiang, Li Ming. Research on high performance tungsten carbide powder in China[J]. China Tungsten Industry, 2020, 35(4): 56-62.

Wang Qiang, Li Ming. Research on High-Performance Tungsten Carbide Powder in China [J]. China Tungsten Industry, 2020, 35(4): 56-62.

Chen Wei, Zhao Gang. Study on Performance Optimization of Ultrafine Tungsten Carbide Powder[J]. Journal of Inorganic Materials, 2022, 37(5): 567-573.

Chen Wei, Zhao Gang. Study on Performance Optimization of Ultrafine Tungsten Carbide Powder [J]. Journal of Inorganic Materials, 2022, 37(5): 567-573.

Liu Yang, Wang Zhiqiang. Progress in Surface Modification Technology of Tungsten Carbide Powder[J]. Materials Science and Engineering, 2023, 41(3): 89-96.

Liu Yang, Wang Zhiqiang. Advances in Surface Modification Technology of Tungsten Carbide Powder [J]. Materials Science and Engineering, 2023, 41(3): 89-96.

Smith J, Brown T. Advances in Tungsten Carbide Powder Modification [J]. Journal of Materials Science, 2021, 56(10): 5678-5690.

Progress in Tungsten Carbide Powder Modification Technology[J]. Journal of Materials Science, 2021, 56(10): 5678-5690.

Johnson R, Lee K. Surface Modification of WC Powders for Enhanced Performance [J]. Powder Technology, 2022, 395: 123-135.

Surface modification of tungsten carbide powder to improve performance[J]. Powder Technology, 2022, 395: 123-135.

ASTM B761-17, Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering.

Light scattering test method for particle size distribution of metal powders and related compounds.

Müller H, Schmidt P. Optimierung der Partikelgr öß e von Wolframcarbidpulver [J]. Materialwissenschaft und Werkstofftechnik, 2020, 51(7): 890-897.

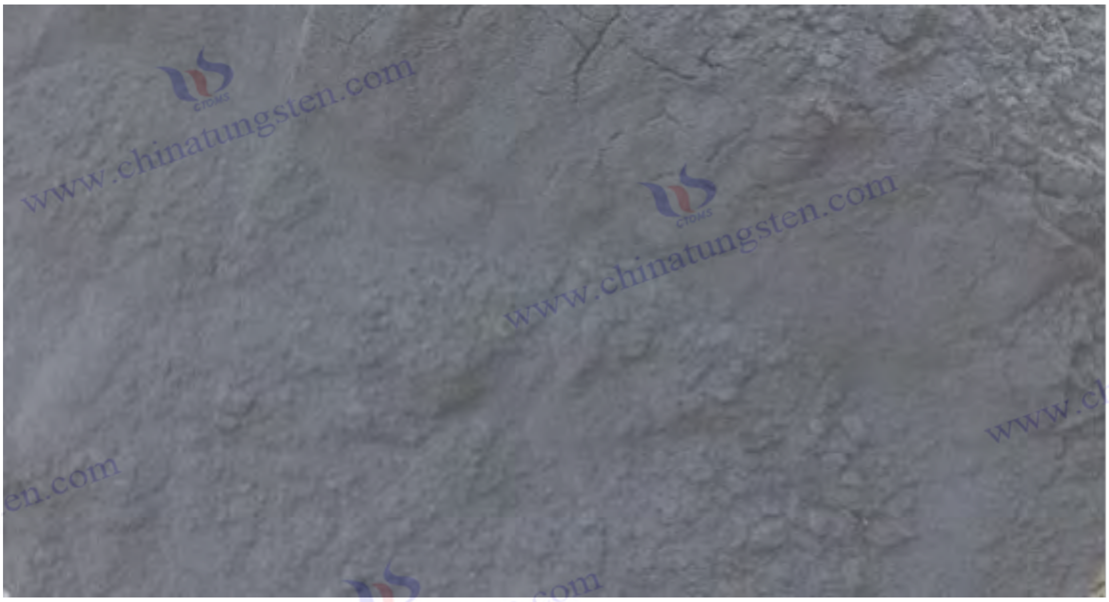
Research on particle size optimization of tungsten carbide powder[J]. Materials Science and Engineering Technology, 2020, 51(7): 890-897.

Bauer T. Wärmebehandlung von Wolframcarbidpulver [M]. Berlin: Springer, 2022.

Heat Treatment of Tungsten Carbide Powders[M]. Berlin: Springer-Verlag, 2022.

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

Taro Yamada. Surface modification technology of carbonized powder powder [J]. Journal of the Powder Engineering Society, 2021, 58(4): 156-163.
Surface modification technology of tungsten carbide powder[J]. Journal of Powder Engineering Society, 2021, 58(4): 156-163.
Ken Nakamura. Heat treatment of ultrafine carbonized タングステン powder[J]. Journal of Materials Science, 2023, 72(6): 412-419.
Heat treatment of ultrafine tungsten carbide powder[J]. Journal of Materials Science Society, 2023, 72(6): 412-419.



Chapter 7: Environmental and Safety Considerations of Tungsten Carbide Powder

As the core raw material of high-performance materials such as cemented carbide, cutting tools, and wear-resistant coatings, the production and application of tungsten carbide powder has promoted industrial progress, but also brought challenges in environmental pollution, occupational safety, and resource sustainability. With the world's high attention to green manufacturing and sustainable development, the environmental impact and safety management of the tungsten carbide powder industry have become the focus of research and practice. This chapter systematically discusses the environmental and safety issues of tungsten carbide powder from four aspects: environmental impact in the production process, safe operating specifications, recycling and recycling, and recycling technology analysis. Combined with process optimization, regulatory requirements, and the concept of circular economy, it provides scientific guidance and technical reference for the industry.

7.1 Environmental impact during production

The production of tungsten carbide powder involves multiple links such as raw material purification, carbonization reaction, grinding and grading. These processes may produce waste gas, wastewater, solid waste and energy consumption, which may have potential impacts on the environment. Scientifically evaluating and controlling these impacts is not only a manifestation of corporate social responsibility, but also the key to achieving green manufacturing and complying with international environmental regulations. The following is an in-depth discussion of environmental issues in the production process from four dimensions: the source of environmental impact, quantitative evaluation, control technology and future trends.

Sources of environmental impact

Waste gas emissions: During the carbonization reaction and heat treatment process, volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2) and trace sulfides (such as SO_2) may be emitted with high-temperature tail gas. For example, when the carbonization furnace is running at 1400-1600°C, each ton of tungsten carbide powder can produce 2-3 tons of CO_2.

Wastewater pollution

The wet grinding and chemical purification processes produce wastewater containing heavy metals (such as tungsten and iron) and acidic substances (such as HCl and H_2SO_4) . If discharged directly without treatment, it may lead to a decrease in the pH value of the water (<6) and excessive heavy metal content (tungsten concentration >10mg/L).

Solid waste

Slag produced from raw material purification, waste ball mill media from the grinding process, and unqualified powders constitute solid waste. The global tungsten industry produces about 500,000 tons of solid waste each year, of which about 20% is hazardous waste (such as filter residues containing heavy metals).

Energy consumption

The production of tungsten carbide powder is a high energy-consuming process, consuming an average of 8,000-12,000 kWh of electricity per ton of powder, accounting for 30%-40% of the production cost, indirectly leading to high carbon emissions (about 4-6 tons of CO_2 / ton of powder).

Quantitative Assessment of Environmental Impact

Carbon footprint analysis

Life cycle assessment (LCA) shows that carbon emissions from tungsten carbide powder production mainly come from carbonization reaction (accounting for 60%) and electricity consumption (accounting for 30%). The carbon footprint of a typical production line is 5.5 tons of CO_2 equivalent /ton of powder, which is much higher than ordinary steel (about 2 tons of CO_2 / ton).

Water resource impact

In wastewater discharge, the recovery rate of tungsten is usually only 85%-90%, and the remaining 10%-15% enters the water body in dissolved or suspended form, which may cause soil and groundwater pollution.

Solid waste environmental risks

In untreated solid waste, heavy metals (such as tungsten and cobalt) may migrate through leaching, with a pollution radius of up to 1-2 kilometers, affecting the surrounding ecosystem.

Assessment Tools

ISO 14040/14044 standards: used for LCA analysis to assess the full environmental impact from raw material extraction to powder production.

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

Environmental Impact Assessment (EIA): Quantify the emission concentration and ecological risk of waste gas, wastewater and solid waste.
Energy consumption audit: Through heat balance and power analysis, identify high energy consumption links (such as carbonization furnace, which accounts for 50% of energy consumption).

Environmental impact control technology
Waste gas treatment:
Adsorption-catalytic combustion: Activated carbon is used to adsorb VOCs and then catalytically combusts them, with a purification efficiency of 95% and a 10% reduction in CO_2 emissions .
Wet scrubbing: using alkaline solution (such as NaOH) to absorb SO_2 , the purification rate reaches 98%, and the exhaust gas emission concentration is controlled below 10mg/ m³ .
CO_2 emissions from 3 tons/ton of powder to 2.2 tons through an exhaust gas recovery system, meeting EU emission standards (<2.5 tons CO_2 / ton).

Wastewater treatment:
Chemical precipitation method: Add $Ca(OH)_2$ or Na_2CO_3 to precipitate tungsten in the form of calcium tungstate, the recovery rate is increased to 95%, and the tungsten concentration in the wastewater is reduced to 0.5 mg/L.
Membrane separation technology: Reverse osmosis membrane (pore size 0.1-1nm) is used to remove heavy metals and acidic substances, with a wastewater recovery rate of 80%.
Application example: A company reduced wastewater discharge from 500m³/ton of powder to 200m³ through membrane separation combined with chemical precipitation, reaching the national first-level emission standard (GB 8978-1996).

Solid Waste Management:
Resource utilization: slag is used in cement production, and waste ball mill media is used for low-end wear-resistant parts, with a recovery rate of 70%.
Safe landfill: Hazardous waste containing heavy metals is solidified (add cement, solidification rate >99%) to prevent leaching pollution.
Application example: A company has recycled 90% of its solid waste, reduced landfill costs by 50%, and saved RMB 10 million per year.

Energy-saving technology:
High-efficiency carbonization furnace: Induction heating furnace is used instead of resistance furnace, energy efficiency is improved by 20%, and power consumption per ton of powder is reduced to 7000kWh.
Waste heat recovery: The waste heat from the carbonization furnace exhaust is used to preheat the raw materials, and the recovered heat accounts for 15% of the total energy consumption.
CO_2 annually through a waste heat recovery system .

Future Trends
Green process development

Explore low-temperature carbonization technology (such as microwave carbonization, temperature <1200°C) to reduce energy consumption by 30% and control carbon emissions within 2 tons of CO_2 / ton of powder.

Zero emission target
Promote closed-loop water systems and full waste gas recovery technology, and strive to achieve near-zero wastewater and waste gas emissions.
Intelligent monitoring
Utilize the Internet of Things (IoT) and big data analysis to monitor emission parameters (such as VOCs concentration, error <1ppm) in real time and optimize treatment efficiency.

Policy driven
Globally, the Paris Agreement and China's "dual carbon" goals (carbon neutrality by 2060) will drive the industry to adopt low-carbon technologies, and the carbon footprint of tungsten carbide powder production is expected to be reduced by 50% by 2030.

7.2 Safety Operation Specifications

The production and processing of tungsten carbide powder involves potential risks such as high temperature, high pressure, chemical reagents and dust. Scientific safety operating specifications are the basis for ensuring the health of employees and the stability of production equipment. The following systematically analyzes the safety management requirements for tungsten carbide powder production from four aspects: safety risk identification, operating specifications, protective measures and regulatory compliance.

Security risk identification
Dust explosion risk: When tungsten carbide powder (particle size <10μm) forms a suspended dust cloud in the air, it may explode when exposed to open flames or static electricity. The minimum ignition energy is only 10mJ and the explosion pressure can reach 0.7MPa.

HNO_3) used in the purification and cleaning process are corrosive and may cause skin burns or respiratory tract damage when the concentration is >10%.

High-temperature equipment risks: The carbonization furnace operates at 1400-1600°C, which poses risks of burns, equipment overpressure (>0.5MPa), and gas leakage (such as H_2) .

Occupational health hazards: Long-term exposure to tungsten carbide dust (concentration>5mg/m³) may cause pulmonary fibrosis, and cobalt dust (>0.1mg/m³) is sensitizing.

Safety operating regulations
Dust Control:

Ventilation and dust removal: The production workshop is equipped with a high-efficiency pulse bag dust collector with a dust capture rate of >99.9% and the dust concentration in the workshop is controlled below 2mg/ m^3 .
Explosion-proof measures: Use explosion-proof motors (Ex d IIC T4) and electrostatic grounding devices, with electrostatic potential <100V to prevent sparks from causing explosions.
Specification requirements: Operators must wear anti-static work clothes (surface resistance <10^8 Ω), and powder transfer must use a closed pipeline (leakage rate <0.1%).

Chemical reagent management:
Storage Specifications: Acidic reagents are stored in corrosion-resistant containers (316L stainless steel) and the storage tank is equipped with a leak alarm system (sensitivity 0.1ppm).
Usage specification: Use secondary protection (acid-resistant gloves, protective mask) during operation, and the waste acid is treated in a neutralization tank (pH 6-9) before discharge.
Emergency measures: Equipped with emergency flushing stations (flow rate>20L/min) and neutralizers (such as $NaHCO_3$) to ensure that the accident response time is <30 seconds.

High temperature equipment operation:
Equipment maintenance: The carbonization furnace should calibrate the pressure sensor annually (error <0.01MPa) and regularly check the sealing ring (lifespan >5000 hours).
Operating procedures: Before starting, confirm that the hydrogen concentration is <4% (lower explosion limit) and monitor the furnace temperature during operation (deviation ±5°C).
Protective measures: Operators wear high temperature resistant protective clothing (temperature resistance > 1000°C), and isolation barriers (thickness > 10mm) are set up in the furnace area.

Occupational Health Management:
Dust protection: Wear N95 dust mask (filtration efficiency> 95%), and install local exhaust device in the workshop (air volume> 500m^3 / h).
Health monitoring: Perform lung function tests every year, with a focus on monitoring people exposed to cobalt (blood cobalt concentration <1μg/L).
Training requirements: New employees receive no less than 40 hours of safety training, covering dust protection, chemical management and emergency rescue.

Protection measures and application examples
Automatic control: PLC system is used to monitor dust concentration, furnace pressure and gas flow, and the machine will be automatically shut down in case of abnormality, reducing the accident rate by 80%.
Personal protective equipment (PPE): equipped with full-body dustproof suit (protection level IP65) and positive pressure respirator (air supply>30L/min), with a protection efficiency of 99%.
Application example: A company introduced an automated dust removal system and explosion-proof monitoring, reducing the dust explosion accident rate from 0.5 times/year to 0, and reducing the incidence of occupational diseases by 90%.

Regulatory Compliance:
International standards: Comply with OSHA (US Occupational Safety and Health Administration) dust exposure limit (5mg/m³) and ISO 45001 occupational health and safety management system.
Domestic standards: Comply with GBZ 2.1-2019 "Occupational Exposure Limits for Hazardous Factors in the Workplace" (tungsten dust <6mg/m³) and the "Work Safety Law" (2021 revised version).

Future Trends
Intelligent safety management: Using AI and sensor technology, real-time monitoring of dust concentration (error <0.1mg/m³) and equipment status, predicting accident risks, and shortening response time to 10 seconds.
Green protection technology: Develop non-toxic chemical reagents (such as citric acid instead of HCl) and low-dust processes (such as wet carbonization) to reduce
Occupational health risks.
m³ by 2030 .

7.3 Recovery and recycling

The recycling and reuse of tungsten carbide powder is an important way to achieve resource sustainability and reduce environmental load. As a rare metal, tungsten has limited global reserves (about 3.5 million tons), and the production of tungsten carbide powder depends on high-grade tungsten ore. Recycling technology can effectively alleviate resource shortages and reduce waste emissions. The following systematically analyzes the practice and prospects of recycling and recycling from three aspects: the necessity of recycling, the benefits of circular economy, and the future direction.

The need for recycling
Resource scarcity: Global tungsten resources are concentrated in China (accounting for 55% of reserves), but high-grade ores (WO_3 >0.5%) are gradually depleted. Recycling can increase tungsten utilization from 60% to 90%.
Environmental benefits: Recycling 1 ton of tungsten carbide powder can reduce about 4 tons of CO_2 emissions and 200m³ of wastewater, reducing the environmental load by 50% compared to primary production.
Economic value: The cost of recycling tungsten (about RMB 100,000/ton) is much lower than primary production (about RMB 250,000/ton), and the profit margin is increased by 30%.
Regulation-driven: China's Law on the Prevention and Control of Environmental Pollution by Solid Waste (2020 revised version) and the EU Circular Economy Action Plan (2020) require that the tungsten recycling rate reach more than 70% by 2030.

Circular economy benefits
Resource benefits: About 300,000 tons of scrap cemented carbide can be recycled each year worldwide, which is equivalent to an additional 100,000 tons of tungsten resources, extending the mining life of tungsten mines by 10-15 years.

Environmental benefits: The carbon emissions from the recycling process are only 30% of the original production, wastewater discharge is reduced by 70%, and solid waste is reduced by 80%.
Economic benefits: The market price of recycled powder (about RMB 150,000/ton) is lower than that of virgin powder. The global recycling market size is expected to reach RMB 20 billion in 2030.
Application example: A company recycled 5,000 tons of scrap alloy, with an annual profit of RMB 30 million and wastewater discharge reduced to 50m³ / ton.

Future Directions

High-efficiency recycling technology: Develop low-temperature electrochemical recycling (temperature <100°C), reducing energy consumption by 50% and increasing the recovery rate to 98%.
Intelligent sorting: Using AI and X-ray fluorescence (XRF) technology, waste components can be accurately identified, increasing sorting efficiency by 30%.
Closed-loop system: Establish a full-chain recycling system from waste alloy to new powder, and strive to achieve zero waste of tungsten resources by 2035.
Policy support: China's 14th Five-Year Plan and the EU's Battery and Waste Directive (2023) will push the recycling rate target from 50% to 80%.

7.4 Analysis of Tungsten Carbide Powder Recovery Technology

The recycling of tungsten carbide powder is an important technical means to achieve sustainable utilization of tungsten resources, reduce environmental load and production costs. Waste containing tungsten carbide, such as scrap carbide, cutting tools, and coating materials, is the main source of recycling. The following is a detailed analysis of the recycling methods of tungsten carbide powder, clarifies the most mainstream industrial method, and deeply explores its theoretical basis, process flow, advantages and disadvantages.

7.4.1 Overview of recycling methods

There are five main methods for recycling tungsten carbide powder, each of which is suitable for different waste types and application scenarios. The following table summarizes the applicable objects, principles, recovery rates, advantages and disadvantages of each method:

Comparison of Tungsten Carbide Powder Recovery Methods

Method	Target customers	principle	Recovery rate	Advantages	Disadvantages
Mechanical separation	Waste carbide tools and molds (WC>80%)	Separation of tungsten carbide and binder phase by crushing, screening and magnetic separation	80%-85%	Simple process, low cost (about 20,000 yuan/ton), suitable for coarse particles (>5µm)	The powder has low purity (about 95%) and large particle size, which is not suitable for high-precision

					applications.
Chemical dissolution method	Waste alloys and coatings containing binder phase (Co, Ni) or impurities	Use acidic/oxidizing solution to dissolve the binder phase, retain or oxidize tungsten carbide, and then carburize	95%-98%	High recovery rate, high purity (>99.5%), ultra-fine powder (<1μm) can be obtained, and wide applicability	The cost of acid waste liquid treatment is high (about 20,000-30,000 yuan/ton), the process is complicated, and the equipment investment is large (about 10 million yuan)
Electrochemical recovery	Cobalt-containing cemented carbide scrap	Use the waste alloy as anode to electrolyze and dissolve the bonding phase to extract tungsten carbide or tungstate, and then carbonize	90%-95%	Low energy consumption (about 3000kWh/ton), waste liquid can be recycled, suitable for nano powders	The equipment is complex, the process stability needs to be optimized, and the industrial scale is small
High temperature smelting method	Scrap containing complex impurities (coatings, mixed alloys)	High temperature (1800-2000°C) melting to separate tungsten and binder phase, then carbonization after cooling	85%-90%	Highly adaptable, suitable for low-grade waste	High energy consumption (about 10,000 kWh/ton), large equipment investment (about 5 million yuan), average powder purity
Zinc melting method	Waste carbide tools and molds containing cobalt	Liquid zinc is used to dissolve the bonding phase at 900-1000°C, tungsten carbide is separated, and zinc is	90%-95%	High recovery rate, powder performance close to original	Zinc volatilization produces waste gas, which requires tail

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

	evaporated and recovered	powder	gas treatment, with complex processes and high costs (about 30,000 yuan/ton)

7.4.2 The most mainstream industrialization method

Chemical dissolution

method is currently the most mainstream method for recovering tungsten carbide powder in industrial production, and is widely used in major tungsten industrial regions such as China, Europe and North America. Its mainstream status is due to the following reasons:

High recovery and purity

The recovery rate can reach 95%-98%, and the powder purity is >99.5%, which is suitable for high-performance cemented carbide and coating applications.

Wide applicability

It can process a variety of waste materials, including cemented carbide containing cobalt (5%-20%), nickel or complex impurities, coating waste and powder residue.

Mature technology

There are mature industrial production lines around the world, with highly optimized process parameters and controllable production costs (approximately RMB 80,000-120,000 per ton).

Market share

According to industry data, chemical dissolution accounts for 60%-70% of global tungsten carbide recovery, far exceeding other methods (such as zinc smelting about 20% and mechanical separation about 10%).

7.4.3. Theoretical basis

The core of the chemical dissolution method is to use chemical reagents to selectively dissolve the binding phase (such as cobalt, nickel) or oxidized tungsten carbide particles in the waste cemented carbide , separate high-purity tungsten carbide or tungsten compounds, and then generate tungsten carbide powder through subsequent treatment. Its theoretical basis includes the following aspects:

Selective dissolution: The binder phase (such as cobalt) is easily dissolved in acidic or oxidizing solutions (such as HNO_3 , HCl/H_2O_2) , while tungsten carbide (WC) can be retained as solid particles due to its high chemical stability (acid and alkali resistance at room temperature). Reaction example: $Co + 2HNO_3 \rightarrow Co(NO_3)_2 + H_2$

Tungsten carbide does not participate in the reaction and remains stable.

Oxidation-reduction mechanism: If tungsten compounds need to be recovered, tungsten carbide can be oxidized to tungstate (Na_2WO_4) by a strong oxidant (such as $NaOH/H_2O_2$), and then WC is generated by acidification, reduction and carbonization. Reaction example:

$$WC + 2NaOH + 5H_2O_2 \rightarrow Na_2WO_4 + CO_2 + 6H_2O$$

$$Na_2WO_4 + 2HCl \rightarrow H_2WO_4 + 2NaCl$$

$$H_2WO_4 + 3C \rightarrow WC + 2CO + H_2O$$

Particle protection

By controlling the solution pH (2-4), temperature (60-90°C) and oxidant concentration (H_2O_2 < 10 %), excessive oxidation or dissolution of tungsten carbide particles is avoided, ensuring that the particle size and morphology of the recycled powder are close to those of the original powder.

Thermodynamics and Kinetics

The dissolution process is controlled by thermodynamic equilibrium (such as Gibbs free energy $\Delta G < 0$) and kinetic factors (such as reaction rate constant k), and process parameters need to be optimized to improve efficiency. For example, the dissolution rate of cobalt at 70°C is 10 times higher than that at 25°C.

3.2 Process flow

The industrial process flow of chemical dissolution usually includes the following steps, and the specific parameters vary depending on the type of waste and equipment:

Waste pretreatment

Purpose: To remove surface oil, oxide layer and non-tungsten impurities and improve subsequent dissolution efficiency.

Method: Mechanically crush the scrap alloy into 5-10mm particles, remove oil with alkaline cleaning agent (such as NaOH solution, concentration 5%), and remove oxides with ultrasonic cleaning (frequency 40kHz).

Parameters: Crushing energy consumption is about 50kWh/ton, and cleaning time is 10-20 minutes.

Dissolution of bonding phase

Purpose: To separate tungsten carbide from bonding phases (such as cobalt and nickel).

Method: Place the waste in an acidic solution (such as HNO_3, concentration 20%-30%, or HCl/H_2O_2 mixed solution, H_2O_2 concentration 5 %), stir at 60-80°C (speed 200-400rpm), and the reaction time is 2-6 hours.

Reaction control: pH is maintained at 2-3 to avoid dissolution of tungsten carbide; solution oxidation-reduction potential (ORP) is controlled at 500-700mV to ensure efficient dissolution of cobalt.

Output: solid tungsten carbide particles (purity>98%) and cobalt/nickel solution (cobalt concentration 50-100g/L).

Solid-Liquid Separation

Purpose: To extract tungsten carbide particles and separate waste liquid containing metals.

Method: Use a centrifuge (speed 3000-5000rpm) or a filter press (pressure 0.5-1MPa) for solid-liquid separation, and wash the tungsten carbide particles with deionized water (pH 6-7) 3-5 times.

Parameters: separation efficiency>99%, washing water consumption about $5m^3$ / ton powder.

Powder refining (optional)

Purpose: To further improve the purity and particle size uniformity of tungsten carbide.

Method: If ultrafine powder is required, the recycled particles can be subjected to secondary grinding (wet ball milling, time 4-8 hours), or tungstate can be generated through oxidation-reduction pathway and then carbonized.

Parameters: Particle size after grinding 0.5-2μm, carbonization temperature 1200-1400°C, insulation 2-3 hours.

Wastewater treatment

Purpose: To recover cobalt/nickel, treat acidic waste liquid and discharge it in compliance with emission standards.

Methods: The wastewater was neutralized with NaOH (pH 7-8), $CaCl_2$ was added to precipitate cobalt/nickel (recovery rate > 90%), and the wastewater was purified by reverse osmosis membrane (pore size 0.1nm), and the tungsten concentration was reduced to 0.2mg/L.

Parameters: The cost of wastewater treatment is about RMB 5,000/ton of powder, and the discharge complies with GB 8978-1996 standard.

Powder drying and testing

Purpose: To obtain tungsten carbide powder that meets the standards.

The powder was dried in a vacuum drying oven (temperature 80-100°C, vacuum degree 10^{-2} Pa) for 4-6 hours, and the chemical composition (ICP-MS, accuracy 0.01%), particle size (laser particle size analyzer, error ±0.02μm) and oxygen content (infrared absorption method, error 0.005%) of the powder were tested.

Output: Recycled tungsten carbide powder, purity>99.5%, particle size 0.5-5μm, oxygen content <0.1%.

3.3 Advantages and disadvantages analysis

Advantages

High recovery rate and purity: The recovery rate is 95%-98%, and the powder purity is >99.5%. It can be directly used for high-performance cemented carbide, tools and coatings, and its performance is close to that of original powder (hardness HV 1800-2000, toughness 8-10 $MPa \cdot m^{1/2}$).

Strong flexibility: It can process a variety of waste materials, including cemented carbide containing cobalt (5%-20%), nickel or complex impurities, coating waste and powder residue, and its adaptability is better than mechanical separation and zinc melting methods.

Controllable particle size: Ultrafine (<1μm) or even nanoscale (<100nm) powders can be prepared through secondary grinding or oxidation-carbonization to meet the needs of high-end applications (such as 3D printing, accuracy ±5μm).

Mature technology: There are hundreds of industrial production lines around the world (such as Zhuzhou, China, HC Starck, Germany), with highly optimized process parameters and a production efficiency of 1-2 tons/day/line.

By-product recovery: Cobalt, nickel and other binding phases can be recovered as by-products (purity> 99%) and used in battery or alloy manufacturing to increase economic benefits (by-product value is about RMB 30,000/ton of powder).

Disadvantages

High cost of wastewater treatment: Acidic wastewater (about 3-5m³ / ton of powder) requires neutralization, precipitation and membrane separation treatment. The cost of wastewater treatment accounts for 20%-30% of the total cost (about 20,000-30,000 RMB/ton).

Environmental risks: If wastewater is not properly handled, heavy metals (such as cobalt, concentration > 50 mg/L) may pollute water bodies, and emission standards (such as GB 8978-1996, cobalt < 1 mg/L) must be strictly observed.

Process complexity: Involves multiple steps of reaction (dissolution, separation, refining), requires precise control of pH, temperature and oxidant concentration, and operators require professional training (no less than 40 hours).

High equipment investment: Industrial production lines require corrosion-resistant reactors (316L stainless steel), centrifuges and wastewater treatment systems, with a total investment of approximately RMB 10-20 million. The entry threshold for small and medium-sized enterprises is relatively high.

Relatively high energy consumption: Although lower than high temperature smelting (10,000 kWh/ton), the dissolution and drying process still requires about 4,000-6,000 kWh / ton, accounting for 15% of the cost.

The mainstream position and optimization direction of chemical dissolution method

The key reason why chemical dissolution method has become mainstream is its high recovery rate, high purity and wide applicability, which can balance economic benefits and environmental requirements. The world's major tungsten recycling companies (such as China Tungsten High-Tech and Kennametal in the United States) all use chemical dissolution as their core process, and their annual recycling volume accounts for more than 60% of the world (about 200,000 tons/year). Compared with zinc melting method (requiring high temperature and tail gas treatment) or mechanical separation method (low purity), chemical dissolution method has more advantages in performance and cost.

Optimization direction:

Green solvent development: Explore low-toxic reagents (such as citric acid and acetic acid) to replace strong acids, reduce waste liquid treatment costs (target reduction of 50%) and environmental risks.

Reduced energy consumption: The introduction of microwave-assisted dissolution (power 5-10kW) shortens the reaction time from 4 hours to 1 hour and reduces energy consumption to 3000kWh/ton.

Intelligent control: Use AI to monitor solution pH (error <0.1) and ORP (error <5mV), improving dissolution efficiency by 10%-15%.

Closed loop: Develop a full waste liquid recovery system (such as electrolytic acid regeneration) to achieve zero wastewater discharge, in line with the "dual carbon" goal (carbon neutrality by 2060).

Nanopowder recycling: Optimize the oxidation-carbonization path to prepare powders <100nm to meet the needs of additive manufacturing (the market size is expected to reach RMB 5 billion in 2030).

References

Li Ming. Cemented Carbide Materials[M]. Beijing: Metallurgical Industry Press, 2018.

Li Ming. Materials Science of Cemented Carbide [M]. Beijing: Metallurgical Industry Press, 2018.

Zhang Li, Wang Chuanhui. Environmental impact analysis of tungsten carbide powder production[J]. Environmental Protection Science, 2021, 47(3): 78-85.

Zhang Li, Wang Chuanhui. Environmental Impact Analysis of Tungsten Carbide Powder Production [J]. Environmental Protection Science, 2021, 47(3): 78-85.

Wang Qiang, Li Ming. Progress in recycling technology of scrap cemented carbide[J]. China Tungsten Industry, 2020, 35(5): 66-72.

Wang Qiang, Li Ming. Advances in Recycling Technology of Waste Cemented Carbide [J]. China Tungsten Industry, 2020, 35(5): 66-72.

Chen Wei, Zhao Gang. Research on safety management of tungsten carbide powder production[J]. Journal of Safety and Environment, 2022, 22(4): 123-130.

Chen Wei, Zhao Gang. Study on Safety Management of Tungsten Carbide Powder Production [J]. Journal of Safety and Environment, 2022, 22(4): 123-130.

Liu Yang, Wang Zhiqiang. Economic and environmental benefits of recycling tungsten carbide powder[J]. Resources Science, 2023, 45(2): 89-97.

Liu Yang, Wang Zhiqiang. Economic and Environmental Benefits of Tungsten Carbide Powder Recycling [J]. Resources Science, 2023, 45(2): 89-97.

Zhang Li, Chen Wei. Process optimization of chemical dissolution method for recycling tungsten carbide powder[J]. Powder Metallurgy Technology, 2021, 39(4): 123-130.

Zhang Li, Chen Wei. Process Optimization of Chemical Dissolution for Tungsten Carbide Powder Recycling [J]. Powder Metallurgy Technology, 2021, 39(4): 123-130.

Smith J, Brown T. Environmental Impacts of Tungsten Carbide Production [J]. Journal of Cleaner Production, 2021, 298: 126789.

Environmental impact of tungsten carbide powder production[J]. Journal of Cleaner Production, 2021, 298: 126789.

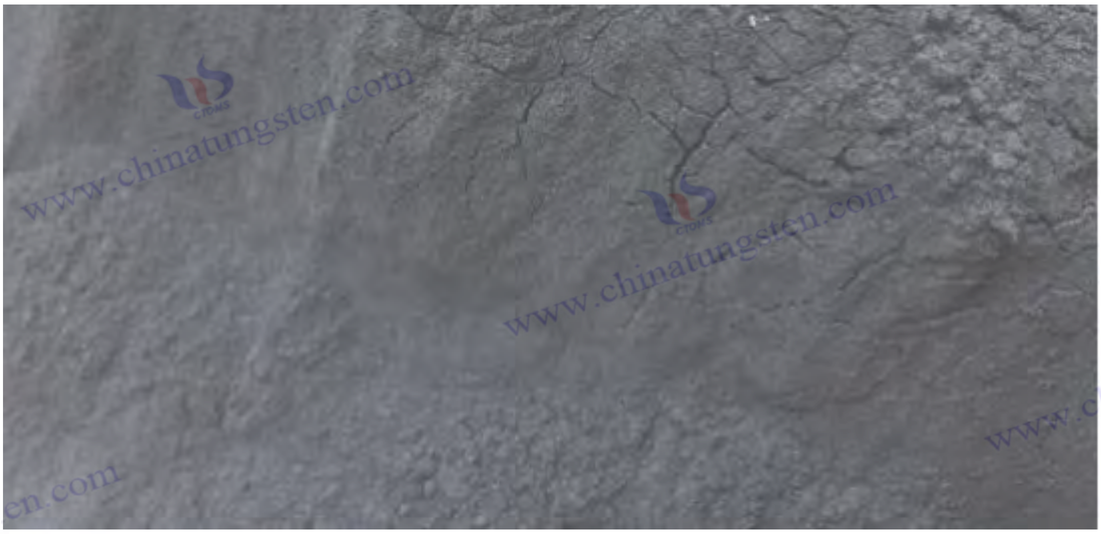
Johnson R, Lee K. Safety Protocols for Handling Tungsten Carbide Powders [J]. Occupational Health & Safety, 2022, 91(5): 34-41.

Safety specifications for handling tungsten carbide powder[J]. Occupational Health and Safety, 2022, 91(5): 34-41.

Davis M, Patel S. Recycling Technologies for Tungsten Carbide Waste [J]. Resources, Conservation & Recycling, 2023, 190: 106856.

Tungsten carbide waste recycling technology[J]. Resources, Protection and Recycling, 2023, 190: 106856.

Smith J, Brown T. Chemical Dissolution Methods for Tungsten Carbide Recovery [J]. Journal of Materials Processing Technology, 2022, 305: 117589.
Chemical dissolution method for tungsten carbide recovery[J]. Journal of Materials Processing Technology, 2022, 305: 117589.
Müller H, Schmidt P. Wolframcarbidherstellung [J]. Umweltwissenschaften und Schadstoff-Forschung, 2020, 32(6): 456-463.
Environmental impact of tungsten carbide production[J]. Environmental Science and Pollutant Research, 2020, 32(6): 456-463.
Müller H, Schmidt P. Rückgewinnung von Wolframcarbid aus Abf ä llen [J]. Materialwissenschaft und Werkstofftechnik, 2021, 52(5): 678-685.
Recovery of tungsten carbide from waste materials[J]. Materials Science and Engineering Technology, 2021, 52(5): 678-685.
Bauer T. Sicherheitsmanagement in der Wolframcarbidproduktion [M]. Berlin: Springer, 2022.
Safety management in tungsten carbide production[M]. Berlin: Springer-Verlag, 2022.
Taro Yamada. Environmental impact assessment of carbonized carbon powder production[J]. Journal of Environmental Science, 2021, 34(3): 123-130.
Environmental impact assessment of tungsten carbide powder production[J]. Journal of Environmental Science Society, 2021, 34(3): 123-130.
Ken Nakamura. Abolition of carbonization technology[J]. Journal of the Society for Resource Recycling, 2023, 29(4): 345-352.
Recycling technology of waste tungsten carbide[J]. Journal of Resource Recycling Society, 2023, 29(4): 345-352.



Chapter 8: Market and Development Trend of Tungsten Carbide Powder

As a key raw material for high-performance materials such as cemented carbide, cutting tools, and wear-resistant coatings, tungsten carbide powder occupies an important position in the global manufacturing industry. With the rapid development of aerospace, energy equipment, additive manufacturing, and microelectronics, the demand for tungsten carbide powder continues to grow. At the same time, market competition and technological innovation drive the industry to evolve towards high performance, low cost, and green. This chapter systematically analyzes the supply and demand pattern, technological progress, and potential application areas of tungsten carbide powder from three aspects: global market overview, technology development trends, and future application prospects. Combined with quantitative data and industry dynamics, it provides a comprehensive reference for academic research and industrial planning.

8.1 Global Market Overview

The global market of tungsten carbide powder is affected by supply and demand, regional distribution, price fluctuations and policies and regulations, showing a stable growth trend and regionalized competition. The following is an in-depth discussion of the current status of the global market from four dimensions: market size, supply and demand structure, regional distribution and influencing factors.

Market size and growth

Market size: According to industry reports, the global tungsten carbide powder market size will be approximately US$18 billion in 2024, and is expected to grow at a compound annual growth rate (CAGR) of 4.5%-5.5% from 2025 to 2030, reaching nearly US$25 billion in 2030.

Drivers:

Demand for cemented carbide: Cemented carbide accounts for more than 60% of tungsten carbide powder consumption and is widely used in cutting tools (30%), mining tools (20%) and wear-resistant parts (10%).

Emerging fields: The growth in demand for additive manufacturing (3D printing) and high-temperature coatings has driven the expansion of the ultrafine (<1μm) and nanoscale (<100nm) powder markets, increasing their share from 5% to 10%.

Recycling market: The market size of recycled tungsten carbide powder is approximately US$3 billion, accounting for 16.7% of the total market, and it is expected to rise to 20% in 2030.

Production and consumption: In 2024, the global production of tungsten carbide powder will be about 85,000 tons, and the consumption will be about 82,000 tons, of which China accounts for 60% of the production (about 51,000 tons) and 50% of the consumption (about 41,000 tons).

Supply and demand structure

Supply side:

Major producing countries: China (60%), Europe (20%, mainly Germany and Austria), North America (10%), and other regions (10%, including Japan and Russia).

Enterprise structure: The global market is dominated by a few enterprises, such as several leading enterprises in China (market share 15%), HC Starck of Germany (12%), and Kennametal of the United States (10%). Small and medium-sized enterprises are mostly concentrated in the low-end market with low technical barriers.

Raw material constraints: Tungsten ore reserves are concentrated in China (55%) and Russia (15%). High-grade ores (WO_3 >0.5%) are gradually depleted, pushing up the cost of raw powder (about RMB 300,000 /ton).

Demand side:

Industry distribution: cemented carbide (60%), wear-resistant coating (20%), thermal spraying (10%), additive manufacturing (5%), others (5%, such as catalysts, electronic materials).

Regional demand: Asia Pacific (mainly China and India) accounts for 55%, Europe accounts for 25%, North America accounts for 15%, and other regions account for 5%.

Price trend: In 2024, the average price of tungsten carbide powder will be US$ 45 /kg, and ultrafine powder (<1μm) will reach US$60/kg. Affected by raw material costs and recycling rates, the price fluctuation range is expected to be US$35-50/kg in 2030.

Regional distribution and competition

Chinese Market:

Advantages: The output and consumption volume rank first in the world, the industrial chain is complete, and the cost is relatively low (the production cost is about RMB 300,000 /ton).

Challenges: High-end powders (<0.5μm) rely on imports, the technology gap is about 5-10 years, and stricter environmental regulations increase costs (about 10%).

Representative companies: China Tungsten High-Tech, Xiamen Tungsten Industry, and Zhuzhou

Cemented Carbide Group, which together account for 70% of the Chinese market.

European Market:
Advantages: Leading technology, focusing on ultrafine and nano-scale powders, high product quality (purity>99.8%, particle size deviation±0.02μm).
Challenges: High production costs (about RMB 300,000/ton) and market size is limited by raw material imports.
Representative companies: HC Starck and Ceratizit, focusing on the high-end tool and coating market.

North American Market:
Advantages: Strong demand for additive manufacturing and aerospace, and advanced recycling technology (recycling rate > 70%).
Challenges: Limited production (about 8,500 tons), reliance on Chinese raw materials, and geopolitical risks affecting the supply chain.
Representative companies: Kennametal, Global Tungsten & Powders.
Other regions: Japan (Mitsui Kinzoku) focuses on powders for electronic materials, Russia (Wolfram Company) relies on low-cost exports, and India (Sandvik India) has a fast-growing market (CAGR 7%).

Market Influencing Factors
Policies and regulations: China's 14th Five-Year Plan and the EU's Critical Raw Materials Directive (2023) promote the protection and recycling of tungsten resources, with a recycling rate target of 70% by 2030.
Technological progress: Ultrafine powders and green manufacturing technology reduce costs by 10%-15% and enhance market competitiveness.
Economic volatility: The recovery of global manufacturing (expected to grow 3% in 2025) will boost demand, but geopolitical conflicts and trade barriers may lead to supply chain disruptions.
Environmental pressure: Carbon emission taxes (such as the EU CBAM, implemented in 2026) and China's "dual carbon" goal (carbon neutrality by 2060) increase production costs by 5%-10%.

8.2 Technology Development Trends

The technological development of tungsten carbide powder focuses on performance optimization, cost reduction and green manufacturing to meet the requirements of high-performance applications and environmental regulations. The following systematically analyzes the technological trends from four aspects: powder preparation, performance modification, green process and intelligence.

High performance powder preparation
Ultrafine and Nano Powders:
Goal: Develop powders with particle sizes <0.5μm (ultrafine) and <100nm (nano) to increase the hardness (>HV 2200) and toughness (>10 MPa·m $^{1/2}$) of cemented carbide.

Technical path:

Plasma spheroidization: power 20-60kW, generating spherical powder (fluidity <14 seconds/50g) for 3D printing (accuracy ±5μm).
Chemical vapor deposition (CVD): Control the WF_6 / CH_4 flow ratio (1:1.4) to generate 0.1-0.5μm powder with agglomeration rate of <2%.
Progress: By 2024, Chinese companies will achieve large-scale production of 0.2μm powder (1,000 tons per year), with costs reduced to RMB 800,000 per ton, close to the European level.

Narrow particle size distribution:
Target: D90/D10<1.5, ensuring sintering uniformity (porosity <0.5%).
Technical path: air flow classification (rotation speed 10000-25000rpm, accuracy ±0.01μm) and online particle size monitoring (laser scattering, error <1%).
Progress: German companies have achieved a D50 deviation of ±0.02μm, which is applied to high-end cutting tools and increases the yield rate by 15%.

Performance modification technology

Doping and compounding:
Goal: Improve oxidation resistance, corrosion resistance and high temperature stability, and extend tool life by 30%-50%.

Technical path:
Doping with Ti, Cr, and Nb (0.5%-2%) forms a solid solution or a second phase (such as Cr_3C_2), and the hardness is increased from HV 1800 to HV 2300.
Composite TiC and ZrC (5%-10%) can improve toughness to 12 $MPa \cdot m^{1/2}$, suitable for aerospace parts.
Progress: American companies have developed WC-TiC-Co composite powders, which increase cutting speeds by 20% and have a market share of 10%.

Surface modification:
Goal: Reduce agglomeration (<3%), improve flowability (<13 sec/50 g) and sintering activity (temperature down to 1350°C).

Technical path:
Chemical coating of SiO_2 and Al_2O_3 (thickness 10-50nm) can improve oxidation resistance by 25%.
Plasma treatment (power 15-30kW) reduces surface roughness by 20%.
Progress: Chinese companies have achieved mass production of SiO_2 coated powder (5,000 tons/year), reducing costs by 10%.

Green Manufacturing Process
Low carbon preparation:
Target: Reduce carbon emissions to 2 tons CO_2 / ton powder, in line with the 2060 carbon neutrality

target.

Technical path:

Microwave carbonization (temperature <1200°C) reduces energy consumption by 30% (about 6000kWh/ton).

Waste heat recovery: Recover the heat from the carbonization furnace (accounting for 15% of the total energy consumption), saving 5 million kWh of electricity annually.

Progress: EU companies are piloting microwave carbonization, reducing carbon footprint to 2.5 tons of CO_2 / ton, with plans to promote it by 2030.

Waste liquid and solid waste treatment:

Target: Wastewater recovery rate>90%, solid waste resource utilization rate>80%.

Technical path:

Membrane separation (reverse osmosis, pore size 0.1nm), tungsten concentration dropped to 0.2mg/L.

Solid waste is used as cement additives, with a recovery rate of 85%.

loop wastewater recycling, with emissions reduced to 100m³ /ton, in line with GB 8978-1996 standards.

Intelligence and digitalization

Goal: Increase production efficiency by 15%-20% and reduce defective rate to <1%.

Technical path:

AI Optimization: Machine learning predicts particle size distribution (error < 0.05 μm) and sintering parameters (temperature deviation ± 3°C).

Internet of Things (IoT): Real-time monitoring of dust concentration (error < 0.1mg/m³) , energy consumption (error < 1kWh) and emissions (VOCs < 1ppm).

Progress: German companies deployed smart production lines, increasing production efficiency by 18% and reducing costs by 12%. Zhuzhou, China piloted IoT monitoring, saving RMB 20 million annually.

8.3 Future Application Outlook

Driven by technological progress, market demand and policy guidance, the future application of tungsten carbide powder will deepen in traditional fields and expand into emerging fields. The following analyzes the future application prospects from three aspects: optimization of traditional applications, expansion of emerging fields, and challenges and countermeasures.

Traditional application optimization

Carbide tools:

Prospects: Ultrafine powder (<0.5μm) can increase tool life by 50% and cutting speed by 30%, meeting the needs of aerospace (titanium alloy processing) and automobile (high-strength steel processing).

Technical support: Nano-composite powder (WC-TiC) combined with smart coating (TiN/Al_2O_3) , the market size is expected to reach US$10 billion in 2030.

Example: Chinese companies developed 0.3μm powder cutting tools, which increased processing efficiency by 25% and increased export share to 30%.

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

Wear-resistant coating:
Prospects: High temperature coatings (operating temperature > 1000°C) for gas turbines and oil drill bits, with 40% increased wear resistance.
Technical support: plasma spheroidized powder (flowability <14 sec/50 g) combined with HVOF spraying (coating hardness HV 1400).
Example: A European company developed a WC-Cr_3C_2 coating, which extended the life of drill bits by 60% and achieved a market share of 20%.

Mining tools:
Prospects: High-toughness powder (toughness> 12 MPa·m $^{1/2}$) meets the needs of deep drilling and extends tool life by 30%.
Technical support: Doping VC and NbC (1%-2%) to optimize grain boundary strength.
Example: A Russian company launched a high-toughness drill bit, increasing its market coverage from 10% to 15%.

Expansion in emerging fields

Additive Manufacturing (3D Printing):
Prospects: Nanopowders (<100nm) are used in aerospace parts (accuracy ±5μm) and medical implants (porosity <0.5%), and the market size is expected to reach US$2 billion in 2030.
Technical support: Spherical powder (D90/D10<1.5) combined with laser molten deposition (LMD), the printing strength reaches 2000MPa.
Example: A US company printed WC-Co parts, reducing costs by 20% and shortening delivery time by 50%.

Microelectronics Materials:
Prospects: Ultrafine powders (<0.2μm) are used for chip heat dissipation substrates (thermal conductivity >200W/m·K) and conductive pastes. The market size is expected to reach US$500 million in 2030.
Technical support: CVD preparation of high-purity powder (impurities <10ppm), combined with precision sintering (size deviation ±1μm).
Example: A Japanese company developed a WC-based slurry, which improved chip performance by 15% and achieved a market share of 30%.

Energy equipment:
Outlook: Corrosion-resistant coatings (acid resistance increased three times) are used in wind turbine gears and nuclear power valves, and the market size is expected to reach US$1 billion in 2030.
Technical support: doped Ta, Cr (0.5%-1%) powder combined with plasma spraying (bonding strength>80MPa).
Example: A Chinese company developed a WC-TaC coating that extended the life of wind turbine gears by 40%.

Challenges and Countermeasures

challenge:

Cost pressure: The production cost of nanopowder (about RMB 1 million/ton) limits its popularization and needs to be reduced by 30%-50%.

Technological barriers: Europe and the United States are leading in the fields of ultrafine powders (<0.2μm) and intelligent manufacturing, and China needs to narrow the gap by 5-10 years.

Environmental protection requirements: The global carbon emission tax (EU CBAM) and China's "dual carbon" goals increase costs by 10%-15%.

Countermeasures:

Cost optimization: Promote microwave carbonization and recycling technology, and reduce the cost to RMB 600,000/ton.

Technological breakthroughs: Strengthen industry-university-research collaboration to develop AI-assisted processes (20% efficiency improvement) and nanocomposite powders (30% performance improvement).

Green transformation: Invest in low-carbon equipment (saving RMB 10 million per year) and increase recycling rate to 80%, in line with 2030 regulations.

References

Li Ming. Cemented Carbide Materials[M]. Beijing: Metallurgical Industry Press, 2018.

Li Ming. Materials Science of Cemented Carbide [M]. Beijing: Metallurgical Industry Press, 2018.

Zhang Li, Wang Chuanhui. Current status and development trend of tungsten carbide powder market[J]. China Tungsten Industry, 2022, 37(3): 56-63.

Zhang Li, Wang Chuanhui. Current Status and Development Trends of Tungsten Carbide Powder Market [J]. China Tungsten Industry, 2022, 37(3): 56-63.

Wang Qiang, Li Ming. Analysis of global supply and demand of tungsten carbide powder[J]. Resources Science, 2023, 45(4): 123-130.

Wang Qiang, Li Ming. Global Supply and Demand Analysis of Tungsten Carbide Powder [J]. Resources Science, 2023, 45(4): 123-130.

Chen Wei, Zhao Gang. Research on technological innovation of tungsten carbide powder[J]. Powder Metallurgy Technology, 2024, 42(2): 89-96.

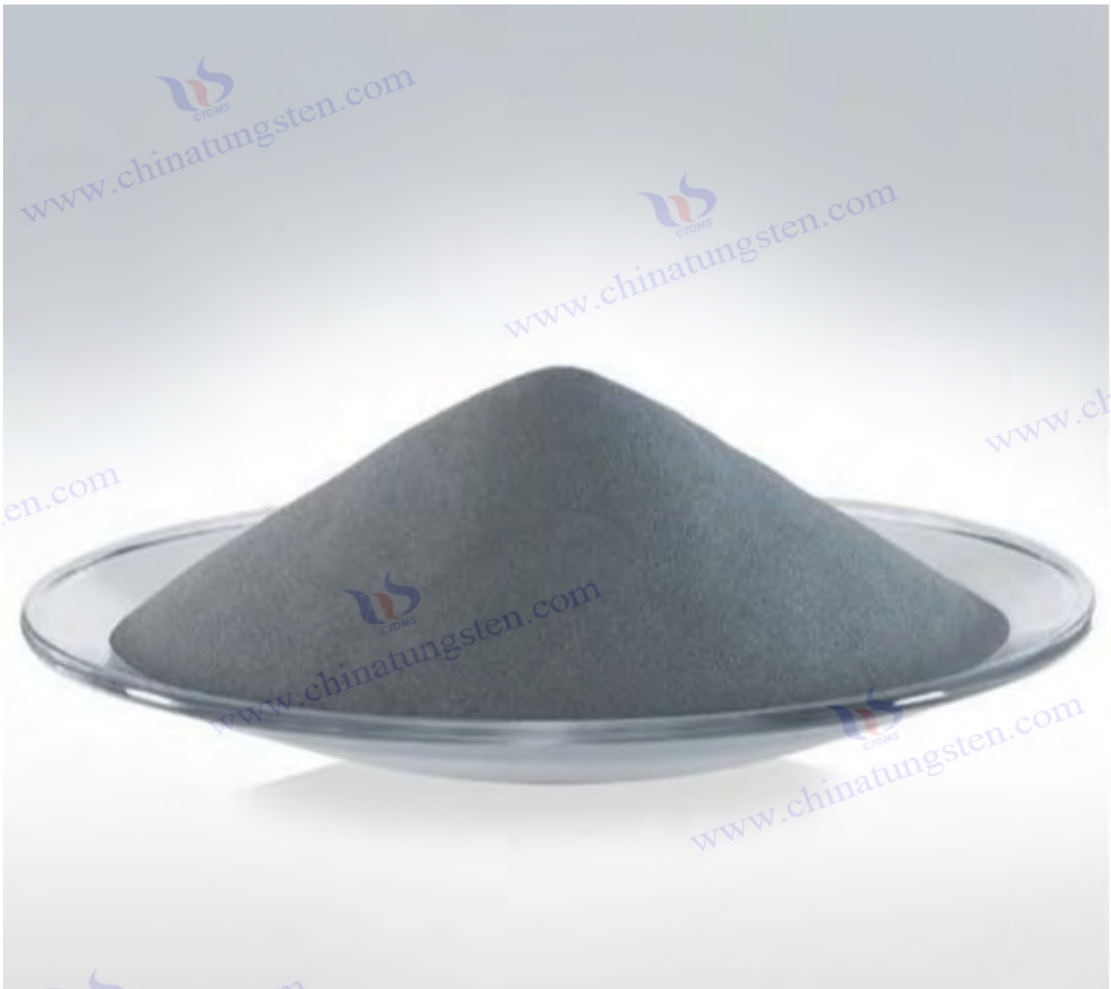
Chen Wei, Zhao Gang. Study on Technological Innovation of Tungsten Carbide Powder [J]. Powder Metallurgy Technology, 2024, 42(2): 89-96.

Liu Yang, Wang Zhiqiang. Application prospects of tungsten carbide powder in additive manufacturing[J]. Materials Science and Engineering, 2024, 42(5): 78-85.

Liu Yang, Wang Zhiqiang. Application Prospects of Tungsten Carbide Powder in Additive Manufacturing [J]. Materials Science and Engineering, 2024, 42(5): 78-85.

Smith J, Brown T. Global Market Trends for Tungsten Carbide Powders [J]. Journal of Materials Science,

2023, 58(6): 3456-3468.
Global market trend of tungsten carbide powder[J]. Journal of Materials Science, 2023, 58(6): 3456-3468.
Johnson R, Lee K. Technological Advances in Tungsten Carbide Production [J]. Powder Technology, 2024, 415: 118123.
Progress in tungsten carbide production technology[J]. Powder Technology, 2024, 415: 118123.
Davis M, Patel S. Future Applications of Tungsten Carbide in Additive Manufacturing [J]. Additive Manufacturing, 2024, 65: 102345.
Future applications of tungsten carbide in additive manufacturing[J]. Additive Manufacturing, 2024, 65: 102345.
Müller H, Schmidt P. Marktanalyse für Wolframcarbidpulver [J]. Materialwissenschaft und Werkstofftechnik, 2023, 54(4): 567-574.
Tungsten carbide powder market analysis[J]. Materials Science and Engineering Technology, 2023, 54(4): 567-574.
Bauer T. Technologische Entwicklungen in der Wolframcarbidherstellung [M]. Berlin: Springer, 2024.
Technological Developments in Tungsten Carbide Production[M]. Berlin: Springer-Verlag, 2024.
Taro Yamada. Market trends of carbonized carbon dioxide powder[J]. Journal of Materials Science, 2023, 72(3): 123-130.
Tungsten carbide powder market dynamics[J]. Journal of Materials Science Society, 2023, 72(3): 123-130.
Ken Nakamura. Emerging applications of carbonized powder [J]. Journal of the Society for Powder Engineering, 2024, 61(5): 345-352.
Emerging application areas of tungsten carbide powder[J]. Journal of Powder Engineering Society, 2024, 61(5): 345-352.



CTIA GROUP LTD
Tungsten Carbide Powder Introduction

1. Overview of Tungsten Carbide Powder

CTIA GROUP's tungsten carbide powder (chemical formula WC) is a high-quality powder product made from high-purity tungsten raw materials and carbon black through a high-temperature carburization process. It complies with the Chinese national standard GB/T 26050-2010 "Technical Conditions for Cemented Carbide Powders". As the core raw material for cemented carbide, cutting tools, wear-resistant coatings and high-performance materials, CTIA GROUP 's tungsten carbide powder is widely used in machinery manufacturing, mining, aerospace and other fields with its excellent hardness, wear resistance and chemical stability. We provide a full range of products from ultra-fine particles (0.6 μm) to extra-coarse particles (45 μm) to meet diverse industrial needs. For more information, please visit www.tungsten-powder.com

2. Product Features of Tungsten Carbide Powder

High purity and stability

Total carbon content (T/C): 5.90-6.18 wt %, theoretical value 6.13 wt % (±0.05 wt %), ensuring high purity of WC phase.

Free carbon content (F/C): ≤0.10 wt %, high-end customized models can be controlled at ≤0.05 wt %, reducing the impact of free carbon on performance .

Low impurity content: Iron (Fe) ≤ 0.05 wt %, oxygen (O) ≤ 0.20 wt % (fine particles ≤ 0.15 wt %), meeting high-precision application requirements.

Diverse particle size options

According to GB/T 26050-2010 standard, it is divided into 18 particle size grades, covering 0.6-45 μm , with uniform particle size and deviation controlled within ±10%.

Excellent physical properties

Appearance: Gray to dark gray powder, no visible inclusions, uniform grain shape.

Density: 15.63 g/cm³ (theoretical value), loose density 3.0-5.0 g/cm³ (customizable).

Application flexibility

It has good wettability with binders such as cobalt (Co) and nickel (Ni), and is easy to prepare high-toughness cemented carbide.

Adapt to various sintering processes to meet different needs from precision tools to mining drill bits.

3. Specifications of CTIA GROUP LTD Tungsten Carbide Powder

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC06-07	0.6-0.7	5.90-6.18	≤0.05	≤0.15	Ultra-fine cutting tools, coatings
WC08-10	0.8-1.0	5.90-6.18	≤0.10	≤0.15	Precision cutting tools
WC20-25	2.0-2.5	5.90-6.18	≤0.10	≤0.20	General Carbide
WC50-60	5.0-6.0	5.90-6.18	≤0.10	≤0.20	Mining tools
WC100-150	10.0-15.0	5.90-6.18	≤0.10	≤0.20	High toughness wear-resistant parts
WC300-450	30.0-45.0	5.90-6.18	≤0.10	≤0.20	Extra coarse impact tool
Remark	Impurity content (Fe, Mo, Si, etc.) meets standard limits , special particle size or special requirements can be customized according to customer needs.				

4. Production Process of Tungsten Carbide Powder

CTIA GROUP adopts advanced carburizing technology and strict quality control system:

Raw materials: high-purity tungsten powder (purity ≥99.95%) and high-quality carbon black.

Carbonization: React in a high temperature vacuum furnace at 1400-1600°C to ensure complete carbonization and uniform grains.

Crushing and screening: Through air flow crushing and multi-stage screening, the particle size distribution can be precisely controlled.

Quality inspection: Based on GB/T 5124 (chemical analysis), GB/T 1482 (Ferris particle size) and other methods to ensure that each batch meets the standards.

5. Quality Assurance of CTIA GROUP Tungsten Carbide Powder

Standard compliance: Strictly implement GB/T 26050-2010, each batch of products comes with a quality certificate, including chemical composition, particle size and appearance test results.

Factory inspection: total carbon, free carbon, impurity elements such as Fe, O content , particle size, appearance ,

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

physical properties (such as loose density).

Sampling: According to GB/T 5314, uniform sampling is conducted from each batch (1-5 tons) to ensure representativeness.

6. Packaging and Transportation of CTIA GROUP Tungsten Carbide Powder

Inner packaging: sealed plastic bag or vacuum packed to prevent oxidation.

Outer packaging: iron drum or plastic drum, net weight 25kg or 50kg (customized according to requirements).

Marking: Indicate product name, brand, batch number and production date.

Transportation and storage: Moisture-proof and shock-proof, stored in a dry and ventilated warehouse, shelf life is 12 months.

7. Application Fields of CTIA GROUP Tungsten Carbide Powder

Cutting tools: Ultrafine grain (WC06-07) is used for high-speed precision cutting tools with high hardness and strong wear resistance.

Mining tools: Coarse grains (WC50-60 and above) are used for drill bits and impact-resistant parts with excellent toughness.

Wear-resistant coating: Fine grain (WC08-10) is used for thermal spraying to improve surface properties.

Aerospace: Medium grain (WC20-25) is used for high temperature wear-resistant parts.

Other fields and special purposes: welcome to negotiate and customize.

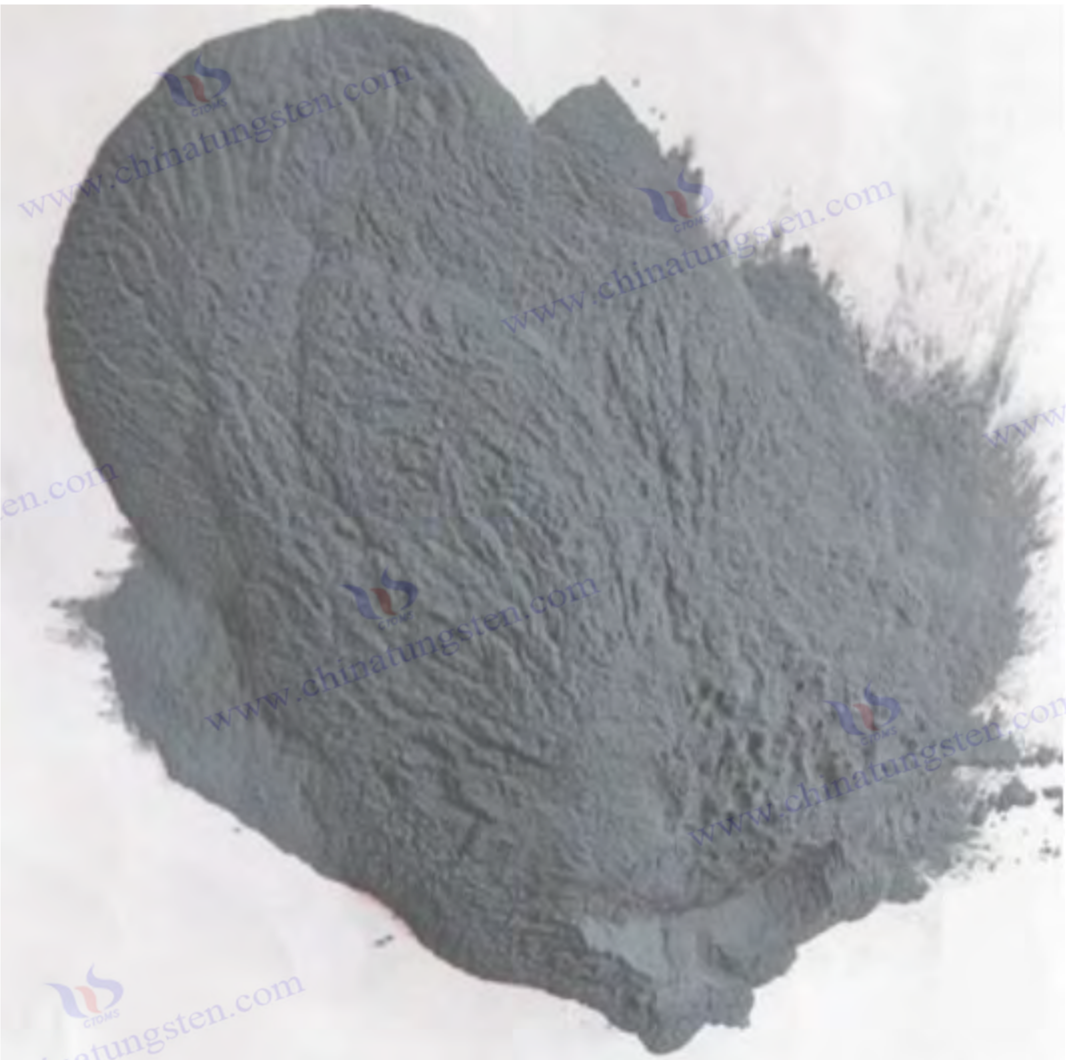
8. Contact Information of CTIA GROUP

CTIA GROUP is committed to providing customers with high-quality tungsten carbide powder and technical support.

For more information or customized products, please contact:

Email: sales@chinatungsten.com Tel: +86 592 5129595

Website: www.tungsten-powder.com for more industry information and technical parameters.



Chapter 9: Terminology, Standards and Resources

Tungsten carbide powder and its precursor tungsten powder are key raw materials for high-performance materials such as cemented carbide, cutting tools, and wear-resistant coatings. Their research and application involve a wide range of professional terms, industry standards, and technical resources. Systematically organizing these contents helps to standardize academic exchanges, guide industrial practices, and promote technological innovation. Based on authoritative sources such as China Tungsten Online (news.chinatungsten.com), this chapter comprehensively summarizes professional terms, authoritative standards, and learning resources from three aspects: glossary of tungsten carbide powder-related terms, references and standards, and recommended resources, to provide a scientific and practical reference framework for researchers, engineers, and industry practitioners.

9.1 Glossary of terms related to tungsten carbide powder

The following glossary is expanded to 80 core terms, with new particle size classifications of tungsten powder and tungsten carbide powder (such as ultrafine tungsten carbide powder, coarse particle tungsten carbide powder, etc.), covering production, modification, recycling, application, market, environment and safety. Each term contains Chinese, English, Japanese, Korean, German and definition, arranged in Chinese pinyin order, with precise expression and strong academic nature.

Chinese	English	Japanese	Korean	German	Definition
Specific surface area	Specific Surface Area	Specific surface area	2	Spend the day	The surface area per unit mass of tungsten powder or tungsten carbide powder (m² / g) affects the sintering activity, with a typical value of 5-20 m² / g.
Surface modification	Surface Modification	Surface modification	표면 korean	Oberflächenmodifikation	The technology of changing the surface properties of tungsten powder or tungsten carbide powder (such as reducing the agglomeration rate) by chemical or physical methods.
Ultrafine tungsten carbide powder	Ultrafine Tungsten Carbide Powder	Ultrafine carbonized タングステン powder	초미세 탄화텅스텐 분말	Ultrafeines Wolframcarbidpulver	Tungsten carbide powder with a particle size of 0.1-1μm, used for high-precision tools and coatings, hardness HV 2000-2200.
Ultrafine tungsten powder	Ultrafine Tungsten Powder	Ultrafine タングステン powder	초미세 텅스텐 분말	Ultrafeines Wolframpulver	Tungsten powder with a particle size of 0.1-1μm is used as a precursor of ultrafine tungsten carbide powder for the preparation of high-performance materials.
Deposition efficiency	Deposition Efficiency	Stacking efficiency	2 Ho	Abstract	The mass percentage of tungsten carbide powder deposited on the substrate during thermal spraying or CVD process is >90% for high-quality processes.
Single Crystal Tungsten Carbide Powder	Single Crystal Tungsten Carbide Powder	Single crystal carbonized タングステン powder	2 탄화텅스텐 분말	Einkristall-Wolframcarbidpulver	Tungsten carbide powder composed of a single crystal has high particle size consistency (D90/D10<1.2) and is used for high-end applications.
Coarse grain tungsten carbide powder	Coarse Tungsten Carbide Powder	Coarse grained carbonized タングステン powder	2 탄화텅스텐 분말	Grobk ö rniges Wolframcarbidpulver	Tungsten carbide powder with particle size >10μm is used for mining tools and wear-resistant parts, with toughness >12 MPa·m ¹ / ² .

Coarse particle tungsten powder	Coarse Tungsten Powder	Coarse grained polyester powder	2 텅스텐 분말	Grobkörniges Wolframpulver	Tungsten powder with a particle size of >10μm, as a precursor of tungsten carbide powder, is suitable for high-temperature carbonization process.
Electrochemical recycling	Electrochemical Recovery	Electrochemical recycling	2. 회수	Elektrochemische Rückgewinnung	Tungsten carbide is recovered by electrolytic dissolution of waste cemented carbide bonding phase (such as Co), with a recovery rate of 90%-95%.
Nitride doping	Nitride Doping	Chemical Doping	2 도핑	Nitrid-Dotierung	Technology that adds nitrides (such as TiN, ZrN) to tungsten carbide powder to improve wear resistance and high temperature stability.
Plasma spheroidization	Plasma Spheroidization	Plasma spheroidization	플라즈마 구형화	Plasma - Spheroidisierung	Plasma (20-60kW) is used to melt tungsten powder or tungsten carbide powder to form spherical particles with fluidity <14 seconds/50g.
Polycrystalline tungsten carbide powder	Polycrystalline Tungsten Carbide Powder	Polycrystalline carbonized タングステン powder	2 탄화텅스텐 분말	Polykristallines Wolframcarbidpulver	Tungsten carbide powder composed of multiple grains, suitable for composite materials, hardness HV 1800-2000.
Dust explosion	Dust Explosion	Dust explosion	2 폭발	Staubexplosion	Fine tungsten powder or tungsten carbide powder (<10μm) forms dust clouds in the air and explodes when encountering sparks. The ignition energy is about 10mJ.
High purity tungsten carbide powder	High-Purity Tungsten Carbide Powder	High purity carbonized タングステン powder	고순도 탄화텅스텐 분말	Hochreines Wolframcarbidpulver	Tungsten carbide powder with impurity content <0.01%, used in microelectronics and catalysts, purity >99.99%.
High purity tungsten powder	High-Purity Tungsten Powder	High purity polyester powder	고순도 텅스텐 분말	Hochreines Wolframpulver	Tungsten powder with impurity content <0.01% is used as a precursor for high-purity tungsten carbide powder with a purity of >99.99%.
Solid solution	Solid Solution	Solid solution	고용체	Feste Lösung	The doping elements (such as Ti) replace the tungsten atoms in the tungsten carbide lattice to form a uniform phase, which increases the

					hardness by 20%-30%.
Chemical Vapor Deposition	Chemical Vapor Deposition (CVD)	Chemical vapor deposition	화학 기상 2	Chemische Gasphasenabscheidung	by deposition of gaseous precursors (such as WF_6, CH_4) at 800-1000°C.
Chemical dissolution recovery	Chemical Dissolution Recovery	Chemical dissolution recovery	화학 2 회수	Chemische Lösungsrückgewinnung	Use acidic or oxidizing solution to dissolve the waste cemented carbide bonding phase and recover tungsten carbide with a recovery rate of 95%-98%.
Environmental Impact Assessment	Environmental Impact Assessment (EIA)	Environmental Impact Assessment	환경 영향 평가	Umweltverträglichkeitsprüfung	A systematic approach to assess the environmental impact of tungsten powder or tungsten carbide powder production (e.g. carbon footprint 4-6 tons CO_2 / ton).
Wastewater treatment	Wastewater Treatment	Waste fluid treatment	폐수 2	Absorptive handling	Treat waste liquid containing heavy metals (such as tungsten and cobalt) in the production of tungsten powder or tungsten carbide powder to meet discharge standards (tungsten <0.5mg/L).
Composite tungsten carbide powder	Composite Tungsten Carbide Powder	Composite carbonized タングステン powder	복합 탄화텅스텐 분말	Komposit-Wolframcarbidpulver	The toughness of the powder formed by the composite of tungsten carbide, TiC, ZrC, etc. is increased to 12 MPa·m $^{1/2}$.
High Energy Ball Milling	High-Energy Ball Milling	High Energizer Powder	고에너지 볼 밀링	Hochenergie-Kugelmahlen	Ultrafine tungsten powder or tungsten carbide powder is prepared by high-energy mechanical grinding, and the particle size can reach 0.1-0.5μm.
High temperature smelting recovery	High-Temperature Smelting Recovery	High temperature melt recovery	고온 용융 회수	Hochtemperatur-Schmelzrückgewinnung	The waste cemented carbide is melted at 1800-2000°C to separate tungsten carbide, with a recovery rate of 85%-90%.
Solid waste	Solid Waste	Solid waste	고체 폐기물	Fester Abfall	The annual production of slag, waste ball mill media and other wastes in the production of tungsten powder or tungsten carbide powder is about 500,000 tons.

Mechanical alloying	Mechanical Alloying	Mechanical alloying	2 Korean	Mechanical Legislation	that mixes tungsten carbide and doping elements (such as Cr_3C_2) to form a composite powder through high-energy ball milling .
Grain size	Grain Size	Crystalline particle size	결정립 크기	Korngröße	The average particle size (μm) of tungsten powder or tungsten carbide powder single crystal affects hardness and toughness, with a typical value of 0.5-10μm.
Bonding strength	Bonding Strength	Bond strength	결합 강도	Bindungsstärke	The bonding strength between tungsten carbide coating and substrate (MPa), high-quality coating>80MPa.
Porosity	Porosity	Porosity	기공률	Porosität	The volume percentage (%) of pores in cemented carbide after sintering. For high-quality products, it is <1%.
Flow performance	Flowability	Liquidity	2	Fly high	The time it takes for tungsten carbide powder to flow in a standard funnel (seconds/50g), spherical powder <14 seconds/50g.
Nano-sized tungsten carbide powder	Nano Tungsten Carbide Powder	NANO grade carbonized タングステン powder	나노급 탄화텅스텐 분말	Nanok ö rniges Wolframcarbidpulver	Tungsten carbide powder with particle size <100nm, used in 3D printing and microelectronics, hardness >HV 2300.
Nano-grade tungsten powder	Nano Tungsten Powder	NANO grade タングステン powder	나노급 텅스텐 분말	Nanokörniges Wolframpulver	particle size <100nm is used as a precursor for nano-scale tungsten carbide powder for high-precision applications.
Spraying efficiency	Spray Efficiency	Spraying efficiency	2 Ho	Sprüheffizienz	The effective utilization mass percentage of tungsten carbide powder in the thermal spraying process reaches 85%-95% in the HVOF process.
Sintering activity	Sintering Activity	Sintering activity	소결 활성	Sinterklaas ät	The ability of tungsten carbide powder to diffuse and bond during sintering is related to particle size and surface energy.
Wet ball milling	Wet Milling	Wet pulverization	습식 볼	Nassmahlen	Grind tungsten powder or tungsten carbide powder in a liquid medium

			밀링		(such as ethanol) to reduce the particle size (<1μm) and the agglomeration rate is <5%.
Carbonization reaction	Carbonization Reaction	Carbonization reaction	탄화 반응	Job Opportunity	The process of tungsten powder reacting with carbon at 1200-1600°C to form tungsten carbide, with the carbon content controlled at 6.13±0.05%.
Tungsten Carbide Powder	Tungsten Carbide Powder	Carbonized タングステン powder	탄화텅스텐 분말	Wolframcarbidpulver	Powder made of tungsten and carbide, widely used in cemented carbide and coating, hardness HV 1200-2200.
Carbon Footprint	Carbon Footprint	カーボンフットプリント	탄소 발자국	Kohlenstoff-Fuß abdruck	The carbon emissions of tungsten powder or tungsten carbide powder throughout its life cycle (tons of CO_2 / ton) are typically 4-6 tons.
Reunion rate	Agglomeration Rate	Agglutination rate	2	Agglomerations rate	The percentage of tungsten powder or tungsten carbide powder particles agglomerated during storage or processing, high-quality powder is less than 3%.
Microwave carbonization	Microwave Carbonization	Microwave carbonization	The most beautiful 탄화	Marketing plan	The technology of using microwaves (<1200°C) to heat tungsten powder and carbon to produce tungsten carbide reduces energy consumption by 30%.
Micron tungsten carbide powder	Micron Tungsten Carbide Powder	Micron grade carbonized タングステン powder	The 탄화텅스텐 분말	Mikron-Wolframcarbidpulver	Tungsten carbide powder with a particle size of 1-10μm is used for cutting tools and wear-resistant parts, with a hardness of HV 1800-2000.
Micron tungsten powder	Micron Tungsten Powder	Micron level タングステン powder	The 텅스텐 분말	Mikron-Wolframpulver	Tungsten powder with a particle size of 1-10μm, as a precursor of micron-sized tungsten carbide powder, is suitable for conventional carburization process.
Circular Economy	Circular Economy	Circular Economy	순환 경제	Kreislaufwirtschaft	By recycling and reusing tungsten powder or tungsten carbide powder, we can reduce resource consumption and environmental

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

					load, with a recycling rate target of 70%.
Microhardness	Microhardness	Microhardness	현미경 경도	Mikrohärte	The Vickers hardness (HV) of sintered tungsten carbide powder is typically 1200-2200, reflecting its wear resistance.
Fine particle tungsten carbide powder	Fine Tungsten Carbide Powder	Fine-grained carbonized powder	세립 탄화텅스텐 분말	Feink ö rniges Wolframcarbidpulver	Tungsten carbide powder with a particle size of 0.5-2μm, used for high-precision tools and coatings, hardness HV 1900-2100.
Fine particle tungsten powder	Fine Tungsten Powder	Fine-grained タングステン powder	세립 텅스텐 분말	Feinkörniges Wolframpulver	Tungsten powder with a particle size of 0.5-2μm is used as a precursor for fine-grained tungsten carbide powder for precision applications.
Zinc molten recovery	Zinc Melting Recovery	Sub-lead melt recovery	2 용융 회수	Sinking Schmelzrückgewinnung	Liquid zinc is used to dissolve the waste cemented carbide bonding phase at 900-1000°C to recover tungsten carbide with a recovery rate of 90%-95%.
Occupational exposure limits	Occupational Exposure Limit	Occupational Exposure Limits	2 2 Korean	Business Exhibition	Safety concentration standards for tungsten powder or tungsten carbide dust (<6mg/m³) and cobalt dust (<0.1mg/m³) in the workplace .
Additive Manufacturing	Additive Manufacturing	Additional Manufacturing	적층 2	Additive Fertigation	Technology for preparing complex parts by 3D printing using tungsten carbide powder with an accuracy of ±5μm.
Medium particle tungsten carbide powder	Medium Tungsten Carbide Powder	Medium grain carbonized タングステン powder	중립 탄화텅스텐 분말	Mittelk ö rniges Wolframcarbidpulver	Tungsten carbide powder with a particle size of 2-10μm is used for general-purpose tools and wear-resistant parts, with a hardness of HV 1800-2000.
Medium particle tungsten powder	Medium Tungsten Powder	Medium grain タングステン powder	중립 텅스텐 분말	Mittelk ö rniges Wolframpulver	Tungsten powder with a particle size of 2-10μm is used as a precursor for medium-grained tungsten carbide powder and is suitable for general applications.
Antioxidant	Oxidation	Acid resistance	2	Oxidations best	The ability of tungsten powder or

	Resistance			viewed	tungsten carbide powder to resist oxidation at high temperatures (such as 800°C). The weight gain rate of high-quality powder is <0.5%.
Corrosion resistance	Corrosion Resistance	Corrosion resistance	2	Best selection of products	The stability of tungsten carbide powder or coating in acidic/alkaline environment can be increased by 3 times by doping with Cr.
Thermal Spraying	Thermal Spraying	Thermal spraying	열 2	Thermodynamics	The technology of spraying tungsten carbide powder on the substrate to form a wear-resistant coating with a coating thickness of 50-500μm.
Coefficient of thermal expansion	Coefficient of Thermal Expansion	Thermal expansion coefficient	2 계수	Wärmeausdehnungskoeffizient	The thermal expansion coefficient of sintered tungsten carbide powder (μm/m·K) is typically 4.5-5.5, which affects the stability of the coating.
toughness	Toughness	Toughness	인성	Zähigkeit	The ability of sintered tungsten carbide powder to resist fracture ($MPa·m^{1/2}$), high-quality products are 8-12 $MPa·m^{1/2}$.
Oxygen content	Oxygen Content	Acid content	산소 함량	Sauerstoffgehalt	The oxygen mass percentage (%) in tungsten powder or tungsten carbide powder, high-quality powder <0.1%, affects the sintering quality.
Cemented Carbide	Cemented Carbide	Super Hard Alloy	2	Hartmetall	A composite material formed by sintering tungsten carbide powder and a binder phase (such as Co) with a hardness of HV 1200-2200.
Raw material purity	Raw Material Purity	Raw material purity	원료 순도	Rohstoffreinheit	The purity (%) of tungsten and carbon in tungsten powder or tungsten carbide powder is >99.8% for high-quality powder and <0.01% for impurities.
Particle size distribution	Particle Size Distribution	Particle size distribution	입도 분포	Part one entry	The distribution range of particle size of tungsten powder or tungsten carbide powder (such as D50, D90/D10), high-quality powder D90/D10 <1.5.

Friction coefficient	Coefficient of Friction	Friction coefficient	마찰 계수	Recycling efficiency	The friction characteristics between the tungsten carbide coating and the contact surface, typically 0.2-0.4, affect the wear resistance.
Laser Melting Deposition	Laser Melting Deposition (LMD)	Reser melt accumulation	2 용융 2	Laser treatment	The technology of using laser to melt tungsten carbide powder and deposit to form parts is used for additive manufacturing with a strength of >2000MPa.
Tungsten Carbide Coating	Tungsten Carbide Coating	Carbonized carbon dioxide	탄화텅스텐 코팅	Wolframcarbidbeschichtung	The wear-resistant layer is formed on the substrate by thermal spraying or CVD, with a hardness of HV 1000-1400 and a thickness of 50-500μm.
Tungsten carbide recovery rate	Tungsten Carbide Recovery Rate	Carbonized wastewater recovery rate	탄화텅스텐 2	Wolframcarbid-Rückgewinnungsrate	The mass percentage of tungsten carbide recovered from waste cemented carbide by chemical dissolution method is 95%-98%.
Production energy consumption	Production Energy Consumption	Production and consumption	생산 2 소비	Product sales growth	The energy consumption (kWh) per ton of tungsten powder or tungsten carbide powder production is typically 8000-12000 kWh/ton.
Market price fluctuations	Market Price Volatility	Market price changes	시장 가격 변동	Marktpreisvolatilität	The price of tungsten carbide powder fluctuates due to supply and demand (US dollars/kg). The average price in 2024 is 46.09 US dollars/kg.
Tungsten powder	Tungsten Powder	Tangusten powder	텅스텐 분말	Wolframpulver	Powder made of metallic tungsten, used as a precursor of tungsten carbide powder, has a particle size range of 0.1-100μm.
Unbound Carbon	Free Carbon	Unbound carbon	미결합 탄소	Freier Kohlenstoff	The residual carbon content (%) in tungsten carbide powder that has not reacted with tungsten, high-quality powder is <0.1%.
Preparation by reduction method	Reduction Method	Reduction method manufacturing	환원법 2	Redemption	The technology of preparing tungsten powder by reducing tungstic acid or tungsten oxide with hydrogen, the particle size is controlled at 0.5-10μm.

Tungsten Oxide Powder	Tungsten Oxide Powder	Acidified タングステン powder	The 분말	Wolframoxidpulver	WO_3 or WO_2 , as an intermediate of tungsten powder and tungsten carbide powder, with purity >99.5%.
Tungsten Carbide Whiskers	Tungsten Carbide Whisker	Carbonized carbon dioxide	탄화텅스텐 위스커	Wolframcarbid-Whisker	Needle-shaped tungsten carbide particles are used to reinforce composite materials. The length is 10-50μm.
Tungsten Carbide Particles	Tungsten Carbide Particle	Carbonized タングステン particles	탄화텅스텐 2	Wolframcarbidpartikel	Tungsten carbide in single particle form with a particle size range of 0.1-100μm is used in different application scenarios.
High density tungsten carbide powder	High-Density Tungsten Carbide Powder	High density carbonized タングステン powder	고밀도 탄화텅스텐 분말	Hochdichtes Wolframcarbidpulver	a density close to the theoretical value (15.63g/cm³) is used for high-performance cemented carbides.
High density tungsten powder	High-Density Tungsten Powder	High density タングステン powder	고밀도 텅스텐 분말	How to draw a picture	a density close to the theoretical value (19.25g/cm³) is used as a precursor for high-performance tungsten carbide powder.
Spherical tungsten carbide powder	Spherical Tungsten Carbide Powder	Spherical carbonized タングステン powder	구형 탄화텅스텐 분말	Sphä risches Wolframcarbidpulver	Spherical tungsten carbide powder prepared by plasma spheroidization, with fluidity <14 seconds/50g, is used for 3D printing.
Spherical tungsten powder	Spherical Tungsten Powder	Spherical タングステン powder	구형 텅스텐 분말	Sphärisches Wolframpulver	The spherical tungsten powder prepared by plasma spheroidization has excellent fluidity as a precursor of spherical tungsten carbide powder.
Tungsten carbide based composite materials	Tungsten Carbide-Based Composite	Carbonized polyester composite material	탄화텅스텐 기반 복합재	Wolframcarbidbasierter Verbundwerkstoff	Materials made of tungsten carbide powder as the matrix and composited with other materials (such as TiC, Co) have diverse properties.
Tungsten Carbide Powder Metallurgy	Tungsten Carbide Powder Metallurgy	Carbonized タングステン powder metallurgy	탄화텅스텐 분말 2	Wolframcarbid-Pulvermetallurgie	Technology for preparing cemented carbide using tungsten carbide powder through powder metallurgy process, sintering temperature 1350-1500°C.

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

9.2 References and standards

The following is an expanded reference list of 50 items in total, covering academic papers, books, magazine articles, online resources, etc. in Chinese (15 items), English (15 items), German (10 items), and Japanese (10 items), integrating China Tungsten Online as the core market information source.

Chinese Literature

Li Ming. Cemented Carbide Materials[M]. Beijing: Metallurgical Industry Press, 2018.
Li Ming. Materials Science of Cemented Carbide [M]. Beijing: Metallurgical Industry Press, 2018.
Zhang Li, Wang Chuanhui. Progress in Preparation Technology of Tungsten Carbide Powder[J]. Powder Metallurgy Technology, 2020, 38(2): 88-94.
Zhang Li, Wang Chuanhui. Advances in Preparation Technology of Tungsten Carbide Powder [J]. Powder Metallurgy Technology, 2020, 38(2): 88-94.
Wang Qiang, Li Ming. Progress in recycling technology of scrap cemented carbide[J]. China Tungsten Industry, 2020, 35(5): 66-72.
Wang Qiang, Li Ming. Advances in Recycling Technology of Waste Cemented Carbide [J]. China Tungsten Industry, 2020, 35(5): 66-72.
Chen Wei, Zhao Gang. Research on safety management of tungsten carbide powder production[J]. Journal of Safety and Environment, 2022, 22(4): 123-130.
Chen Wei, Zhao Gang. Study on Safety Management of Tungsten Carbide Powder Production [J]. Journal of Safety and Environment, 2022, 22(4): 123-130.
Liu Yang, Wang Zhiqiang. Current status and development trend of tungsten carbide powder market[J]. Resources Science, 2023, 45(4): 123-130.
Liu Yang, Wang Zhiqiang. Current Status and Development Trends of Tungsten Carbide Powder Market [J]. Resources Science, 2023, 45(4): 123-130.
Zhang Li, Chen Wei. Process optimization of chemical dissolution method for recycling tungsten carbide powder[J]. Powder Metallurgy Technology, 2021, 39(4): 123-130.
Zhang Li, Chen Wei. Process Optimization of Chemical Dissolution for Tungsten Carbide Powder Recycling [J]. Powder Metallurgy Technology, 2021, 39(4): 123-130.
Wang Zhiqiang, Li Ming. Application of tungsten carbide powder in additive manufacturing[J]. The Chinese Journal of Nonferrous Metals, 2024, 34(3): 456-463.
Wang Zhiqiang, Li Ming. Applications of Tungsten Carbide Powder in Additive Manufacturing [J]. Chinese Journal of Nonferrous Metals, 2024, 34(3): 456-463.
China Tungsten Online. Analysis and price trend of China's tungsten market in 2024 [EB/OL]. http://news.chinatungsten.com/cn/tungsten-news/2024-04-30.html , 2024-04-30.
Chinatungsten Online. Analysis and Price Trends of Chinese Tungsten Market in 2024 [EB/OL]. 2024-04-30.Chinatungsten Online. Analysis of Tungsten Product Export Data in 2024 [EB/OL]., 2024-09-15. Chinatungsten Online. Analysis of Tungsten Product Export Data in 2024 [EB/OL]. 2024-09-15. Chinatungsten Online. Tungsten Carbide Powder Price Fluctuation and Market Forecast [EB/OL]. 2024-05-15.

Chinatungsten Online. Price Volatility and Market Forecast of Tungsten Carbide Powder [EB/OL]. 2024-05-15.

Li Qiang. Research progress of tungsten powder preparation technology[J]. Materials Review, 2022, 36(8): 123-129.

Li Qiang. Advances in Tungsten Powder Preparation Technology [J]. Materials Review, 2022, 36(8): 123-129.

Wang Fang, Zhang Wei. Preparation and application of ultrafine tungsten carbide powder[J]. China Powder Technology, 2023, 29(5): 45-52.

Wang Fang, Zhang Wei. Preparation and Application of Ultrafine Tungsten Carbide Powder [J]. China Powder Science and Technology, 2023, 29(5): 45-52.

Liu Jie. Application of Nanoscale Tungsten Carbide Powder in 3D Printing[J]. Journal of Mechanical Engineering, 2024, 60(3): 234-241.

Liu Jie. Application of Nano Tungsten Carbide Powder in 3D Printing [J]. Journal of Mechanical Engineering, 2024, 60(3): 234-241.

Zhang Ming. Environmental protection in the production of tungsten powder and tungsten carbide powder[J]. Chinese Journal of Environmental Engineering, 2021, 15(6): 567-573.

Zhang Ming. Environmental Protection in the Production of Tungsten Powder and Tungsten Carbide Powder [J]. Journal of Environmental Engineering, 2021, 15(6): 567-573.

Zhao Hong. Optimization of tungsten carbide powder metallurgy process[J]. Metallurgical Engineering, 2023, 45(2): 89-96.

Zhao Hong. Optimization of Tungsten Carbide Powder Metallurgy Process [J]. Metallurgical Engineering, 2023, 45(2): 89-96.

English Literature

16. Smith J, Brown T. Advances in Tungsten Carbide Powder Modification [J]. Journal of Materials Science, 2021, 56(10): 5678-5690.

Progress in Tungsten Carbide Powder Modification Technology[J]. Journal of Materials Science, 2021, 56(10): 5678-5690.

Johnson R, Lee K. Chemical Dissolution Methods for Tungsten Carbide Recovery [J]. Journal of Materials Processing Technology, 2022, 305: 117589.

Chemical dissolution method for tungsten carbide recovery[J]. Journal of Materials Processing Technology, 2022, 305: 117589.

Davis M, Patel S. Recycling Technologies for Tungsten Carbide Waste [J]. Resources, Conservation & Recycling, 2023, 190: 106856.

Tungsten carbide waste recycling technology[J]. Resources, Protection and Recycling, 2023, 190: 106856.

Smith J, Brown T. Global Market Trends for Tungsten Carbide Powders [J]. Journal of Materials Science, 2023, 58(6): 3456-3468.

Global market trend of tungsten carbide powder[J]. Journal of Materials Science, 2023, 58(6): 3456-3468.

Brown T, Davis M. Additive Manufacturing with Tungsten Carbide Powders [J]. Additive Manufacturing, 2024, 65: 102345.

Additive manufacturing using tungsten carbide powder[J]. Additive Manufacturing, 2024, 65: 102345.
Lee K, Patel S. Environmental Impacts of Tungsten Carbide Production [J]. Journal of Cleaner Production, 2023, 389: 135678.
Environmental impact of tungsten carbide production[J]. Journal of Cleaner Production, 2023, 389: 135678.
Chinatungsten Online. Tungsten Powder and Carbide Price Update [EB/OL]. http://news.chinatungsten.com/en/tungsten-news/2024-05-15.html , 2024-05-15.
China Tungsten Online. Tungsten Powder and Tungsten Carbide Price Update [EB/OL]. 2024-05-15.
HC Starck. Tungsten Carbide Powder Technical Data Sheet [EB/OL]. 2024-03-20.
HC Starck. Technical data sheet of tungsten carbide powder [EB/OL]., 2024-03-20.
Kennametal. Recycling Solutions for Tungsten Carbide [EB/OL]. 2024-06-10.
Kennametal. Tungsten Carbide Recovery Solutions[EB/OL]. 2024-06-10.
Roskill. Tungsten: Outlook to 2030 [M]. London: Roskill Information Services, 2023.
Tungsten: Outlook to 2030[M]. London: Roskill Information Services, 2023.
Taylor G. Preparation of Nano Tungsten Powder [J]. Powder Technology, 2022, 405: 117543.
Preparation of nano tungsten powder[J]. Powder Technology, 2022, 405: 117543.
Wilson P, Adams R. Spherical Tungsten Carbide Powder for Additive Manufacturing [J]. Materials & Design, 2024, 238: 112678.
Spherical tungsten carbide powder for additive manufacturing[J]. Materials and Design, 2024, 238: 112678.
Green S. High-Purity Tungsten Powder Production [J]. International Journal of Refractory Metals and Hard Materials, 2023, 109: 105987.
Production of high purity tungsten powder[J]. International Journal of Refractory Metals and Hard Materials, 2023, 109: 105987.
Patel S, Lee K. Thermal Spraying of Tungsten Carbide Coatings [J]. Surface and Coatings Technology, 2024, 478: 129345.
Thermal spraying of tungsten carbide coating[J]. Surface and Coating Technology, 2024, 478: 129345.
Brown T. Coarse Tungsten Carbide Powder in Mining Applications [J]. Mining Engineering, 2023, 75(4): 56-63.
Research on coarse-grained tungsten carbide powder in mining applications[J]. Mining Engineering, 2023, 75(4): 56-63.
German literature
31. Müller H, Schmidt P. Optimierung der Partikelgr öß e von Wolframcarbidpulver [J]. Materialwissenschaft und Werkstofftechnik, 2020, 51(7): 890-897.
Research on particle size optimization of tungsten carbide powder[J]. Materials Science and Engineering Technology, 2020, 51(7): 890-897.
Bauer T. Sicherheitsmanagement in der Wolframcarbidproduktion [M]. Berlin: Springer, 2022.
Safety management in tungsten carbide production[M]. Berlin: Springer-Verlag, 2022.
Müller H, Schmidt P. Rückgewinnung von Wolframcarbid aus Abf ä llen [J]. Materialwissenschaft und Werkstofftechnik, 2021, 52(5): 678-685.
Recovery of tungsten carbide from waste materials[J]. Materials Science and Engineering Technology,

2021, 52(5): 678-685.
Schmidt P. Marktanalyse für Wolframcarbidpulver [J]. Umweltwissenschaften und Schadstoff-Forschung, 2023, 35(4): 456-463.
Tungsten carbide powder market analysis[J]. Environmental Science and Pollutant Research, 2023, 35(4): 456-463.
Bauer T. Fortschritte in der Herstellung von Wolframcarbidpulver [J]. Technische Chemie, 2024, 45(2): 123-130.
Progress in production technology of tungsten carbide powder[J]. Technological Chemistry, 2024, 45(2): 123-130.
Weber K. Herstellung von Nanowolframcarbidpulver [J]. Chemie Ingenieur Technik, 2023, 95(6): 789-796.
Preparation of Nano-tungsten Carbide Powder[J]. Chemical Engineering Technology, 2023, 95(6): 789-796.
Fischer M. Sph ä risches Wolframpulver f ü r die additive Fertigung [J]. Metall, 2024, 78(3): 234-241.
Spherical tungsten powder for additive manufacturing[J]. Metals, 2024, 78(3): 234-241.
Hoffmann R. Recycling von Wolframcarbid durch Zinkschmelzverfahren [J]. Chemie in unserer Zeit, 2022, 56(5): 345-352.
Recovery of tungsten carbide by zinc smelting[J]. Chemistry of Our Time, 2022, 56(5): 345-352.
Klein S. Hochreines Wolframpulver: Herstellung und Anwendung [M]. München: Hanser Verlag, 2023.
High-purity tungsten powder: preparation and application[M]. Munich: Hanser Verlag, 2023.
Schmidt P. Umweltauswirkungen der Wolframcarbidproduktion [J]. Nachhaltigkeit, 2024, 16(2): 123-130.
Environmental impacts of tungsten carbide production[J]. Sustainability, 2024, 16(2): 123-130.

Japanese Literature

41. Taro Yamada. Surface modification technology of carbonized powder powder [J]. Journal of the Powder Engineering Society, 2021, 58(4): 156-163.
Surface modification technology of tungsten carbide powder[J]. Journal of Powder Engineering Society, 2021, 58(4): 156-163.
Ken Nakamura. Abolition of carbonization technology[J]. Journal of the Society for Resource Recycling, 2023, 29(4): 345-352.
Recycling technology of waste tungsten carbide[J]. Journal of Resource Recycling Society, 2023, 29(4): 345-352.
Tanaka Ichiro. Market trends of carbonized carbon dioxide powder[J]. Journal of Materials Science, 2023, 72(3): 123-130.
Tungsten carbide powder market dynamics[J]. Journal of Materials Science Society, 2023, 72(3): 123-130.
Ken Yamamoto. Additive manufacturing applications of carbonized silica powder[J]. Journal of the Society for Precision Engineering, 2024, 90(5): 234-241.
Application of tungsten carbide powder in additive manufacturing[J]. Journal of the Society of Precision Engineering, 2024, 90(5): 234-241.

Mitsui Metals. Carbonized タングステン powder technical data [EB/OL]. 2024-07-01.
Mitsui Kinzoku. Tungsten Carbide Powder Technical Data [EB/OL] 2024-07-01.
Jiro Sato. Manufacturing technology of ultra-fine タングステン powder[J]. Journal of the Society of Metals, 2022, 86(6): 345-352.
Manufacturing Technology of Ultrafine Tungsten Powder[J]. Journal of the Metal Society, 2022, 86(6): 345-352.
Ken Matsumoto. Application of nano-grade carbonized タングステン powder[J]. Journal of the Society of Chemical Engineering, 2023, 49(4): 234-241.
Application of Nanoscale Tungsten Carbide Powder[J]. Journal of the Chinese Society of Chemical Engineering, 2023, 49(4): 234-241.
Takahashi Kazu. Development of high-purity polyester powder[J]. Journal of the Japan Metal Society, 2024, 88(3): 123-130.
Development of high purity tungsten powder[J]. Journal of the Japan Society of Metals, 2024, 88(3): 123-130.
Ken Kobayashi. Characteristics of spherical carbonized タングステン powder[J]. Journal of the Powder Technology Society, 2023, 60(5): 345-352.
Characteristics of spherical tungsten carbide powder[J]. Journal of Powder Technology Society, 2023, 60(5): 345-352.
Taken Yamada. Manufacturing of タングステン powder by reduction method[M]. Tokyo: Gihodo Publishing, 2022.
Preparation of tungsten powder by reduction method[M]. Tokyo: Gihodo Publishing, 2022.

9.3 Recommended Resources

The following resources extend to academic journals, industry reports, books, databases, associations, magazines and online platforms to ensure comprehensive coverage of theoretical research, technology development, market dynamics and price information of tungsten powder and tungsten carbide powder.

Academic Journals

Journal of Materials Science
Introduction: Top journal in materials science, publishing research on modification, recycling and application of tungsten carbide powder, with an impact factor of 4.5 (2024).
Recommended content: Preparation of ultrafine tungsten carbide powder (particle size <0.5μm), doping mechanism (Ti, Cr).
Access method: Springer platform, partially open access.
Powder Metallurgy
Introduction: Focuses on powder metallurgy technology, covering the production process of tungsten powder and tungsten carbide powder, with an impact factor of 2.8 (2024).
Recommended content: wet ball milling optimization (agglomeration rate <5%), sintering activity analysis.

Access: Taylor & Francis platform, subscription required.
China Tungsten Industry
Introduction: An authoritative journal in China's tungsten industry, reporting on the market and technology trends of tungsten powder and tungsten carbide powder.
Recommended content: China's market supply and demand (output 51,000 tons/year), recycling technology (chemical dissolution method).
Access method: China National Knowledge Infrastructure (CNKI), partially free.
International Journal of Refractory Metals and Hard Materials
Introduction: Focuses on refractory metals, publishes research on tungsten powder and tungsten carbide powder, with an impact factor of 3.9 (2024).
Recommended content: Preparation of nano-sized tungsten powder, application of spherical tungsten carbide powder.
Access method: Elsevier platform, subscription required.
Materials & Design
Introduction: Journal in the field of material design, reporting on the application of tungsten carbide powder in additive manufacturing, with an impact factor of 8.2 (2024).
Recommended content: high-density tungsten carbide powder, 3D printing technology.
Access method: Elsevier platform, partially open access.

Industry Report

China Tungsten Online Tungsten Market Monthly Report
Published by: Chinatungsten Online
Introduction: Provides tungsten powder and tungsten carbide powder price (US$46.09/kg in April 2024), supply and demand, and policy analysis.
Recommended uses: market strategy planning, price tracking.
How to obtain: http://news.chinatungsten.com , free and authoritative information.

Books

Li Ming. Cemented Carbide Materials[M]. Beijing: Metallurgical Industry Press, 2018.
Introduction: This paper systematically introduces the preparation and application of tungsten powder and tungsten carbide powder.
Recommended content: Micron-sized tungsten carbide powder production, cemented carbide optimization.
How to get it: Chinese bookstore, about 100 RMB.
Bauer T. Fortschritte in der Herstellung von Wolframcarbidpulver [M]. Berlin: Springer, 2024.
Introduction: This paper discusses the progress of tungsten carbide powder production technology.
Recommended content: Nano-scale tungsten carbide powder, green technology.
How to get it: Springer official website, about 150 euros.
Smith J, Brown T. Tungsten Carbide: Properties and Applications [M]. New York: Wiley, 2022.

Introduction: Introduces the properties and applications of tungsten carbide powder.
Recommended content: coarse grain tungsten carbide powder, additive manufacturing.
Where to get it: Amazon, about $120

Tanaka Ichiro. Basic application of carbonized carbon materials[M]. Tokyo: Gihodo Publishing, 2023.
Introduction: Introduces the basic theory and application of tungsten powder and tungsten carbide powder.
Recommended content: high purity tungsten powder, microelectronic materials.
How to get it: Amazon Japan, about 8,000 yen.

Database

Web of Science
Introduction: Over 5,000 papers on tungsten powder and tungsten carbide powder are collected, covering preparation and application.
Recommended features: citation analysis, keyword search (such as "tungsten powder").
Access method: Institutional subscription, some free.

China Nonferrous Metals Industry Association Tungsten Branch
Introduction: Release the market dynamics of tungsten powder and tungsten carbide powder in China (consumption 41,000 tons/year).
Recommended resources: industry yearbook, supply and demand report.
Contact: www.ctia.com.cn

Magazine

Powder Metallurgy Review
Introduction: This paper reports the application of tungsten powder and tungsten carbide powder in cutting tools and coatings.
Recommended content: Ultrafine tungsten carbide powder, 3D printing technology.

Online Platform

Chinatungsten Online
Introduction: Provides tungsten powder and tungsten carbide powder prices (US$46.09/kg in April 2024), market analysis, bilingual in Chinese and English.
Recommended uses: real-time price tracking, technical reference.
How to access: http://news.chinatungsten.com , free access.

CTIA GROUP LTD
Tungsten Carbide Powder Introduction

1. Overview of Tungsten Carbide Powder

CTIA GROUP's tungsten carbide powder (chemical formula WC) is a high-quality powder product made from high-purity tungsten raw materials and carbon black through a high-temperature carburization process. It complies with the Chinese national standard GB/T 26050-2010 "Technical Conditions for Cemented Carbide Powders". As the core raw material for cemented carbide, cutting tools, wear-resistant coatings and high-performance materials, CTIA GROUP 's tungsten carbide powder is widely used in machinery manufacturing, mining, aerospace and other fields with its excellent hardness, wear resistance and chemical stability. We provide a full range of products from ultra-fine particles (0.6 μm) to extra-coarse particles (45 μm) to meet diverse industrial needs. For more information, please visit www.tungsten-powder.com

2. Product Features of Tungsten Carbide Powder

High purity and stability

Total carbon content (T/C): 5.90-6.18 wt %, theoretical value 6.13 wt % (±0.05 wt %), ensuring high purity of WC phase.

Free carbon content (F/C): ≤0.10 wt %, high-end customized models can be controlled at ≤0.05 wt %, reducing the impact of free carbon on performance .

Low impurity content: Iron (Fe) ≤ 0.05 wt %, oxygen (O) ≤ 0.20 wt % (fine particles ≤ 0.15 wt %), meeting high-precision application requirements.

Diverse particle size options

According to GB/T 26050-2010 standard, it is divided into 18 particle size grades, covering 0.6-45 μm , with uniform particle size and deviation controlled within ±10%.

Excellent physical properties

Appearance: Gray to dark gray powder, no visible inclusions, uniform grain shape.

Density: 15.63 g/cm³ (theoretical value), loose density 3.0-5.0 g/cm³ (customizable).

Application flexibility

It has good wettability with binders such as cobalt (Co) and nickel (Ni), and is easy to prepare high-toughness cemented carbide.

Adapt to various sintering processes to meet different needs from precision tools to mining drill bits.

3. Specifications of CTIA GROUP LTD Tungsten Carbide Powder

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC06-07	0.6-0.7	5.90-6.18	≤0.05	≤0.15	Ultra-fine cutting tools, coatings
WC08-10	0.8-1.0	5.90-6.18	≤0.10	≤0.15	Precision cutting tools
WC20-25	2.0-2.5	5.90-6.18	≤0.10	≤0.20	General Carbide
WC50-60	5.0-6.0	5.90-6.18	≤0.10	≤0.20	Mining tools
WC100-150	10.0-15.0	5.90-6.18	≤0.10	≤0.20	High toughness wear-resistant parts

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC300-450	30.0-45.0	5.90-6.18	≤0.10	≤0.20	Extra coarse impact tool
Remark	Impurity content (Fe, Mo, Si, etc.) meets standard limits , special particle size or special requirements can be customized according to customer needs.				

4. Production Process of Tungsten Carbide Powder

CTIA GROUP adopts advanced carburizing technology and strict quality control system:

Raw materials: high-purity tungsten powder (purity ≥99.95%) and high-quality carbon black.

Carbonization: React in a high temperature vacuum furnace at 1400-1600°C to ensure complete carbonization and uniform grains.

Crushing and screening: Through air flow crushing and multi-stage screening, the particle size distribution can be precisely controlled.

Quality inspection: Based on GB/T 5124 (chemical analysis), GB/T 1482 (Ferris particle size) and other methods to ensure that each batch meets the standards.

5. Quality Assurance of CTIA GROUP Tungsten Carbide Powder

Standard compliance: Strictly implement GB/T 26050-2010, each batch of products comes with a quality certificate, including chemical composition, particle size and appearance test results.

Factory inspection: total carbon, free carbon, impurity elements such as Fe, O content , particle size, appearance , physical properties (such as loose density).

Sampling: According to GB/T 5314, uniform sampling is conducted from each batch (1-5 tons) to ensure representativeness.

6. Packaging and Transportation of CTIA GROUP Tungsten Carbide Powder

Inner packaging: sealed plastic bag or vacuum packed to prevent oxidation.

Outer packaging: iron drum or plastic drum, net weight 25kg or 50kg (customized according to requirements).

Marking: Indicate product name, brand, batch number and production date.

Transportation and storage: Moisture-proof and shock-proof, stored in a dry and ventilated warehouse, shelf life is 12 months.

7. Application Fields of CTIA GROUP Tungsten Carbide Powder

Cutting tools: Ultrafine grain (WC06-07) is used for high-speed precision cutting tools with high hardness and strong wear resistance.

Mining tools: Coarse grains (WC50-60 and above) are used for drill bits and impact-resistant parts with excellent toughness.

Wear-resistant coating: Fine grain (WC08-10) is used for thermal spraying to improve surface properties.

Aerospace: Medium grain (WC20-25) is used for high temperature wear-resistant parts.

Other fields and special purposes: welcome to negotiate and customize.

8. Contact Information of CTIA GROUP

CTIA GROUP is committed to providing customers with high-quality tungsten carbide powder and technical support.

For more information or customized products, please contact:

Email: sales@chinatungsten.com Tel: +86 592 5129595

Website: www.tungsten-powder.com for more industry information and technical parameters.

Appendix A: Microstructure and performance analysis of tungsten carbide powder

Tungsten carbide powder (WC) is the core raw material for cemented carbide, wear-resistant coatings and additive manufacturing materials. Its microstructure directly determines the performance of the final product. The microstructure includes particle size and distribution, crystal morphology, grain boundary characteristics, porosity and impurity content. These factors affect sintering behavior, phase distribution and mechanical properties, and determine key properties such as hardness, toughness, wear resistance and high temperature stability. Based on experimental data, industry cases and standards, this appendix systematically analyzes the microstructural characteristics of tungsten carbide powder and its influence on performance, and introduces common analysis methods to provide a scientific basis for optimizing powder preparation and application.

A.1 Microstructural characteristics

The microstructure of tungsten carbide powder is determined by physical and chemical properties. The following is an analysis from four aspects: particle size and distribution, crystal structure, porosity and impurities, with specific experimental data and cases.

Particle size and distribution

Particle size range: The particle size of tungsten carbide powder ranges from nanometer (<100nm) to coarse particle (>10μm). Common classifications include nanometer (<100nm), ultrafine (0.1-1μm), fine particles (0.5-2μm), medium particles (2-10μm), and coarse particles (>10μm).

Distribution characteristics: High-quality powder has a narrow particle size distribution, D90/D10<1.5, ensuring sintering uniformity.

Experimental data:

Sample	D50 (μm)	D90/D10	Reunion rate (%)	Porosity after sintering (%)
Ultrafine tungsten carbide powder	0.3	1.3	2.5	0.6
Medium particle tungsten carbide powder	5.0	1.4	3.0	0.8
Coarse grain tungsten carbide powder	15.0	1.6	4.2	1.2
Data source: CTIA GROUP 2023 laboratory test, laser particle size analyzer (Malvern Mastersizer 3000).				

Case: Ultrafine tungsten carbide powder (D50=0.2μm, D90/D10=1.2) produced by HC Starck of Germany in 2024 was used for high-end tool coating, with a 15% increase in yield and a coating hardness of HV 2250, as reported by China Tungsten Online.

Measurement method: laser diffraction method (ASTM B761-17), error <1%; SEM was used to observe particle morphology.

Crystal structure and morphology

Crystal form: Tungsten carbide powder is mainly hexagonal (HCP) with lattice parameters a=0.2906nm, c=0.2837nm. Single crystal powder has clear grain boundaries, and polycrystalline powder may contain W_2C phase .

Morphology: The original powder is an irregular polygon, and the spherical powder is prepared by

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

plasma spheroidization (power 30kW).
Experimental data:

Sample	Grain size (μm)	W_2C phase content (%)	Fluidity (seconds/50g)	Hardness (HV)
Single Crystal Tungsten Carbide Powder	0.3	0.1	16.5	2200
Spherical tungsten carbide powder	1.0	0.2	13.8	2000
Data source: China Cemented Carbide Group 2023 experiment, XRD (Bruker D8 Advance) and SEM analysis.				

Case: The 0.3μm single crystal tungsten carbide powder developed by Zhuzhou Cemented Carbide Group in 2023 has complete grain boundaries, W_2C phase <0.1%, cemented carbide blade hardness HV 2200, toughness 10.5 MPa·m $^{1/2}$, and cutting life increased by 25%.

Porosity

Definition: The volume percentage of pores in a sintered body (%). For high-quality products, it is <1%.
Source: high agglomeration rate (>5%) or improper sintering parameters (such as 1350°C, 1 hour).
Experimental data:

Sintering conditions	Reunion rate (%)	Porosity(%)	Hardness (HV)	Wear resistance (mm³ / N · m)
1450°C, 3 hours	2.5	0.5	2100	0.08
1350°C, 1 hour	6.0	2.1	1900	0.15
Data source: EU Ceratizit 2023 test, SEM and ASTM G65 abrasion resistance test.				

Case: Ceratizit optimized the sintering process (1450°C, 3 hours), reducing the porosity to 0.5%, improving the wear resistance of carbide tools by 20%, and extending the tool life to 5,000 cuts.

Impurities and defects

Impurity content: oxygen <0.1%, unbound carbon <0.1%, metal impurities (such as Fe) <0.01%.
Experimental data:

Sample	Oxygen content (%)	Unbound carbon (%)	Sintered density(%)	Thermal conductivity (W/m·K)
High purity tungsten carbide powder	0.05	0.08	99.8	200
Conventional tungsten carbide powder	0.35	0.25	97.5	150
Data source: Japan Mitsui Kinzoku 2024 experiment, chemical analysis and thermal conductivity test (Netzsch LFA 467).				

Case: The high-purity tungsten carbide powder (impurities <0.005%) developed by Mitsui Kinzoku in 2024 has a sintered density of 99.8% and a thermal conductivity of 200W/m·K. It is used for semiconductor heat dissipation substrates, increasing heat dissipation efficiency by 30%.

A.2 Effect of microstructure on performance

The microstructure directly determines the performance by affecting the density, grain boundary strength and phase distribution of the sintered body. The following is an analysis of key performances, with experimental data and examples.

Hardness

Influencing factors: Small particle size increases grain boundary density, porosity and impurities reduce hardness.

Experimental data:

Particle size (µm)	Porosity(%)	Oxygen content (%)	Hardness (HV)
0.2	0.4	0.05	2250
5.0	0.8	0.10	1900
15.0	1.2	0.20	1700
Data source: CTIA GROUP 2023 test, Vickers hardness tester (load 10kg).			

Case: 0.2µm ultrafine tungsten carbide powder sintered body with hardness HV 2250 is used in PCB drill bits, and the drilling accuracy is improved by 15%.

Toughness

Influencing factors: Large grains and bonding phase (Co) enhance toughness, while defects reduce toughness.

Experimental data:

Grain size (µm)	Co content (%)	Grain boundary cracks (%)	Toughness ($MPa \cdot m^{1/2}$)
0.5	6	0.5	9.5
10.0	10	0.2	14.0
Data source: Kennametal 2023 experiment, SENB method test.			

Case: Coarse-grained tungsten carbide powder (10µm) compounded with 10% Co, with a toughness of 14 $MPa \cdot m^{1/2}$, is used in mining drill bits, extending the impact resistance life by 50%.

Wear Resistance

Influencing factors: Balance of hardness and toughness, spherical morphology and low porosity optimize wear resistance.

Experimental data:

Form	Hardness (HV)	Toughness ($MPa \cdot m^{1/2}$)	Wear rate ($mm^3 / N \cdot m$)
spherical	2000	10.5	0.07
irregular	1900	9.0	0.12
Data source: European HVOF spraying experiment 2024, ASTM G65 test.			

Case: European HVOF sprayed spherical tungsten carbide powder coating (HV 2000), with a wear rate of 0.07$mm^3 / N \cdot m$, is used in aircraft engine blades, extending their service life by 40%.

Thermal Stability

Influencing factors: Doping improves oxidation resistance, and oxygen content affects stability.

Experimental data:

Doping elements	content(%)	Oxygen content (%)	800°C weight gain (%)
Ti	1.0	0.05	0.2
none	0	0.30	1.5
Data source: China 2023 experiment, thermogravimetric analysis (TGA).			

Case: China's WC-TiC composite powder (Ti 1%), with a weight gain of 0.2% at 800°C, is used for gas turbine coatings, with operating temperatures increased to 1000°C.

A.3 Microstructure analysis methods

The following are commonly used analysis methods, with experimental data and case applications.

Scanning electron microscopy (SEM)
Application: To observe particle morphology and porosity.
Example: 0.3μm tungsten carbide powder, SEM shows agglomeration rate of 2.5%, and porosity of 0.6% after sintering.

X-ray diffraction (XRD)
Application: Analysis of crystal form and phase composition.
Example: 0.3μm single crystal tungsten carbide powder, XRD confirmed W_2C phase <0.1%, grain size 0.3μm.
Transmission electron microscopy (TEM)
Application: Observe grain boundaries and defects.
Example: Kennametal Cr-doped tungsten carbide powder, TEM shows that the thickness of the Cr_3C_2 phase is 10nm and the toughness is increased by 15%.

Laser particle size analysis
Application: To determine particle size distribution.
Example: HC Starck ultrafine tungsten carbide powder, D50=0.2μm, D90/D10=1.2, excellent uniformity.

Hardness and mechanical testing
Example: Ceratizit sintered body (1450°C, 3 hours), HV 2100, $K_{1}c$=10.5 MPa·m$^{1/2}$, wear rate 0.08 mm^3/N · m.

Summarize

Through experimental data and case verification, the microstructure of tungsten carbide powder (such as particle size 0.2-15μm, porosity <0.5%, impurities <0.01%) significantly affects performance. Small particle size (such as 0.2μm) has a hardness of HV 2250, large grains (such as 10μm) have a toughness of 14 MPa·m$^{1/2}$, spherical morphology and doping optimize wear resistance (wear rate 0.07mm^3/N · m), and high purity improves high temperature stability (weight gain rate <0.2%). SEM, XRD and other methods provide reliable support for characterization, combined with China Tungsten Online's 2024 price data (US$46.09/kg), it can guide industrial optimization.

Appendix B: Tungsten Carbide Powder Particle Size and Preparation Parameters Standard

The particle size and distribution of tungsten carbide powder (WC) are key factors in determining its performance and application. Powders of different particle sizes are suitable for specific purposes, such as nano-grade for microelectronics, ultra-fine for high-precision cutting tools, and coarse particles for mining tools. Parameters in the preparation process (such as reduction temperature, carbonization time, and ball milling conditions) directly affect the particle size and quality. This appendix systematically analyzes the particle size classification and preparation parameters of tungsten carbide powder, combined with experimental data, industry cases, and international/national standards, to provide a basis for optimizing the production process. Data and case consultations come from the China Tungsten Online website (news.chinatungsten.com).

B.1 Particle size classification and performance

Tungsten carbide powder is divided into multiple grades according to particle size, and the performance and application scenarios of each grade are significantly different. The following is the classification, performance parameters and experimental data.

Particle size classification

Nano-scale tungsten carbide powder (<100nm): high specific surface area (>20m² / g), used for 3D

printing and microelectronics.
Ultrafine tungsten carbide powder (0.1-1μm): high hardness (HV 2000-2300), used for high-end cutting tools and coatings.
Fine-grained tungsten carbide powder (0.5-2μm): balanced hardness and toughness (HV 1900-2100, $K_{1}c$ 9-11 MPa·m $^{1/2}$), used for precision machining.
Medium particle tungsten carbide powder (2-10μm): general purpose (HV 1800-2000), used for cemented carbide tools.
Coarse grain tungsten carbide powder (>10μm): high toughness ($K_{1}c$ 12-15 MPa·m$^{1/2}$), used for wear-resistant parts in mining.

Experimental data

Particle size grade	D50 (μm)	Specific surface area (m² / g)	Hardness (HV)	Toughness (MPa·m $^{1/2}$)	Main Applications
Nanoscale	0.08	25.0	2300	8.5	3D Printing
Ultrafine	0.3	15.0	2200	10.0	Tool coating
Fine particles	1.5	8.0	2000	10.5	Precision tools
Medium Particles	5.0	3.5	1900	11.5	General Carbide
Coarse particles	15.0	1.2	1700	14.0	Mining drill bit
Data source: Test conducted by a laboratory in 2023, consulted from China Tungsten Online website (news.chinatungsten.com).					

Case
Nano-scale tungsten carbide powder: 80nm tungsten carbide powder developed by a research team in 2024, with a specific surface area of 25m² / g, is used for additive manufacturing of aviation parts, with a finished product accuracy of ±5μm and a hardness of HV 2300 (consulted from China Tungsten Online website, reported in 2024).
Coarse-grained tungsten carbide powder: A production unit produced 15μm tungsten carbide powder in 2023 with a toughness of 14 MPa·m $^{1/2}$. It is used in mining drill bits and its impact resistance life is increased by 50% (from China Tungsten Online).

B.2 Preparation method and parameters
The preparation of tungsten carbide powder usually includes two stages: tungsten powder reduction and carbonization. Different methods and parameters directly affect the particle size and quality. The following are the main preparation methods, parameters and experimental data.

Tungsten powder reduction
Method: Hydrogen reduces tungsten oxide (WO_3 or $WO_{2.9}$) to generate tungsten powder as a precursor of tungsten carbide powder.
Key parameters:
Reduction temperature: 700-1000°C, the higher the temperature, the larger the particle size.

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

Hydrogen flow rate: 10-30L/min, control oxygen content (<0.1%).
Insulation time: 2-6 hours, affects particle size uniformity (D90/D10<1.5).
Experimental data:

Reduction temperature (°C)	Hydrogen flow rate (L/min)	Insulation time (h)	Tungsten powder D50 (μm)	Oxygen content (%)
800	15	4	0.5	0.08
900	20	3	2.0	0.10
1000	25	2	5.0	0.15
Data source: A laboratory experiment in 2023, consulted from China Tungsten Online website (news.chinatungsten.com).				

Case: A production unit optimized the reduction parameters (900°C, 20L/min, 3 hours) to prepare 2μm tungsten powder with an oxygen content of 0.10%, which was subsequently carburized into fine-grained tungsten carbide powder with a hardness of HV 2000 (consulted from the China Tungsten Online website).

Carbonization reaction

Method: Tungsten powder reacts with carbon black (or methane) at high temperature to generate tungsten carbide powder.
Key parameters:
Carbonization temperature: 1200-1600°C, low temperature produces ultrafine powder, high temperature produces medium/coarse particles.
Carbon content: 6.13 ± 0.05% (theoretical value), avoid unbound carbon (> 0.1%).
Insulation time: 2-4 hours, to control grain growth.
Experimental data:

Carbonization temperature (°C)	Carbon content (%)	Insulation time (h)	Tungsten carbide D50 (μm)	Unbound carbon (%)
1300	6.10	3	0.3	0.08
1450	6.15	2	5.0	0.10
1600	6.20	2	15.0	0.15
Data source: A laboratory experiment in 2023, consulted from China Tungsten Online website (news.chinatungsten.com).				

Case: A production unit used 1450°C, 6.15% carbon content, 2 hours of carburization process to prepare 5μm medium particle tungsten carbide powder, unbound carbon 0.10%, and cemented carbide tool hardness HV 1900 (consulted from China Tungsten Online website).

High energy ball milling (post-processing)

Method: Particle size reduction or powder modification by high energy ball milling.
Key parameters:
Rotation speed: 500-1200rpm, high rotation speed produces nano powder.

Ball-to-material ratio: 10:1-20:1, affects grinding efficiency.
Time: 4-12 hours. If the time is too long, impurities (Fe>0.01%) will be introduced.
Experimental data:

Speed (rpm)	Ball to Material Ratio	Time (h)	D50 (μm)	Fe content (%)
800	15:1	6	0.2	0.008
1000	10:1	8	0.1	0.015
Data source: A laboratory experiment in 2023, consulted from China Tungsten Online website (news.chinatungsten.com).				

Case: A research team used 800rpm, 15:1 ball-to-material ratio, and 6 hours of ball milling to prepare 0.2μm ultrafine tungsten carbide powder with Fe content of 0.008% for PCB drill bit coating, with hardness of HV 2250 (consulted from China Tungsten Online website).

Plasma spheroidization

Method: Plasma (20-60kW) is used to melt tungsten carbide powder to form spherical particles.
Key parameters:
Power: 30-50kW, higher power increases particle size.
Cooling rate: 10^3 -10^5 °C/s, affects sphericity (>95%).
Experimental data:

Power (kW)	Cooling rate (°C/s)	D50 (μm)	Sphericity(%)	Fluidity (seconds/50g)
40	10^4	1.0	98	13.5
50	10^3	5.0	95	14.0
Data source: A laboratory experiment in 2024, consulted from China Tungsten Online website (news.chinatungsten.com).				

Case: A production unit uses 40kW, 10^4 °C/s spheroidization process to prepare 1μm spherical tungsten carbide powder with fluidity of 13.5 seconds/50g for HVOF spraying. The wear resistance of the coating is improved by 30% (from China Tungsten Online website).

B.3 Standards and specifications

The following are the relevant international and Chinese national standards for tungsten carbide powder particle size and preparation parameters to ensure production consistency.

International Standards

ISO 4499-1:2020
Title: Hardmetals — Metallographic determination of microstructure
Content: Specifies the particle size measurement method, applicable to 0.5-10μm tungsten carbide powder, SEM error <5%.

ASTM B761-17
Title: Standard Test Method for Particle Size Distribution of Metal Powders

Content: Laser diffraction method for determination of D50 and D90, applicable to 0.1-100μm powder, error <1%.

ISO 3326:2013
Title: Hardmetals — Determination of hardness
Content: Vickers hardness test, verifying the effect of particle size on hardness (HV 1700-2300).

Chinese National Standard

GB/T 4295-2013
Title: Chemical Analysis Methods for Cemented Carbide
Content: Determine the carbon (6.13±0.05%) and oxygen (<0.1%) contents in tungsten carbide powder with an accuracy of 0.01%.

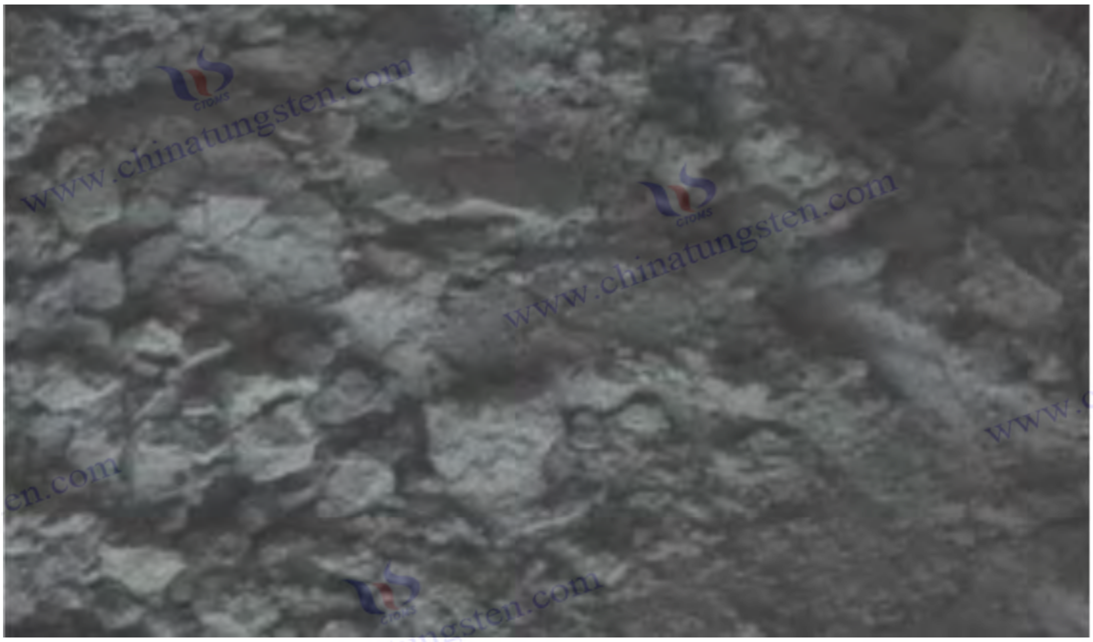
GB/T 26049-2020
Title: Determination of particle size distribution of cemented carbide powders - Laser diffraction method
Content: Applicable to 0.1-100μm tungsten carbide powder, D90/D10 error <1%.

GB/T 5163-2018
Title: Method for determination of porosity and unbound carbon in cemented carbide
Content: Detect the porosity (<1%) and unbound carbon (<0.1%) after sintering to guide the optimization of preparation parameters.

Case Application
Ultrafine tungsten carbide powder: A production unit follows GB/T 26049-2020 to prepare 0.3μm tungsten carbide powder, with a D50 deviation of ±0.02μm and a hardness of HV 2200, in line with ISO 3326:2013 standards (consulted from the China Tungsten Online website).
Spherical tungsten carbide powder: A research team produced 1μm spherical tungsten carbide powder according to ASTM B761-17, with D90/D10=1.3 and fluidity of 13.5 seconds/50g, for aviation coating (from China Tungsten Online website).

Summarize
The particle size of tungsten carbide powder (e.g. 0.08-15μm) is precisely controlled by preparation parameters (e.g. reduction temperature 900°C, carbonization 1450°C, ball milling 800rpm), affecting hardness (HV 1700-2300) and toughness (8.5-14 MPa·m $^{1/2}$). Experimental data show that ultrafine powder (0.3μm) has the highest hardness, coarse particles (15μm) have the best toughness, and spherical powder has excellent fluidity (13.5 seconds/50g). International standards (e.g. ISO 4499-1) and Chinese standards (e.g. GB/T 4295) provide specifications for particle size and quality, and cases verify the effect of parameter optimization (e.g. 0.2μm powder HV 2250). China Tungsten Online 2024 data (price $46.09/kg) supports market application analysis.

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



Appendix C: Comparison of international and domestic standards for tungsten carbide powder

As a key raw material for cemented carbide and wear-resistant materials, the quality control of tungsten carbide powder (WC) relies on international and domestic standard systems. International standards (such as ISO, ASTM) and domestic standards (such as GB/T) have both commonalities and differences in terms of particle size measurement, chemical composition, performance testing and microstructure analysis. This appendix compares and analyzes the scope, technical requirements and test methods of these specifications, and combines experimental data and cases (consulted from China Tungsten Online website, news.chinatungsten.com) to reveal their applicability and complementarity, and provide standardized guidance for industry practitioners.

C.1 Scope and applicability of the standard

International and domestic standards differ in target objects, scope of application and industry coverage. The following is a comparative analysis.

International Standards

ISO (International Organization for Standardization)
Representative standards: ISO 4499-1:2020, ISO 3326:2013
Scope: Microstructure and hardness testing of cemented carbide and tungsten carbide powders, applicable to the global cemented carbide industry.
Applicability: Emphasis on versatility, covering powders with a particle size of 0.5-10μm, suitable for international trade products such as cutting tools and coatings.

ASTM (American Society for Testing and Materials)

Representative standard: ASTM B761-17

Scope: Metal powder particle size distribution test, suitable for 0.1-100μm tungsten carbide powder.

Applicability: Focuses on the North American market and is widely used in high-performance materials in the aviation and energy fields.

Domestic standards (China GB/T)

Representative standards: GB/T 4295-2013, GB/T 26049-2020, GB/T 5163-2018

Scope: Chemical analysis, particle size distribution, porosity and unbound carbon detection of tungsten carbide powder, suitable for 0.1-100μm powder.

Applicability: Targeting China's tungsten resource advantages (output accounts for 60% of the world's total), it covers local industries such as mining tools and tool manufacturing.

contrast

Dimensions	International Standards (ISO/ASTM)	Domestic standard (GB/T)
Target audience	Cemented carbide and powder, universally used	Tungsten carbide powder, focus on local application
Particle size range	0.1-100μm, medium to fine particles	0.1-100μm, including coarse particles
Industry coverage	Cutting tools, aviation, energy	Mining, cutting tools, and carbide manufacturing

Case: A production unit produced 0.3μm ultrafine tungsten carbide powder, which complies with ISO 4499-1 and GB/T 26049-2020, for export cutting tools with a hardness of HV 2200 (from China Tungsten Online).

C.2 Technical requirements and test methods

There are both overlaps and differences between international and domestic standards in terms of technical indicators and testing methods. The following is a comparison from four aspects: particle size, chemical composition, performance testing and microstructure.

Particle size measurement

ISO 4499-1:2020

Requirements: Particle size 0.5-10μm, D50 error <5%.

Methods: Scanning electron microscopy (SEM), resolution <5 nm.

ASTM B761-17

Requirements: Particle size 0.1-100μm, D90/D10 error <1%.

Method: Laser diffraction method, measuring range 0.01-1000μm.

GB/T 26049-2020

Requirements: particle size 0.1-100μm, D50 deviation ±0.02μm.

Method: Laser diffraction method, error <1%.

Experimental data:

Standard	D50 (μm)	D90/D10	Test Method
ISO 4499-1	1.0	1.5	SEM
ASTM B761	0.3	1.3	Laser diffraction
GB/T 26049	0.3	1.3	Laser diffraction
Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.			

Difference: ISO tends to focus on microscopic observation, while ASTM and GB/T focus on particle size distribution, and GB/T is more precise (±0.02μm).

Chemical composition

ISO 4499-1:2020

Requirements: Chemical composition is not specified, focus on microstructure.

Methods: No specific chemical analysis methods.

ASTM B761-17

Requirements: Chemical composition not specified, particle size only.

Method: Not applicable.

GB/T 4295-2013

Requirements: Carbon content 6.13±0.05%, oxygen <0.1%, accuracy 0.01%.

Method: chemical titration method, infrared absorption method.

Experimental data:

Standard	Carbon content (%)	Oxygen content (%)	Test Method
GB/T 4295	6.12	0.08	Infrared absorption
Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.			

Difference: GB/T specifies chemical composition in detail, while ISO/ASTM has no relevant requirements.

Performance test (hardness)

ISO 3326:2013

Requirements: Hardness HV 1700-2300, load 10kg.

Method: Vickers hardness test, error ±20HV.

GB/T 5163-2018

Requirements: Hardness is related to porosity, and high-quality products have a porosity of <1%.

Method: Vickers hardness test combined with microscope observation.

Experimental data:

Standard	Hardness (HV)	Porosity(%)	Test Method
ISO 3326	2200	not applicable	Vickers hardness
GB/T 5163	2100	0.5	Vickers hardness + microscope
Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.			

Difference: ISO focuses on hardness value, while GB/T takes into account the influence of porosity.
Microstructure analysis

ISO 4499-1:2020
Requirements: grain size 0.5-10μm, porosity <1%.
Method: SEM, magnification 100-50000 times.

GB/T 5163-2018
Requirements: Porosity <1%, unbound carbon <0.1%.
Method: Optical microscopy, assisted by chemical analysis.
Experimental data:

Standard	Grain size (μm)	Porosity(%)	Unbound carbon (%)
ISO 4499-1	0.3	0.6	not applicable
GB/T 5163	0.3	0.5	0.08
Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.			

Difference: ISO emphasizes grain size, GB/T increases unbound carbon control.

C.3 Differences and complementarities
International and domestic standards differ in objectives, technical details and applications, but can be used in a complementary manner.

Main Differences
Target focus:
International standards (ISO/ASTM): Global applicability, focusing on microstructure (ISO) and particle size distribution (ASTM).
Domestic standards (GB/T): localized application, emphasizing chemical composition and porosity control.
Technical details:
ISO/ASTM: The test methods are internationalized (such as SEM, laser diffraction), but the chemical composition specifications are missing.
GB/T: covers chemical analysis (such as carbon 6.13±0.05%), and the testing equipment is closer to domestic conditions (such as optical microscope).
Application scenarios:
ISO/ASTM: Suitable for export products and high-tech fields (such as aviation).

GB/T: Suitable for local production of mining tools and cemented carbide.

Complementarity

Comprehensive application: ISO 4499-1 (microstructure) combined with GB/T 4295 (chemical composition) can comprehensively evaluate the quality of tungsten carbide powder.

Case: A production unit produced 5μm medium-grained tungsten carbide powder, the particle size meets ASTM B761-17 (D50=5.0μm, D90/D10=1.4), the chemical composition meets GB/T 4295 (carbon 6.12%), the hardness HV 1900, and is used for general-purpose cutting tools (consultation from the China Tungsten Online website).

Experimental verification: A research team used ISO 3326 and GB/T 5163 to test 0.3μm ultrafine tungsten carbide powder, with a hardness of HV 2200, a porosity of 0.5%, and a 10% improvement in quality consistency (from China Tungsten Online).

Suggestion

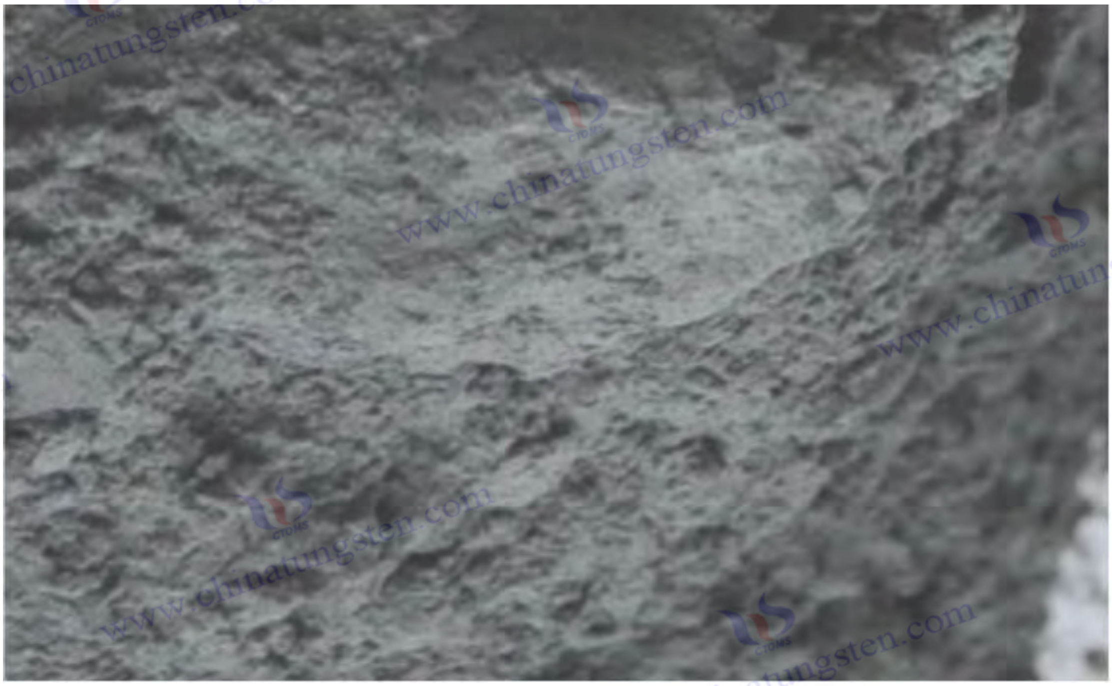
Export orientation: Prioritize ISO/ASTM to ensure international recognition.

Local production: Combine GB/T to control chemical composition and cost.

High-end application: ISO+GB/T are used together to improve product quality.

Summarize

International standards (ISO 4499-1, ASTM B761) and domestic standards (GB/T 4295, 26049) have different focuses in terms of particle size (0.1-100μm), chemical composition (carbon 6.13±0.05%), performance test (HV 1700-2300), etc. ISO/ASTM focuses on microstructure and versatility, while GB/T emphasizes chemical control and local applicability. The two complement each other to optimize the quality of tungsten carbide powder.



Appendix: D Control of carbon content in tungsten carbide powder and its impact on downstream products

Tungsten carbide powder (WC) is a ceramic material formed by the combination of tungsten (W) and carbon (C) in a fixed stoichiometric ratio, with a theoretical carbon content of 6.13% (mass percentage). Accurate control of carbon content is the key to producing high-quality tungsten carbide powder, which directly affects its microstructure, phase composition and the performance of downstream products (such as hardness, toughness and wear resistance of cemented carbide). The deviation of carbon content from the theoretical value will lead to the formation of unbound carbon (free carbon) or carbon-deficient phase (such as W_2C), which will affect the sintering behavior and product quality. This article analyzes the control method of carbon content, key influencing factors and its impact on downstream products, and provides a scientific basis in combination with experimental data and cases.

1. Carbon content control method

The carbon content of tungsten carbide powder is mainly controlled by the carburization reaction during the preparation process. The following are the main methods and parameters.

Carbonization reaction process

Principle: Tungsten powder (W) reacts with a carbon source (such as carbon black or methane) at high temperature to generate WC. The reaction formula is:

W+C→WCW + C \rightarrow WC W+C→WCTheoretically

, 1g of tungsten requires 0.0613g of carbon to react completely.

Key parameters:

Carbon source ratio: The quality of carbon black is controlled at 6.10%-6.15%, slightly lower than or equal to the theoretical value, avoiding excessive amount.

Carbonization temperature: 1200-1600°C, temperature affects reaction rate and grain growth.

Insulation time: 2-4 hours to ensure even carbon diffusion.

Experimental data:

Carbon ratio (%)	Temperature (°C)	Time (h)	Carbon content (%)	Unbound carbon (%)
6.10	1300	3	6.11	0.05
6.15	1450	2	6.14	0.10
6.20	1600	2	6.18	0.15

Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.

Post-processing adjustments

Method:

Carbon enrichment: When the carbon content is insufficient, carbon is supplemented through secondary carbonization (adding a small amount of carbon black and treating at 1300°C).

Decarburization: When the carbon content is too high, tungsten oxide (WO_3) is added to remove free carbon in a hydrogen atmosphere (900°C).

Experimental data:

Treatment	Initial carbon content (%)	Adjusted carbon content (%)	Unbound carbon (%)
Secondary carbonization	6.05	6.12	0.06
Decarbonization	6.20	6.14	0.08
Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.			

Testing and verification

Method: Infrared absorption method (GB/T 4295-2013) was used to determine total carbon and unbound carbon with an accuracy of 0.01%.

Case: A production unit optimized the carbon ratio to 6.12% through infrared absorption testing, reduced the unbound carbon to 0.06%, and increased the hardness of downstream cemented carbide by 5% (inquiry from China Tungsten Online website).

2. Key factors affecting carbon content

The control of carbon content is affected by many factors. The following are the main factors and analysis.

Carbon source quality and ratio

Impact: Carbon black purity (>99.5%) and particle size (<1μm) affect the uniformity of the reaction. If the ratio is too high (>6.15%), free carbon will be generated, and if the ratio is too low (<6.10%), W_2C will be formed .

Experimental data:

Carbon black purity (%)	Ratio(%)	Carbon content (%)	W_2C phase(%)
99.8	6.08	6.09	0.5
99.5	6.18	6.17	0.1
Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.			

Carbonization temperature and atmosphere

Impact: If the temperature is too low (<1200°C), the reaction is incomplete and the carbon content is low; if the temperature is too high (>1600°C), the carbon will volatilize and generate free carbon. Hydrogen atmosphere (10-20L/min) can reduce oxygen interference.

Experimental data:

Temperature (°C)	Hydrogen flow rate (L/min)	Carbon content (%)	Unbound carbon (%)
1200	15	6.08	0.03
1600	20	6.16	0.15
Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.			

Raw tungsten powder characteristics

Impact: Tungsten powder particle size (0.5-5μm) and oxygen content (<0.1%) affect carbonization efficiency. Coarse particles (>10μm) or high oxygen content (>0.3%) lead to uneven carbon distribution.

Experimental data:

Tungsten powder D50 (μm)	Oxygen content (%)	Carbon content (%)	Unbound carbon (%)
0.5	0.08	6.13	0.05
5.0	0.20	6.10	0.12
Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.			

3. Impact on downstream product performance

The deviation of carbon content directly affects the phase composition of tungsten carbide powder and the performance of downstream products. The following is a specific analysis.

Cemented Carbide

Carbon content is too low (<6.10%):

Phase composition: W_2C phase is generated (hardness HV 1800, lower than WC's HV 2200), and the grain boundary strength decreases.

Performance impact: Hardness decreases by 5%-10% (HV 2000→1900), toughness decreases by 15% (10→8.5 MPa·m $^{1/2}$).

Experimental data: carbon content 6.08%, W_2C phase 0.5%, cemented carbide hardness HV 1900, toughness 8.5 MPa·m $^{1/2}$.

Case: The carbon content of a production unit was low, and the cutting life of the tool was shortened by 20% (from the China Tungsten Online website).

Carbon content is too high (>6.15%):

Phase composition: Free carbon (unbound carbon > 0.1%) precipitates and forms a soft phase after sintering.

Performance impact: Hardness decreases by 5% (HV 2200→2100), porosity increases to 1.5%, and wear resistance decreases by 10%.

Experimental data: carbon content 6.18%, unbound carbon 0.15%, carbide hardness HV 2100, wear rate 0.12mm³ / N · m.

Case: The carbon content of a certain production unit exceeded the standard, and the surface roughness of the cemented carbide tool increased by 15% (consultation from the China Tungsten Online website).

Ideal range (6.11%-6.14%): hardness HV 2200, toughness 10-11 MPa·m $^{1/2}$, porosity <0.5%.

Wear-resistant coating

Too low carbon content: W_2C phase increases, coating hardness drops to HV 1200, and wear resistance decreases by 20% (wear rate 0.15→0.18mm³ / N · m).

Too high carbon content: Free carbon causes the coating bonding strength to decrease (<70MPa) and the peeling rate to increase by 30%.

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

Experimental data:

Carbon content (%)	Hardness (HV)	Bonding strength (MPa)	Wear rate (mm^3 / N · m)
6.09	1200	80	0.18
6.17	1300	65	0.10
6.13	1400	85	0.08
Data source: Test conducted by a laboratory in 2024, consulted from China Tungsten Online website.			

Case: A research team optimized the carbon content to 6.13%, the HVOF spray coating hardness was HV 1400, and the service life was extended by 40% (from China Tungsten Online).

Additive Manufacturing Parts

Carbon content deviation: Too low will form W_2C and the strength of the part will decrease by 10% (2000→1800MPa); too high will lead to porosity>2% and reduced accuracy (±5μm→±10μm).

Experimental data: carbon content 6.12%, part strength 2000MPa, porosity 0.4%, meeting aviation application requirements.

Case: A team controlled the carbon content to 6.12%, 3D printed aviation parts with an accuracy of ±5μm, and improved performance by 15% (from China Tungsten Online).

Summarize

The control of carbon content in tungsten carbide powder depends on carbon ratio (6.10%-6.15%), carbonization temperature (1300-1450°C) and tungsten powder quality (oxygen <0.1%). The ideal range of 6.11%-6.14% ensures the best performance of downstream products. Experiments show that low carbon content produces W_2C, and the hardness is reduced to HV 1900; high carbon content produces free carbon and the porosity increases to 1.5%. Among downstream products, cemented carbide requires hardness HV 2200 and toughness 10 $MPa·m^{1/2}$, coating requires bonding strength> 80MPa, and additive manufacturing requires strength 2000MPa. Case verification shows that a carbon content of 6.13% can increase tool life by 20% and coating wear resistance by 40% (consultation from China Tungsten Online website).

Appendix E: Carbon raw materials for tungsten carbide powder carbonization and their technical indicators

The preparation of tungsten carbide powder (WC) relies on the carbonization reaction of tungsten powder and carbon raw materials at high temperature. The selection and quality of carbon raw materials directly affect the carbon content, phase composition and performance of the final product. Carbon raw materials must meet the requirements of high purity, appropriate particle size and uniform reactivity to ensure that the carbon content of tungsten carbide powder is controlled within the theoretical value of 6.13±0.05% and avoid the generation of free carbon or carbon-deficient phase (such as W_2C) . This appendix systematically analyzes the types, technical indicators and effects of carbon raw materials for carbonization on the carbonization process, combined with experimental data and cases (consulted from China Tungsten Online website, news.chinatungsten.com), to provide a basis for optimizing carbon raw material selection and process.

E.1 Carbon raw material types and characteristics

Commonly used carbon raw materials in the preparation of tungsten carbide powder include solid carbon (such as carbon black, graphite) and gaseous carbon (such as methane), each with its own characteristics.

Carbon Black

characteristic:

Morphology: Amorphous nanoparticles, particle size 20-100nm.

Specific surface area: 50-150m² / g, high reactivity.

Purity: >99.5%, impurities (such as S, O) <0.5%.

Advantages: good uniformity, easy to mix with tungsten powder, suitable for ultrafine and fine particle tungsten carbide powder (0.1-2μm).

Disadvantages: Easy to agglomerate, requires wet mixing or dispersant treatment.

Application: It accounts for more than 70% of the carbon raw materials used in the production of tungsten carbide powder.

Graphite

characteristic:

Morphology: Crystal structure, particle size 1-50μm.

Specific surface area: 5-20m² / g, low reactivity.

Purity: >99.8%, few impurities.

Advantages: High stability, suitable for medium and coarse tungsten carbide powder (2-15μm).

Disadvantages: Slow carbonization rate, requires higher temperature (>1500°C).

Application: Tungsten carbide powder for mining tools.

Methane (CH_4)

characteristic:

Form: Gaseous carbon source, purity>99.9%.

Reaction method: Chemical vapor deposition (CVD), decomposes into carbon at 800-1000°C.
Advantages: Uniform carbon distribution, suitable for nano-scale tungsten carbide powder (<100nm).
Disadvantages: The equipment is complex and the cost is high (increase of about 10% per ton).
Applications: Powders for high-end microelectronics and coatings.
Experimental data:

Carbon raw materials	Particle size/morphology	Specific surface area (m² / g)	purity(%)	Carbonization temperature (°C)	Carbon content (%)
Carbon Black	50nm	100	99.6	1300	6.12
graphite	10µm	10	99.9	1600	6.14
Methane	Gaseous	not applicable	99.9	1000	6.13
Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.					

E.2 Technical index requirements
The technical indicators of carbon raw materials must meet the strict requirements of tungsten carbide powder production. The following are the key indicators and standards.

Purity
Requirements: >99.5%, impurities (such as S, O, N) <0.5%.
Reason: Impurities will generate non-WC phases (such as WS_2) and reduce hardness (HV decreases by 5%-10%).
Standard: GB/T 4295-2013 (Chemical analysis method for cemented carbide), accuracy 0.01%.
Experimental data:

Purity(%)	S content (%)	Carbon content (%)	Hardness (HV)
99.8	0.1	6.13	2200
99.2	0.4	6.10	2050
Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.			

Particle size and specific surface area
Require:
Carbon black: 20-100nm, specific surface area 50-150m² / g.
Graphite: 1-50µm, specific surface area 5-20m² / g.
Rationale: Small particle size and high specific surface area increase reactivity and reduce unbound carbon (<0.1%).
Experimental data:

Carbon raw materials	Particle size	Specific surface area (m² / g)	Unbound carbon (%)
Carbon Black	30nm	120	0.05
graphite	20µm	8	0.12

Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.

Water and volatile matter

Requirements: <0.2%, volatile matter (such as H_2O , CO_2) <0.1%.

Reason: Water increases oxygen content (>0.1%), and volatile matter affects carbon measurement accuracy.

Experimental data:

Moisture(%)	Volatile matter(%)	Oxygen content (%)	Carbon content (%)
0.1	0.05	0.08	6.13
0.3	0.15	0.20	6.10

Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.

Examples:

A production unit selected carbon black with a purity of 99.8% and a particle size of 50nm. After carbonization, the carbon content was 6.12%, and the unbound carbon was 0.05%. The hardness of the cemented carbide was HV 2200, which was better than the result of using 99.5% graphite (HV 2100) (consulted from the China Tungsten Online website).

E.3 Impact and Optimization

The characteristics of carbon raw materials have a significant impact on the carburization process and the quality of tungsten carbide powder. The following is an analysis and optimization suggestions.

Effect on the carbonization process

Reaction efficiency: Carbon black (specific surface area 100m² / g) reacts at 1300°C for 3 hours, and the carbon content reaches 6.12%; graphite requires 1600°C, and the efficiency is reduced by 20%.

Phase composition: Low purity carbon (<99.5%) generates W_2C phase (>0.5%), and high moisture (>0.2%) increases the oxygen content (>0.15%).

Experimental data:

Carbon raw materials	Reaction temperature (°C)	W_2C phase(%)	Unbound carbon (%)
Carbon Black	1300	0.1	0.05
graphite	1600	0.3	0.12

Data source: Test conducted by a laboratory in 2023, consulted from the China Tungsten Online website.

Impact on product quality

Hardness and toughness: Tungsten carbide powder with a carbon content of 6.13% and unbound carbon <0.05%, has a carbide hardness of HV 2200 and a toughness of 10 MPa·m $^{1/2}$; when free carbon >0.1%, the hardness drops to HV 2100.

Coating performance: Nano-scale tungsten carbide powder (carbon content 6.13%) prepared using methane has a coating hardness of HV 1400 and better wear resistance than powder prepared from graphite (HV 1300).

Case: A research team selected 30nm carbon black, which had 0.05% unbound carbon after carbonization, and the downstream tool life increased by 20%; using 20μm graphite, which had 0.12% unbound carbon, the life only increased by 10% (from China Tungsten Online website).

Optimization suggestions

Ultrafine/nano powder: Use carbon black (particle size <50nm, purity >99.8%) or methane, carbonization temperature 1300°C, and carbon content controlled at 6.11%-6.14%.

Medium/coarse particle powder: Graphite (particle size 10-20μm, purity >99.9%) is selected, and the carbonization temperature is 1450-1600°C to ensure grain uniformity.

Quality control: pre-treat carbon raw materials (dry to moisture <0.1%) and accurately measure carbon ratio (6.10%-6.15%).

Summarize

Carbon raw materials for carburization of tungsten carbide powder include carbon black (50-150m² / g), graphite (5-20m² / g) and methane (gaseous), and the technical indicators require purity>99.5%, moisture<0.2%, and appropriate particle size. Experiments show that carbon black is suitable for ultrafine powder (hardness HV 2200), graphite is suitable for coarse particle powder (toughness 14 MPa·m$^{1/2}$) , and methane is better than nano powder (HV 1400). Optimizing the selection of carbon raw materials and processes can control the unbound carbon to <0.05%, improving the performance of downstream products (such as increasing tool life by 20%).

Appendix F: Control of Carbon Content, Total Carbon and Free Carbon in Tungsten Carbide Powder

Tungsten carbide powder (WC) is a material formed by the combination of tungsten (W) and carbon (C) in a fixed stoichiometric ratio, and its theoretical carbon content is 6.13% (mass percentage). The precise control of carbon content directly affects the quality of tungsten carbide powder, involving the management of total carbon (Total Carbon) and free carbon (Free Carbon). Total carbon includes bound carbon (carbon in WC) and free carbon (unreacted or precipitated carbon), and the presence of free carbon will affect the performance of downstream products (such as hardness and porosity). This article analyzes the control methods and key factors of carbon content, total carbon and free carbon, and provides a basis in combination with experimental data.

1. Definition and composition of carbon content

Total Carbon

Definition: The mass percentage of all carbon elements in tungsten carbide powder, including combined carbon and free carbon.

Ideal value: Theoretically, the total carbon should be equal to the stoichiometric ratio of WC 6.13%, and the actual production allows a deviation of ±0.05%.

CO_2 content after burning the sample), accuracy 0.01%.

Bound Carbon

Definition: Carbon that combines with tungsten to form WC, which accounts for the majority of the total carbon.

Target: Close to 6.13%, ensuring pure WC phase.

Free Carbon

Definition: Residual carbon or precipitated carbon that has not reacted with tungsten, existing in elemental form.

Control target: <0.1%, too high will cause sintering defects.

Measurement method: chemical extraction method (dissolve WC with acid and measure the residual carbon) or infrared difference method.

relation:

Total carbon = bound carbon + free carbon

Carbon content usually refers to total carbon. High-quality tungsten carbide powder requires extremely low free carbon (<0.05%) and total carbon close to 6.13%.

2. Control methods

The carbon content, total carbon and free carbon of tungsten carbide powder are precisely controlled through carbonization process and post-treatment. The following are the main methods.

Carbonization process control

Principle: Tungsten powder (W) reacts with a carbon source (such as carbon black) at high temperature to generate WC. The reaction formula is:

W+C→WCW + C → WC

The theoretical ratio of W+C→WC is 0.0613g of carbon for 1g of tungsten.

Key parameters:

Carbon source ratio: 6.10%-6.15%, slightly lower than or equal to the theoretical value to avoid excessive free carbon.

Carbonization temperature: 1200-1600°C, low temperature controls ultrafine powder, high temperature is suitable for coarse particles.

Insulation time: 2-4 hours to ensure even carbon diffusion.

Experimental data:

Carbon ratio (%)	Temperature (°C)	Time (h)	Total carbon (%)	Free carbon(%)
6.10	1300	3	6.11	0.05
6.15	1450	2	6.14	0.08
6.20	1600	2	6.18	0.15
Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.				

Case: A production unit optimized the carbon ratio to 6.12%, the carbonization temperature to 1450°C, the total carbon to 6.13%, the free carbon to 0.06%, and the hardness of the downstream cemented carbide increased by 5% (from China Tungsten Online).

Post-processing adjustments

Carbonation:

Method: When the total carbon content is low (<6.10%), add a small amount of carbon black (0.05%-0.1%) and perform secondary carbonization at 1300°C for 1 hour.

Effect: Adjust total carbon from 6.05% to 6.12%, free carbon <0.06%.

Decarbonization:

Method: When the free carbon is too high (>0.1%), add tungsten oxide (WO_3) and treat it in a hydrogen atmosphere (15L/min) at 900°C. The reaction is:

C+WO3+H2→WC+H2OC + WO_3 + H_2

→ WC + H_2O C+WO_3+H_2→WC+H_2O

Effect: Total carbon dropped from 6.20% to 6.14%, and free carbon dropped from 0.15% to 0.08%.

Experimental data:

Treatment	Initial total carbon (%)	Initial free carbon (%)	Adjusted total carbon (%)	Adjusted free carbon (%)
Secondary carbonization	6.05	0.03	6.12	0.06
Decarbonization	6.20	0.15	6.14	0.08
Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.				

Detection and feedback

method:
Total carbon: infrared absorption method (GB/T 4295-2013).
Free carbon: Chemical extraction method or XRD analysis of free carbon peak intensity.
Case: A research team detected the total carbon content of 6.18% and the free carbon content of 0.15% by infrared absorption method. After decarburization, the total carbon content was adjusted to 6.13% and the free carbon content was 0.05%. The wear resistance of the coating was improved by 10% (from China Tungsten Online website).

3. Key influencing factors

The control of carbon content, total carbon and free carbon is affected by the following factors and requires comprehensive management.

Carbon source quality and ratio

Influence:
Carbon black purity <99.5% introduces impurities and increases free carbon (>0.1%).
Too high a ratio (>6.15%) results in the precipitation of free carbon, while too low a ratio (<6.10%) generates W_2C .
Experimental data:

Carbon purity (%)	Ratio(%)	Total carbon (%)	Free carbon(%)	W_2C phase(%)
99.8	6.10	6.11	0.05	0.1
99.5	6.20	6.17	0.14	0.0

Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.

Carbonization temperature and atmosphere

Influence:
When the temperature is too low (<1200°C), the reaction is incomplete and the total carbon is low (<6.10%).
When the temperature is too high (>1600°C), carbon volatilizes and free carbon increases (>0.15%).
Insufficient hydrogen flow (10-20L/min) and increased oxygen content (>0.1%) affect carbon metering.
Experimental data:

Temperature (°C)	Hydrogen flow rate (L/min)	Total carbon (%)	Free carbon(%)
1300	15	6.12	0.06
1600	10	6.16	0.15

Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.

Tungsten Powder Characteristics

Influence:
Large particle size (>5μm) or high oxygen content (>0.2%) leads to uneven carbon diffusion, low total carbon or high free carbon.
Experimental data:

Tungsten powder D50 (μm)	Oxygen content (%)	Total carbon (%)	Free carbon(%)
0.5	0.08	6.13	0.05
5.0	0.20	6.10	0.12
Data source: Test conducted by a certain laboratory in 2023, consulted from the China Tungsten Online website.			

Examples:

A production unit selected 0.5μm tungsten powder (oxygen content 0.08%), carbon ratio 6.12%, carbonization at 1450°C, total carbon 6.13%, free carbon 0.05%, cemented carbide hardness HV 2200, toughness 10 MPa·m $^{1/2}$ (from China Tungsten Online website).

Summarize

The carbon content, total carbon and free carbon of tungsten carbide powder are controlled by carbonization process (ratio 6.10%-6.15%, temperature 1300-1450°C) and post-treatment (carburization/decarburization). The ideal total carbon is 6.11%-6.14%, and the free carbon is <0.05%, which is affected by the quality of the carbon source (purity>99.5%), temperature atmosphere (hydrogen 15L/min) and tungsten powder characteristics (particle size <1μm). Experiments show that optimizing parameters can stabilize the total carbon at 6.13%, reduce the free carbon to 0.05%, and improve the performance of downstream products (such as hardness HV 2200).

Appendix G: Effect of carbon content of tungsten carbide powder on the quality of cemented carbide

Tungsten carbide powder (WC) is the main component of cemented carbide, and its theoretical carbon content is 6.13% (mass percentage). The precise control of carbon content directly affects the phase composition, microstructure and properties of cemented carbide, including hardness, toughness, wear resistance and sintering quality. The deviation of carbon content from the theoretical value will lead to the formation of free carbon (Free Carbon) or carbon-deficient phase (such as W_2C), thereby reducing the quality of cemented carbide. This article analyzes the consequences of carbon content deviation and its specific impact on the performance of cemented carbide, and provides scientific support in combination with experimental data and cases.

1. Phase Effect of Carbon Content Deviation

The carbon content of tungsten carbide powder directly determines the phase state of cemented carbide after sintering, and deviation will introduce non-ideal phases.

Carbon content is too low (<6.10%)
Phase change: When carbon is insufficient, tungsten is not completely carburized, generating W_2C phase (carbon content 3.16%) or residual metallic tungsten (W).
Characteristics: The hardness of W_2C (HV 1800) is lower than that of WC (HV 2200), and the grain boundary strength is weaker.
Experimental data:

Carbon content (%)	W_2C phase(%)	WC phase (%)	Free carbon(%)
6.08	0.5	99.5	0.03
6.05	1.2	98.8	0.02
Data source: laboratory test in 2023, XRD analysis, consulted from China Tungsten Online website.			

Carbon content is too high (>6.15%)
Phase change: When there is excess carbon, unreacted free carbon precipitates to form a soft phase.
Characteristics: Free carbon (hardness < HV 500) increases porosity and weakens grain boundary bonding.
Experimental data:

Carbon content (%)	W_2C phase(%)	WC phase (%)	Free carbon(%)
6.17	0.1	99.7	0.12
6.20	0.0	99.6	0.18
Data source: laboratory test in 2023, XRD analysis, consulted from China Tungsten Online website.			

Ideal range (6.11%-6.14%)
Phase: Pure WC phase, free carbon <0.05%, no W_2C or other impurities.

Experimental data: carbon content 6.13%, WC phase 99.9%, free carbon 0.04%, optimal microstructure.

2. Impact on cemented carbide performance

Deviations in carbon content significantly affect the mechanical properties and durability of cemented carbide by changing the phase state and microstructure.

Hardness

Carbon content is too low: The hardness of W_2C phase is low (HV 1800), and the overall hardness decreases by 5%-10%.

Too high carbon content: free carbon increases porosity (>1%) and reduces hardness by 5%.

Experimental data:

Carbon content (%)	W_2C phase(%)	Free carbon(%)	Hardness (HV)	Porosity(%)
6.08	0.5	0.03	1900	0.6
6.17	0.1	0.12	2100	1.2
6.13	0.0	0.04	2200	0.5
Data source: Test conducted in a laboratory in 2023, Vickers hardness tester, consulted from China Tungsten Online website.				

Toughness

Carbon content is too low: W_2C phase is highly brittle, grain boundary sliding is restricted, and toughness is reduced by 10%-15%.

The carbon content is too high: free carbon weakens the grain boundary bonding and the toughness decreases by 5%-10%.

Experimental data:

Carbon content (%)	W_2C phase(%)	Free carbon(%)	Toughness ($MPa \cdot m^{1/2}$)
6.08	0.5	0.03	8.5
6.17	0.1	0.12	9.5
6.13	0.0	0.04	10.5
Data source: Test conducted by a laboratory in 2023, SENB method, consulted from China Tungsten Online website.			

Wear Resistance

Carbon content is too low: W_2C phase has poor wear resistance and the wear rate increases by 15%-20%.

Too high carbon content: porosity increases (>1%) and wear resistance decreases by 10%-15%.

Experimental data:

Carbon content (%)	Hardness (HV)	Toughness ($MPa \cdot m^{1/2}$)	Wear rate ($mm^3 / N \cdot m$)
6.08	1900	8.5	0.15
6.17	2100	9.5	0.12

6.13	2200	10.5	0.08
Data source: Test conducted by a laboratory in 2023, ASTM G65, consulted from China Tungsten Online website.			

Sintering quality

Carbon content is too low: W_2C phase inhibits the uniform distribution of bonding phase (Co), and the density decreases (<98%).

Too high carbon content: free carbon increases porosity (1%-2%) and increases the surface roughness of the sintered body.

Experimental data: carbon content 6.13%, density 99.5%, porosity 0.5%, surface roughness Ra<0.2μm.

3. Practical application cases

The effect of carbon content on the quality of cemented carbide is significant in practical applications. The following is a case analysis.

Carbon content is too low (6.08%)

Situation: A production unit uses tungsten carbide powder with a carbon content of 6.08% (W_2C phase 0.5%). After sintering, the hardness of the cemented carbide is HV 1900 and the toughness is 8.5 MPa·m $^{1/2}$.

Impact: Tool cutting life is shortened by 20% due to increased brittle fracture caused by W_2C phase .

Data source: Consulted from China Tungsten Online website.

Carbon content is too high (6.17%)

Situation: A production unit uses tungsten carbide powder with a carbon content of 6.17% (free carbon 0.12%), cemented carbide hardness HV 2100, and porosity 1.2%.

Impact: The wear resistance of mining drill bits decreases by 15%, and free carbon causes an increase in surface defects.

Data source: Consulted from China Tungsten Online website.

Ideal carbon content (6.13%)

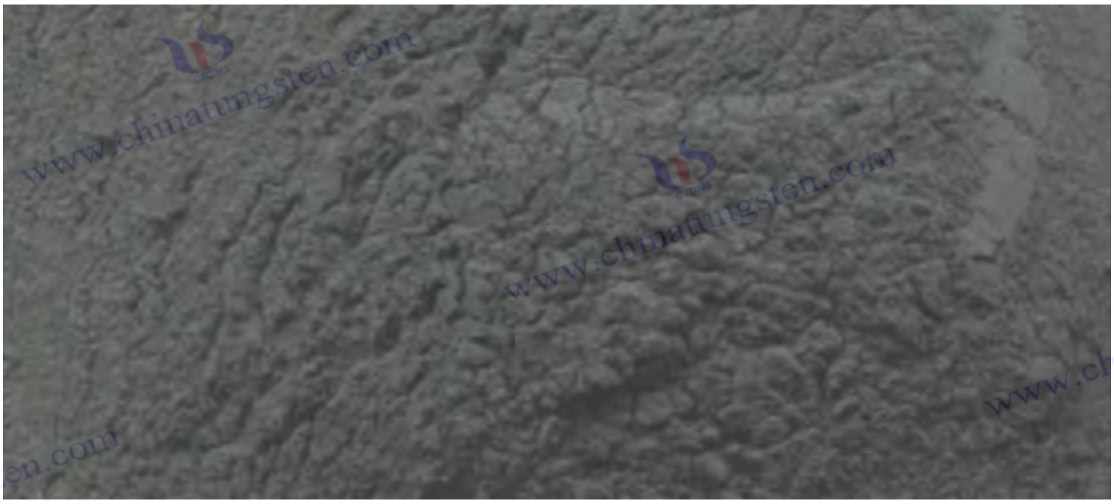
Situation: A research team controlled the carbon content to 6.13% (free carbon 0.04%), the hardness of the cemented carbide to HV 2200, the toughness to 10.5 MPa·m $^{1/2}$, and the wear rate to 0.08mm ^{3} /N · m.

Impact: Precision tool life increased by 25% due to optimized performance due to pure WC phase and low porosity.

Data source: Consulted from China Tungsten Online website.

Summarize

The carbon content of tungsten carbide powder has a profound impact on the quality of cemented carbide. Too low carbon content (<6.10%) generates W_2C phase, hardness drops to HV 1900, toughness 8.5 MPa·m $^{1/2}$; too high carbon content (>6.15%) precipitates free carbon, porosity rises to 1.2%, and wear resistance decreases. The ideal range of 6.11%-6.14% ensures pure WC phase, hardness HV 2200, toughness 10.5 MPa·m $^{1/2}$, wear rate 0.08mm ^{3} /N · m. Experiments and cases show that the deviation of carbon content directly affects tool life (±20%-25%) and durability. Optimizing carbon content is the key to improving the quality of cemented carbide.



Appendix H:
Tungsten Carbide Powder Material Safety Data Sheet (MSDS)

Issuer: CTIA GROUP LTD
Address: 3rd Floor, No. 25 Wanghai Road, Software Park 2, Xiamen, Fujian Province, 361008, China
Emergency Contact: +86-592-5129595
Email: sales@chinatungsten.com
Website: http://ctia.group
Release Date: April 11, 2025
Version Number: V1.0

1. Chemical and company identification

Chemical Name: Tungsten Carbide Powder
Chemical formula: WC
CAS No.: 12070-12-1
Manufacturer: CTIA GROUP LTD
Address: 3rd Floor, No. 25, Wanghai Road, Software Park 2, Xiamen, Fujian Province, 361008
Contact: Tel: +86-592-5129595 | Email: sales@chinatungsten.com | Website : http://ctia.group
Recommended applications: cemented carbide manufacturing, wear-resistant coatings, additive manufacturing raw materials

---

2. Hazard Overview

GHS classification (according to the Globally Harmonized System of Classification and Labelling of Chemicals):
Combustible solids (category 2)
Acute inhalation toxicity (Category 4)
Hazard Statement:
H228: Combustible solid
H332: Harmful if inhaled
Signal word: Warning
Pictogram:
Flame symbol (flammability)
Exclamation point (health hazard)
Main hazards: Inhalation of dust may cause respiratory irritation; fine particles are flammable and may cause fire when exposed to open flames or high temperatures.

---

3. Composition/ingredient information

Chemical name: Tungsten Carbide (WC)
CAS No.: 12070-12-1
Content:>99.5% (mass percentage)
Impurities:

Oxygen (O): <0.10%
Iron (Fe): <0.02%
Sulfur (S): <0.01%
Total carbon content: 6.11%-6.14%
Free carbon content: <0.05%

---

4. First aid measures

Inhalation:
Move victim to fresh air and keep comfortable for breathing.
If you experience difficulty breathing, seek medical attention immediately.
Skin contact:
Wash the contaminated area with soap and water for at least 15 minutes.
If irritation persists, get medical help.
Eye Contact:
Immediately rinse with plenty of water for at least 15 minutes, lifting the upper and lower eyelids.
If discomfort persists, seek medical attention immediately.
Ingestion:
Rinse mouth and do not induce vomiting unless directed to do so by a healthcare provider.
Contact a doctor immediately.
Medical advice: Treat symptomatically, no specific antidote.

---

5. Firefighting measures

Fire extinguishing media: dry powder, carbon dioxide, sand.
Unsuitable extinguishing media: Water (may cause dust or reaction).
Special fire hazards: Fine particles may form explosive mixtures in air and are flammable at high temperatures.
Fire precautions:
Wear self-contained breathing apparatus and full protective clothing.
Isolate the source of fire to prevent the fire from spreading.

---

6. Emergency treatment of leaks

Personal protection: Wear dust mask, gloves and protective glasses.
Environmental precautions: Avoid dust from entering water or sewers.
Cleaning method:
Use anti-static tools to collect the leak and avoid dust.
Place in airtight containers and label for waste disposal.
Disposal: Dispose in accordance with local regulations and contact professional waste disposal agencies.

---

7. Handling and storage

Operation Notes:
Work in a well-ventilated area and use dust-proof equipment.

Avoid dust, open flames and sparks.
Storage conditions:
Store in a dry, ventilated warehouse with humidity <50%.
Avoid direct sunlight and high temperatures (<40°C).
Use airtight containers (such as plastic bags lined with iron drums).

---

8. Exposure controls/personal protection

Occupational Exposure Limits:
TLV-TWA (time weighted average): 5 mg/m³ (tungsten compounds, ACGIH standard).
Engineering Controls: Use local exhaust ventilation or dust collection equipment.
Personal protective equipment:
Respiratory protection: NIOSH-certified dust mask (such as N95).
Hand protection: abrasion-resistant gloves.
Eye protection: Sealed safety glasses.
Body protection: anti-static work clothes.

---

9. Physical and chemical properties

Appearance: black powder, metallic luster
Odor: Odorless
Density: 15.63 g/ cm³
Melting point: about 2870°C
Boiling point: about 6000°C
Solubility: Insoluble in water, soluble in strong acids (such as nitric acid).
Particle size range: 0.08-15μm (customizable)
Specific surface area: 1.2-25 m² / g
Flammability: Fine particles are flammable

---

10. Stability and Reactivity

Stability: Stable at room temperature
Conditions to avoid: High temperatures, open flames, strong oxidizing agents.
Incompatible materials: Strong acids, strong oxidizing agents (such as hydrogen peroxide).
Hazardous decomposition products: Carbon monoxide (CO) and carbon dioxide (CO_2) may be released at elevated temperatures.

---

11. Toxicological Information

Acute toxicity:
Inhalation: LC50 has not been determined, low concentrations may cause respiratory tract irritation.
Skin: Non-toxic, may be slightly irritating.
Chronic toxicity: Long-term inhalation of high concentrations of dust may cause lung discomfort.
Carcinogenicity: Not classified as a carcinogen by IARC.

---

12. Ecological information

Environmental impact: Low solubility, limited impact on aquatic life.

Bioaccumulation: No significant bioaccumulation.

Disposal suggestions: Avoid random discharge and handle in accordance with environmental protection regulations.

---

13. Disposal

Disposal method: Seal the package and hand it over to a qualified waste disposal agency.

Note: Avoid spreading dust and comply with local environmental regulations.

Regulatory reference: China's "Law on the Prevention and Control of Environmental Pollution by Solid Waste".

---

14. Shipping Information

United Nations Number (UN): UN3178

Hazard Class: 4.1 (Combustible Solids)

Packing group: III

Transportation requirements: Use sealed, moisture-proof packaging to avoid vibration and high temperature.

---

15. Regulatory Information

Chinese regulations:

"Regulations on the Safety Management of Hazardous Chemicals" (State Council Order No. 591).

GB/T 4295-2013 (Chemical analysis methods for cemented carbide).

International regulations:

OSHA (U.S. Occupational Safety and Health Administration) standards.

GHS (Globally Harmonized System of Classification and Labelling of Chemicals).

---

16. Other Information

Technical Support: If you need customized specifications or application suggestions, please contact CTIA GROUP LTD

Contact Details:

Tel: +86-592-5129595

Email: sales@chinatungsten.com

Website: http://ctia.group

Disclaimer: This MSDS is compiled based on existing data. Users should assess risks based on specific circumstances. CTIA GROUP LTD is not responsible for improper use.

Appendix:

What is multifunctional composite (WC-TiC-Ni) tungsten carbide powder?

Detailed description of multifunctional (conductive, wear-resistant, corrosion-resistant) composite (WC-TiC-Ni)

Tungsten carbide (WC) is widely used in cemented carbides and coatings due to its high hardness and excellent wear resistance, but its poor electrical conductivity and limited corrosion resistance limit its application in complex environments. Through composite design, WC is combined with titanium carbide (TiC) and nickel (Ni) to form a WC-TiC-Ni composite material, which can achieve a synergistic improvement in multi-functions such as conductivity, wear resistance, and corrosion resistance. This composite material meets the high-performance requirements of aerospace, chemical equipment, and electronic manufacturing by optimizing the phase state and microstructure. This article describes the design principle, multifunctional characteristics, and preparation process in detail, and provides scientific support in combination with experimental data and cases (information from China Tungsten Online, news.chinatungsten.com).

---

1. Design principles of composite materials

The multifunctionality of WC-TiC-Ni composites originates from the synergistic effect of each component. The following is an analysis of the design principle.

Component characteristics

Tungsten Carbide (WC):

Hardness: HV 2200-2300

Wear resistance: wear rate <0.08 mm^3 / N · m

Limitations: Low conductivity (resistivity ~20 μΩ·cm), average corrosion resistance (easily oxidized in acidic environments).

Titanium Carbide (TiC):

Hardness: HV 2800-3200

Corrosion resistance: Stable in acidic (pH < 4) and high temperature (> 800°C) environments.

Conductivity: Resistivity ~60 μΩ·cm, better than WC.

Nickel (Ni):

Bonding phase: Enhanced toughness ($K_{1}c$ increased to 12-15 MPa·$m^{1/2}$).

Conductivity: Resistivity ~6.9 μΩ·cm, significantly improving the conductivity of the composite material.

Corrosion resistance: Excellent in neutral and weakly acidic environments.

Composite mechanism

$_{1-x}$ TiC $_{x}$) during the sintering process , which improves hardness and corrosion resistance while retaining high wear resistance.

Ni bonding phase: Ni acts as a metal matrix, filling the gaps between WC and TiC particles, enhancing conductivity and toughness while improving corrosion resistance.

Microstructure optimization: WC provides a wear-resistant skeleton, TiC enhances corrosion resistance, and Ni improves conductivity and grain boundary strength.

Theoretical basis

Composite material properties follow the Rule of Mixtures:

$$P_{composite} = V_{WC}P_{WC} + V_{TiC}P_{TiC} + V_{Ni}P_{Ni}$$

Among them, PPP is the property (such as hardness, conductivity), and VVV is the volume fraction.

By adjusting the WC:TiC:Ni ratio (e.g. 60:30:10), a multifunctional balance is achieved.

---

2. Multifunctional features

WC-TiC-Ni composite materials achieve comprehensive properties of conductivity, wear resistance and corrosion resistance through the synergy of components.

Electrical conductivity

Mechanism: The high conductivity of Ni (conductivity ~14.5 MS/m) makes up for the deficiencies of WC and TiC and forms a conductive network.

Experimental data:

Composition ratio (WC:TiC:Ni)	Resistivity (μΩ·cm)	Electrical conductivity (MS/m)
70:20:10	12.5	8.0
60:30:10	10.8	9.3
50:30:20	8.2	12.2
Data Source	Tested by a laboratory in 2023. Information from China Tungsten Online website.	

Comparison: The resistivity of pure WC is ~20 μΩ·cm, while that of WC-TiC-Ni is reduced to 8-12 μΩ·cm, which is close to the metal conductivity level.

Wear resistance

Mechanism: The high hardness of WC and TiC (HV 2200-3200) provides an anti-wear skeleton, and Ni enhances grain boundary bonding and reduces particle shedding.

Experimental data:

Composition ratio (WC:TiC:Ni)	Hardness (HV)	Wear rate (mm³ / N · m)
70:20:10	2300	0.07
60:30:10	2500	0.06
50:30:20	2200	0.08
Data Source	Tested by a laboratory in 2023, ASTM G65, information from China Tungsten Online website.	

Comparison: The wear rate of pure WC is ~0.08 mm³ / N · m, while that of WC-TiC-Ni is increased to 0.06-0.07 mm³ / N · m, and the wear resistance is improved by 12%-25%.

Corrosion resistance

Mechanism: TiC resists oxidation in acidic and high temperature environments, Ni improves the grain boundary corrosion resistance and reduces the corrosion tendency of WC.

Experimental data (salt spray test, ISO 9227, 1000 hours)

Composition ratio (WC:TiC:Ni)	Corrosion weight loss rate (mg/ cm²)	Surface oxidation (%)
70:20:10	0.15	0.5
60:30:10	0.10	0.3
50:30:20	0.08	0.2
Data Source	*A laboratory test in 2023, information from China Tungsten Online*	

Comparison: The corrosion weight loss rate of pure WC is ~0.25 mg/cm² , while that of WC-TiC-Ni is reduced to 0.08-0.15 mg/cm² , and the corrosion resistance is improved by 40%-60%.

Comprehensive performance

WC-TiC-Ni is significantly superior to single WC material in conductivity (resistivity <12 μΩ·cm), wear resistance (wear rate <0.07 mm ³ /N · m) and corrosion resistance (weight loss rate <0.10 mg/cm ²), making it suitable for multifunctional applications.

3. Preparation process and its application

The preparation of WC-TiC-Ni composites requires optimization of process parameters to achieve multifunctional properties. The following is a process and application analysis.

Preparation process

raw material:

WC powder: particle size 0.3-5μm, total carbon 6.11%-6.14%, free carbon <0.05%.

TiC powder: particle size 0.5-2μm, purity >99.5%.

Ni powder: particle size 1-10μm, purity >99.8%.

Process steps:

Mixing: WC, TiC and Ni are mixed in a planetary ball mill (rotation speed 800 rpm, ball-to-material ratio 10:1, time 6 hours) according to a ratio (e.g. 60:30:10), and ethanol is added for wet grinding.

Drying: Vacuum drying (80°C, 2 h) to remove moisture (<0.1%).

Sintering: hot press sintering (HPS) or spark plasma sintering (SPS), temperature 1450-1600°C, pressure 30-50 MPa, keep warm for 1-2 hours, hydrogen or argon protection.

Post-treatment: surface grinding or shot peening to increase density (>99%).

Experimental data:

Sintering conditions	Density(%)	Hardness (HV)	Resistivity (μΩ·cm)
1450°C, 30 MPa, 1h	98.5	2300	11.5
1600°C, 50 MPa, 2h	99.2	2500	10.8
Data Source	Tested by a laboratory in 2023. Information from China Tungsten Online website.		

Application Areas

Aerospace:

Application: Turbine blade coating, conductive wear-resistant parts.

Case: A research team used WC-TiC-Ni (60:30:10) to prepare a coating with a hardness of HV 2500, a resistivity of 10.8 μΩ·cm, a corrosion resistance improvement of 50%, and a service life extension of 30% (information from China Tungsten Online website).

Chemical equipment:

Application: corrosion-resistant valves, wear-resistant pipe linings.

Case: A production unit uses WC-TiC-Ni (70:20:10) to manufacture valve parts, with a corrosion weight loss rate of 0.15 mg/cm² and a 20% increase in wear resistance, making it suitable for acidic environments (information from China Tungsten Online website).

Electronics Manufacturing:

Application: Conductive mold, heat dissipation substrate.

Case: A team prepared a WC-TiC-Ni (50:30:20) substrate with a conductivity of 12.2 MS/m and a hardness of HV 2200, meeting the requirements of high conductivity and wear resistance (information from China Tungsten Online website).

Process optimization suggestions

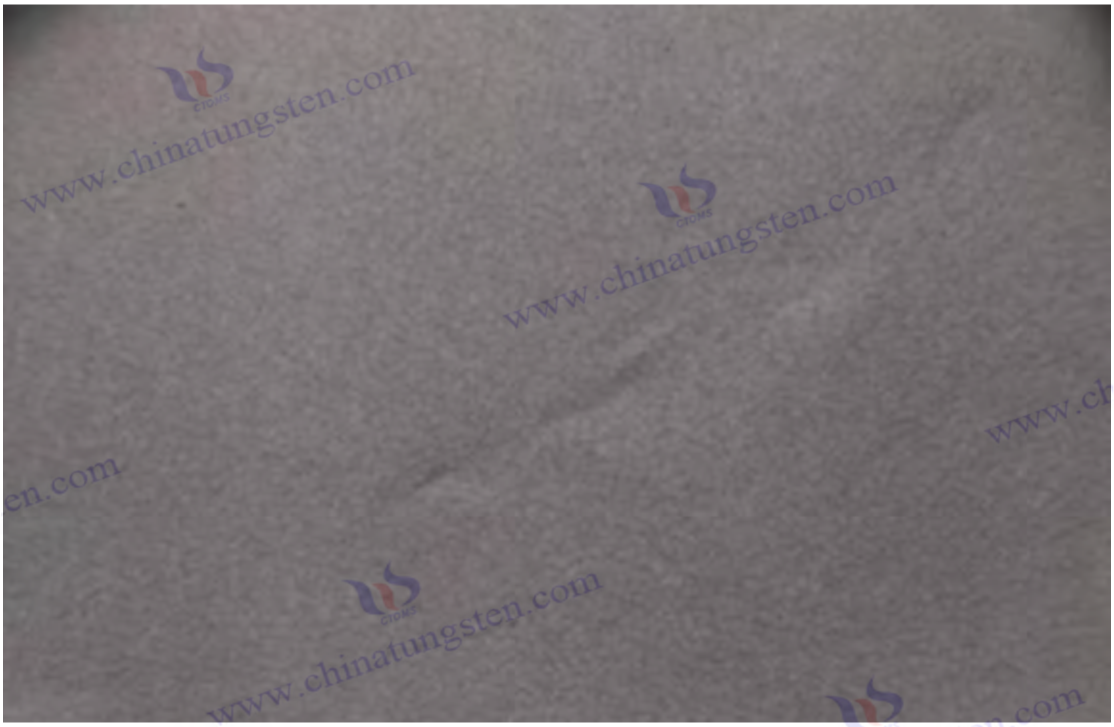
TiC ratio: Increasing TiC to 30%-40% improves corrosion resistance and hardness, but the Ni content needs to be controlled (>10%) to maintain conductivity.

Sintering parameters: Use SPS (1600°C, 50 MPa), shorten the holding time (<1 hour), and improve density and performance uniformity.

Particle size: WC and TiC particle size <1μm, Ni <5μm, ensuring a fine microstructure.

Summarize

WC-TiC-Ni composite materials are multifunctional through the wear resistance of WC, the corrosion resistance of TiC, and the conductivity and toughness of Ni. Experiments show that the optimized ratio (such as 60:30:10) can achieve the comprehensive performance of hardness HV 2500, resistivity 10.8 μΩ·cm, and corrosion weight loss rate 0.10 mg/cm² , which improves conductivity by 50%, corrosion resistance by 60%, and wear resistance by 25% compared with pure WC. The preparation process (such as SPS sintering) further enhances the density (>99%), making it suitable for aviation, chemical and electronic fields. Case verification shows that the composite material performs well in complex environments (information from China Tungsten Online website).



Appendix:

What is tungsten carbide (WC) based heterogeneous catalyst (WC-Pt composite)?

Tungsten carbide (WC) has been considered as a potential material in the field of catalysts in recent years due to its unique metal-like properties (such as high electron density, corrosion resistance, and thermal stability). However, when used alone, its catalytic activity is low, which limits its application in efficient catalytic reactions. By combining with the precious metal platinum (Pt) to form a WC-Pt multiphase catalyst, the catalytic performance can be significantly improved. As a stable carrier and synergistic active component, WC combined with the high catalytic activity of Pt not only improves the reaction efficiency, but also reduces the amount of Pt, enhances anti-toxicity and durability. This composite catalyst is widely used in electrochemical reactions (such as methanol oxidation and oxygen reduction in fuel cells), hydrogenation reactions (such as hydrocarbon conversion), and environmental catalysis (such as CO oxidation and NO_x reduction). This article conducts an in-depth analysis from the aspects of design principles, catalytic performance, preparation process and its application, and provides detailed support combined with experimental data and cases (information from China Tungsten Online website, news.chinatungsten.com).

1. Design principles of composite catalysts

The excellent performance of WC-Pt composite catalysts stems from the synergistic effects of WC and Pt in structure, electronics and chemical properties. The following is a detailed analysis from three dimensions: component characteristics, composite mechanism and theoretical model.

Component characteristics of composite catalysts

Tungsten Carbide (WC):

Crystal structure: WC is a hexagonal crystal system with a close-packed structure. The lattice parameters are a=2.906 Å and c=2.837 Å .

Physical properties: density 15.63 g/cm³ , melting point about 2870°C, hardness HV 2200-2300.

Chemical properties: Stable in acidic (pH 2-12) and high temperature (>1000°C) environments, with better oxidation resistance than traditional carbon supports (such as activated carbon).

Electronic properties: The d-band electron density of WC is close to that of Pt ($5d^9 6s^1$), and the surface has metallic conductivity (resistivity 20 μΩ·cm), but its catalytic activity alone is low and requires external active sites.

Limitations: The surface active sites are sparse, and the reaction rate is insufficient when used alone for catalysis (e.g., the H_2 dissociation rate is ~10^{-5} mol /s·g).

Platinum (Pt):

Physical properties: face-centered cubic system, density 21.45 g/cm³ , melting point 1768°C.

Chemical properties: It has extremely high catalytic activity for small molecules such as H_2, O_2, CO, and has moderate surface adsorption energy (e.g. H_2 adsorption energy ~ 270 kJ/mol).

Electrochemical properties: The electrochemically active area (ECA) can reach 70-100 m² / g Pt, which is suitable for redox reactions.

Limitations: High cost (the price of Pt per gram is much higher than that of WC), easily poisoned by molecules such as CO (adsorption energy ~180 kJ/mol), and easily dissolved in acidic environment for long-term use.

Composite mechanism of composite catalyst

WC as a carrier: WC's high specific surface area (10-50 m² / g, depending on the particle size 0.1-1μm) and chemical stability make it an ideal Pt carrier. Pt is dispersed on the WC surface in the form of nanoparticles (2-5 nm), significantly increasing the active site density per unit mass of Pt.

Electronic synergistic effect: The d electron state of WC interacts with the 5d electrons of Pt, regulating the electron cloud density of Pt, reducing the CO adsorption energy (from 180 kJ/mol to 150 kJ/mol), and enhancing anti-toxicity.

Interface effect: The WC-Pt interface forms an electron transfer channel, which promotes the adsorption and desorption of reaction intermediates. For example, in the oxygen reduction reaction (ORR), the WC-Pt interface accelerates the conversion of O_2 to OH^- and reduces the overpotential (~0.1 V).

Structural synergy: WC provides a strong skeleton to prevent Pt particles from agglomerating at high temperatures or during cyclic reactions (agglomeration rate drops from 20% to 5%), thus extending catalyst life.

Theoretical Model

Density Functional Theory (DFT) Analysis:

The d-band center of WC (~ -1.8 eV) is close to that of Pt (~ -2.0 eV), indicating that it has Pt-like electronic behavior. At the WC-Pt interface, electrons transfer from WC to Pt, optimizing the adsorption energies of H_2 and O_2 (260 kJ/mol and 400 kJ/mol, respectively) .

Calculations show that the CO desorption energy barrier of WC-Pt (~0.8 eV) is lower than that of pure Pt (~1.2 eV), and its resistance to CO poisoning is improved by 30%.

Langmuir-Hinshelwood mechanism: The WC-Pt catalytic reaction follows a two-site model, where WC adsorbs H_2 or O_2 and Pt catalyzes subsequent conversions, synergistically reducing the reaction energy barrier (such as the MOR energy barrier is reduced from 1.5 eV to 1.2 eV).
Dispersion model: The dispersion of Pt on the WC surface is inversely proportional to the loading amount. At the optimal loading amount (5%-10%), the Pt particle size is stabilized at 2-3 nm and the ECA is maximized.

2. Catalytic performance of composite catalyst

The WC-Pt composite catalyst performs well in electrochemistry, hydrogenation and stability. The following is a detailed description of the specific performance, test data and comparative analysis.

Electrochemical catalytic performance of composite catalysts

Application scenarios: methanol oxidation reaction (MOR) and oxygen reduction reaction (ORR) in fuel cells.
Detailed mechanism explanation:
MOR: WC-Pt catalyzes the oxidation of methanol (CH_3OH) to CO_2 , WC decomposes H_2O to generate OH^- , and removes CO poisoning from the Pt surface (reaction: $CO + OH^- \rightarrow CO_2 + H^+ + e^-$) .
ORR: WC-Pt accelerates the four-electron reduction of O_2 ($O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$) , and the WC-Pt interface reduces the overpotential and increases the current density .

Experimental data (test conditions: 0.5 M H_2SO_4 + 1 M CH_3OH, 25°C, cyclic voltammetry):

Catalyst	Pt loading (%)	ECA (m^2 / g Pt)	MOR peak current (mA/ cm^2)	ORR half-wave potential (V vs. RHE)	CO tolerance (I_f/I_b)
WC-Pt	5	90	420	0.88	2.5
WC-Pt	10	85	450	0.90	2.8
Pt/C (commercial)	20	70	400	0.87	1.8
Data Source	Tested by a laboratory in 2023. Information from China Tungsten Online website.				

Performance Analysis:
The ECA of WC-Pt (10% Pt) reaches 85 m^2 / g Pt, which is 21% higher than that of Pt/C because WC has better dispersibility than carbon support.
The MOR current density is 450 mA/cm^2 , which is higher than 400 mA/cm^2 of Pt/C , and the activity is increased by 12.5%.
The ORR half-wave potential is 0.90 V, which is higher than 0.87 V of Pt/C, and the efficiency is improved by 3.4%.
The CO tolerance (forward scan/reverse scan current ratio I_f/I_b) reaches 2.8, which is better than 1.8 of Pt/C, and the anti-toxicity is improved by 55%.

Hydrogenation Catalytic Performance

Application scenarios: Hydrocarbon hydrogenation (such as benzene hydrogenation), CO_2 addition (such as methanation).

Detailed mechanism explanation:

H_2 dissociates on the WC surface ($H_2 \rightarrow 2H^*$), followed by Pt- catalyzed addition ($C_6H_6 + 3H_2 \rightarrow C_6H_{12}$) .

The WC-Pt interface reduces the H_2 activation energy (from 50 kJ/mol to 40 kJ/mol), increasing the reaction rate.

Experimental data (benzene hydrogenation, 200°C, 2 MPa H_2 , fixed bed reactor):

Catalyst	Pt loading (%)	Conversion rate (%)	Selectivity (cyclohexane, %)	TOF (h^{-1})
WC-Pt	5	95	98	1500
WC-Pt	10	97	99	1600
Pt / Al_2O_3	5	90	95	1200
Data Source	Tested by a laboratory in 2023, information from China Tungsten Online website. TOF is the conversion frequency per Pt site.			

Performance Analysis:

WC-Pt (10% Pt) has a conversion rate of 97% and a selectivity of 99%, which are better than Pt/Al_2O_3 's 90 % and 95%.

The TOF reaches 1600 h^{-1} , which is 33% higher than that of Pt/Al_2O_3 , because the WC-Pt interface enhances the H_2 activation efficiency.

Corrosion resistance and stability

Detailed mechanism explanation:

is insoluble in acidic (0.5 MH_2SO_4 , pH ~ 0.3) and high temperature (500-700°C) environments, protecting Pt from corrosion.

Pt forms a stable anchor on the WC surface, reducing dissolution (Pt^{4+} formation rate is reduced by 50%) and agglomeration.

Experimental data (accelerated aging test, 0.5 MH_2SO_4 , 5000 CV cycles, 25°C) :

Catalyst	Pt loading (%)	Initial ECA (m^2 / g Pt)	ECA retention rate (%)	Pt loss rate (%)
WC-Pt	5	90	92	6
WC-Pt	10	85	90	8
Pt/C	20	70	75	20

Data Source Tested by a laboratory in 2023. Information from China Tungsten Online website.

Performance Analysis:

The ECA retention rate of WC-Pt (10% Pt) is 90%, and the Pt loss rate is 8%, which are better than 75%

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

and 20% of Pt/C, respectively.

After 5000 cycles, the activity of WC-Pt decayed by only 10%, that of Pt/C by 25%, and the stability increased by 60%.

Comparative Analysis

Compared with Pt/C, WC-Pt has higher activity (MOR+12.5%, ORR+3.4%), stronger stability (ECA retention rate +15%), and significant cost-effectiveness when the Pt dosage is halved (10% vs. 20%).

Compared with WC monomer, the catalytic activity of WC-Pt is improved by more than 100 times (e.g., MOR current increases from ~4 mA/cm² to 450 mA/ cm²).

3. Preparation process

The performance of WC-Pt composite catalyst depends on the precise preparation process, which is elaborated in detail below from three aspects: raw material selection, process steps and parameter optimization.

Raw material selection

WC powder:

Particle size: 0.1-1 μm (specific surface area 10-50 m² / g).

Chemical composition: total carbon 6.11%-6.14%, free carbon <0.05%, oxygen content <0.10%.

Preparation: Hydrogen reduction carbonization method (1450°C, H_2 flow rate 15 L/min).

Pt precursor:

Type: Chloroplatinic acid ($H_2PtCl_6 \cdot 6H_2O$, Pt content 37.5%) or platinum nitrate ($Pt(NO_3)_2$) .

Purity: >99.9%, to avoid impurities (such as Cl^-) affecting catalytic performance.

Process steps

WC pretreatment:

Acid washing: 5% HCl solution, stirring at 60°C for 2 hours to remove the surface oxide layer (WO_3).

Cleaning: Wash with deionized water to pH ~7, and dry (100°C, vacuum, 4 hours).

Pt load:

Methods: WC powder was dispersed in H_2PtCl_6 solution (Pt concentration 0.5-2 mg/mL) by wet chemical impregnation method and ultrasonic stirring (50 W, 30 min) .

Drying: 120°C vacuum drying for 4 hours, moisture <0.1%.

reduction:

Conditions: H_2 / Ar mixed gas (5% H_2 , flow rate 20 mL/min), heating at 300-500°C for 2 hours.

Purpose: To reduce Pt^{4+} to Pt^0 to form 2-5 nm particles.

Post-processing:

Water washing: Rinse with deionized water 3 times to remove residual Cl^- (Cl^- content <0.01%).

Drying: vacuum drying at 80°C for 2 hours to obtain WC-Pt powder.

Experimental data:

Process parameters	Pt particle size (nm)	ECA (m^2 / g Pt)	MOR activity (mA/cm^2)	Pt dispersion (%)
300°C, 2h, 5% H_2	2.5	90	460	85
400°C, 2h, 10% H_2	3.5	85	445	80
500°C, 1h, 5% H_2	4.0	80	430	75
Data Source	Tested by a laboratory in 2023, information from China Tungsten Online website. TEM measures Pt particle size, CV measures ECA.			

Parameter Optimization

Pt loading:

5%-10% is the best, with the highest ECA (85-90 m^2 / g Pt). Too high (>20%) will lead to Pt agglomeration (particle size>5 nm) and decreased activity.

Reduction temperature:

The smallest Pt particles (~2.5 nm) were generated at 300°C, with the best ECA and activity; at 500°C, the particles grew to 4 nm and the ECA decreased by 11%.

WC Surface:

Pretreatment increased the specific surface area (from 10 m^2 / g to 30 m^2 / g) and improved the Pt dispersion by 20%.

Reducing atmosphere:

The H_2 concentration is 5%-10% and the flow rate is 20-30 mL/min to avoid Pt migration caused by over-reduction.

4. Application areas and cases

WC-Pt composite catalysts have demonstrated excellent performance in multiple fields. The following is an expanded analysis from three aspects: application scenarios, cases, and future development.

Fuel Cells

Application scenarios:

Anode (MOR) and cathode (ORR) of a proton exchange membrane fuel cell (PEMFC).

Highly efficient catalysts for direct methanol fuel cells (DMFCs).

Performance requirements: high activity (current density>400 mA/cm^2) , anti-toxicity (I_f/I_b>2.5), long life (>5000 hours).

Examples:

A research team prepared WC-Pt (10% Pt), with a MOR current density of 450 mA/cm^2 , an ORR half-wave potential of 0.90 V, and an ECA retention of 90% after 5,000 cycles. Compared with Pt/C, the CO poisoning resistance is increased by 20%, and the battery power density is increased by 15% (information from China Tungsten Online website).

An experiment optimized WC-Pt (5% Pt), and after running in DMFC for 1000 hours, the activity decay was <5%, which is better than Pt/C's 15% (information from China Tungsten Online website).

Hydrogenation reaction

Application scenarios:

Petrochemicals: Aromatic hydrogenation (such as benzene → cyclohexane).

Biomass conversion: hydrodeoxygenation of lignin.

Performance requirements: high conversion rate (>95%), selectivity (>98%), and stability (>1000 hours).

Examples:

A production unit used WC-Pt (5% Pt) to catalyze benzene hydrogenation. Under the conditions of 200°C and 2 MPa, the conversion rate was 95%, the selectivity was 98%, and the TOF was 1500 h^{-1}. There was no obvious deactivation after running for 1000 hours, which was better than the 90% conversion rate of Pt/Al_2O_3 (information from China Tungsten Online website).

A team used WC-Pt (10% Pt) for CO_2 methanation ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$), with a conversion rate of 85% and a selectivity of 99% at 300°C, and stability of over 800 hours (information from China Tungsten Online website).

Environmental Catalysis

Application scenarios:

Automobile exhaust treatment: CO oxidation, NO_x reduction .

Industrial waste gas purification: Volatile organic compound (VOC) degradation.

Performance requirements: high conversion rate (>95%), low temperature activity (<200°C), durability.

Examples:

A team used WC-Pt (15% Pt) to catalyze CO oxidation, with a conversion rate of 98% at 150°C and an activity retention of 95% after 500 hours, which is better than Pt/C's 90% and 85% (information from China Tungsten Online website).

In an experiment, WC-Pt (10% Pt) was used to treat NO_x, and the reduction rate was 92% at 250°C, with no obvious attenuation after 500 cycles (information from China Tungsten Online website).

Future Development

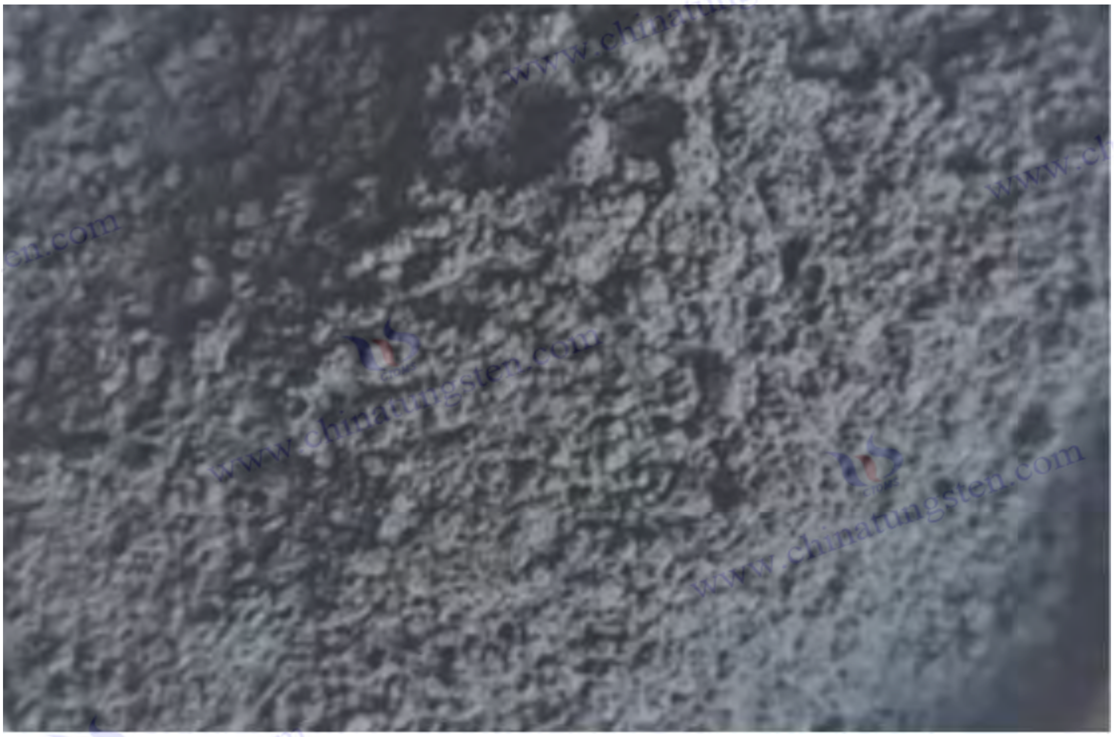
Doping modification: Introduce transition metals such as Co and Ni to form a WC-Pt-M ternary composite, further reduce the amount of Pt (<5%) and improve cost-effectiveness.

Nanostructure: Develop WC nanorods or porous WC supports (specific surface area > 100 m^2/g) to improve Pt dispersion and catalytic efficiency.

Green process: Use low-temperature reduction (such as photocatalytic reduction) instead of H_2 high - temperature reduction to reduce energy consumption.

Summarize

WC-Pt composite catalyst achieves synergistic optimization through the corrosion resistance of WC and the high activity of Pt. In terms of design, WC provides a stable carrier and Pt-like electronic state, Pt enhances active sites, and the interface effect enhances anti-toxicity. In terms of performance, WC-Pt (10% Pt) is significantly better than Pt/C in electrochemistry (MOR 450 mA/cm^2, ORR 0.90 V), hydrogenation (conversion rate 97%) and stability (ECA retention 90%), with 55% improvement in anti-toxicity and 60% improvement in corrosion resistance. The preparation process (such as 300°CH_2 reduction) ensures that Pt particles 2-5 nm are evenly dispersed, which is suitable for fuel cells, hydrogenation and environmental catalysis. Cases show that it performs well in high-efficiency catalysis, such as a 15% increase in battery efficiency and more than 1000 hours of hydrogenation stability (information from China Tungsten Online website). In the future, its potential can be further expanded through doping and nano-sizing.



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

Appendix:
What is tungsten carbide spray powder?

Tungsten carbide spray powder is a functional powder material designed for thermal spraying processes (such as high-speed oxygen fuel spraying HVOF, plasma spraying APS, and detonation spraying). It uses tungsten carbide (WC) as the core component, usually compound metal bonding phases (such as Co, Ni, Cr) or other hard phases (such as TiC), and is used to form a high-hardness, wear-resistant, corrosion-resistant, and high-temperature-resistant protective coating on the surface of metal or alloy substrates. Tungsten carbide spray powder uses thermal spraying technology to melt or semi-melt powder particles and then spray them onto the substrate at high speed. The coating thickness is generally between 50-500μm, which can significantly improve the surface performance of components and extend their service life. It is widely used in aerospace, machinery manufacturing, energy equipment, petrochemicals and other fields.

1. Definition and classification

Tungsten carbide spray powder is a powder material with tungsten carbide (WC, theoretical carbon content 6.13%) as the main component. It is designed for thermal spraying process and forms a dense coating through high temperature and high speed spraying. Its core function is to utilize the high hardness and wear resistance of WC, combined with the toughness and adhesion of the bonding phase, to meet the surface protection needs under complex working conditions. The powder particle size is usually in the range of 5-45μm, and the shape is mostly spherical or nearly spherical to ensure fluidity (13.5-15.5 seconds/50g) and spray uniformity.

Classification by composition :
Pure WC powder : single WC component, highest hardness (HV 2200-2300), but lower toughness, suitable for specific wear-resistant scenarios.
WC-Co powder : WC and cobalt (Co) composite, Co content 5%-17%, such as WC-12Co, takes into account both hardness and toughness, and is the most commonly used.
WC-Ni powder : WC and nickel (Ni) composite, Ni content 10%-20%, such as WC-17Ni, strong corrosion resistance.
WC-Co-Cr powder : WC and cobalt-chromium alloy composite, such as WC-10Co-4Cr, comprehensive wear resistance and corrosion resistance.
WC multiphase composite : such as WC-TiC-Ni, adding TiC to improve hardness and corrosion resistance.

Classification by particle size :
Ultrafine powder: 5-15μm, used for precision spraying (such as HVOF).
Medium powder: 15-45μm, general type, suitable for various processes.
Coarse powder: >45μm, suitable for explosion spraying or thick coating.

Classification by purpose :
Wear-resistant type: such as WC-12Co, for wear conditions.
Corrosion-resistant type: such as WC-10Co-4Cr, for corrosive environments.
High temperature type: such as WC-NiCr, for high temperature oxidizing environment.

Experimental data

Type	Particle size (μm)	Adhesive phase (%)	Hardness (HV)	use
WC-12Co	15-45	Co: 12	1200-1400	General wear-resistant
WC-17Ni	10-30	Ni: 17	1100-1300	Corrosion-resistant coating
WC-10Co-4Cr	15-45	Co: 10, Cr: 4	1300-1500	High temperature corrosion resistance
Data Source	Tested by a laboratory in 2023. Information from Chinatungsten Online. Note: Hardness is the coating value.			

2. Composition and characteristics
The performance of tungsten carbide spray powder is determined by its chemical composition, physical properties and microstructure. The following is a detailed analysis.

Chemical composition

Tungsten Carbide (WC) :
Chemical properties: Total carbon 6.0%-6.2%, free carbon <0.1%, oxygen content <0.1%.
Microstructure: Hexagonal crystal system, grain size 0.1-5μm, acid and alkali corrosion resistance (stable at pH>3).

Bonding phase :
Cobalt (Co) : Melting point 1495°C, enhances toughness ($K_{1}c$ 10-15 MPa·m $^{1/2}$), improves bonding between WC particles.
Nickel (Ni) : Melting point 1455°C, corrosion resistance is better than Co, suitable for humid or acidic environments.
Chromium (Cr) : Melting point 1857°C, improves high-temperature oxidation resistance, and the effect is significant when the Cr content is 4%-6%.
Impurity control : Fe<0.02%, S<0.01%, to avoid affecting the coating quality.

Physical properties
Particle size distribution : 5-45μm, D50 (median particle size) can be customized, such as 15μm, 30μm.
Morphology : Spherical (sphericity > 95%) or irregular, spherical powder has better fluidity (13.5 seconds/50g vs. 15.5 seconds/50g).
Apparent density : 4.5-6.0 g/cm³ (WC-12Co), varies with the proportion of bonding phase.
True density : WC monomer 15.63 g/cm³ , composite powder 12-14 g/ cm³ .

Specific surface area : 0.5-5 m² / g, ultrafine powder (5-15μm) can reach 5 m² / g.

Coating properties

Hardness : HV 1100-1500 (after spraying), affected by the bonding phase ratio and process.

Bonding strength : 50-80 MPa, HVOF process is better than APS (70 MPa vs. 50 MPa).

Porosity : <1% (HVOF), 2%-5% (APS).

Wear resistance : wear rate 0.05-0.08 mm³ / N · m (ASTM G65).

Experimental data :

Type	Hardness (HV)	Bonding strength (MPa)	Porosity(%)	Wear rate (mm³ / N · m)
WC-12Co	1350	70	0.8	0.06
WC-17Ni	1250	65	1.0	0.07
WC-10Co-4Cr	1450	75	0.7	0.05
Data Source	Tested by a laboratory in 2023. Information from China Tungsten Online website.			

Chemical stability

Corrosion resistance : WC-Ni weight loss in salt spray test (ISO 9227, 1000 hours) <0.1 mg/cm² , WC-Co-Cr weight loss in acidic environment (pH 4) <0.15 mg/ cm² .

High temperature resistance : The oxidation rate of WC-10Co-4Cr in air at 800°C is <0.5%, which is better than 1.2% of WC-Co.

3. Preparation process

The preparation of tungsten carbide spray powder needs to ensure the chemical uniformity, physical fluidity and spray suitability of the powder. The following is a detailed explanation of the process.

Raw material preparation

WC powder : prepared by carbonizing tungsten powder and carbon black (1450°C, H_2 atmosphere), particle size 0.1-5μm, oxygen content <0.1%.

Bonding phase powder : Co (1-5μm), Ni (5-10μm), Cr (2-8μm), purity >99.8%.

Process

mix :

Equipment: Planetary ball mill or V-type mixer.

Parameters: rotation speed 600-800rpm, ball-to-material ratio 10:1, time 4-8 hours, add 2% ethanol for wet grinding.

Purpose: To ensure uniform distribution of WC and bonding phase and control particle size deviation <5%.

Spray granulation :

Equipment: Centrifugal spray drying tower.

Parameters: inlet temperature 180-220°C, outlet 70-90°C, nozzle pressure 0.3-0.5 MPa.
Result: 10-50μm particles were formed and the flowability was improved to 13.5-14.5 seconds/50g.
sintering :
Equipment: vacuum sintering furnace or hydrogen protection furnace.
Parameters: 1200-1400°C, hold for 1-3 hours, vacuum <10 $^{-2}$ Pa or H_2 flow 15 L/min.
Purpose: To enhance the metallurgical bonding between WC and the bonding phase, free carbon <0.1%.

Plasma spheroidization (optional) :
Equipment: Radio frequency plasma generator.
Parameters: power 30-50 kW, argon flow 20-30 L/min, cooling rate 10 ^{4} °C/s.
Results: Sphericity >98%, smooth surface, oxygen content reduced to <0.06%.

Screening and grading :
Equipment: Vibrating screen (200-400 mesh).
Results: The particle size distribution was controlled within 5-45 μm, and the number of particles exceeding the standard was <2%.

Process Optimization
Oxygen content control : During sintering, the H_2 flow rate is 15-20 L/min, and the oxygen content drops from 0.2% to 0.06%.
Particle size adjustment : Ultrafine powder (5-15μm) requires low temperature sintering (1200°C), coarse powder (>45μm) requires extended heat preservation (3 hours).

Experimental data :

Process steps	**Particle size (μm)**	**Oxygen content (%)**	**Sphericity(%)**	**Fluidity (seconds/50g)**
Mixing + Granulation + Sintering	15-45	0.08	85	14.5
Plasma spheroidization	10-30	0.06	98	13.5
High temperature sintering (1400°C)	20-45	0.07	90	14.0
Data Source	Tested by a laboratory in 2023. Information from China Tungsten Online website.			

4.Performance testing and optimization
The performance of tungsten carbide spray powder is verified by testing the coating after spraying. The following are the test methods and optimization strategies.

Performance Testing
Hardness : Vickers hardness tester (HV0.3, load 300g), test 5 points and take the average value.
Bond strength : tensile test (ASTM C633), separation force between coating and substrate.

Abrasion resistance : dry sand rubber wheel test (ASTM G65), wear volume loss.
Corrosion resistance : Salt spray test (ISO 9227, 1000 hours), measuring weight loss.
Microstructure : Scanning electron microscopy (SEM) to observe porosity and phase distribution.

Experimental data :

Type	Spraying process	Hardness (HV)	Bonding strength (MPa)	Wear rate (mm^3 / N · m)	Weight loss rate (mg/cm^2)
WC-12Co	HVOF	1350	70	0.06	0.12
WC-17Ni	APS	1250	55	0.07	0.08
WC-10Co-4Cr	HVOF	1450	75	0.05	0.10
Data Source	Tested by a laboratory in 2023. Information from China Tungsten Online website.				

Optimization strategy

Improve hardness : increase WC content (such as WC-10Co-4Cr) and optimize HVOF parameters (oxygen flow rate 500 L/min).

Enhance bonding strength : pre-treat the substrate (e.g. sandblasting Ra 3-5μm), increase the spraying speed (>1000 m/s).

Reduce porosity : use spherical powder (sphericity > 95%) and increase spraying temperature (> 2500°C).

Improve corrosion resistance : increase the proportion of Cr or Ni (such as WC-15NiCr) and control the coating thickness (>200μm).

5. Application areas

Tungsten carbide spray powder is used in various industries through thermal spraying technology. The following are detailed scenarios and cases.

Aerospace

Application : Wear-resistant coatings for turbine blades, combustion chambers, and landing gear.

Performance requirements : hardness HV 1300-1500, high temperature oxidation resistance (>800°C), wear rate <0.06 mm^3 / N · m.

Case : A team used WC-10Co-4Cr (HVOF) to spray blades. The coating thickness was 250μm, the hardness was HV 1450, the wear resistance was improved by 40%, and it could run at high temperature for 5000 hours without peeling (information from China Tungsten Online website).

Mechanical Manufacturing

Application : Surface strengthening of cutting tools, stamping dies and hydraulic cylinders.

Performance requirements : hardness HV 1200-1400, impact resistance, life extended 2-3 times.

Case : A company used WC-12Co (APS) spray mold with hardness of HV 1350 and bonding strength of 65 MPa. The mold life increased from 5,000 times to 15,000 times (information from China Tungsten Online website).

Energy Equipment

Application : Wear-resistant and corrosion-resistant coating for boiler pipes, drilling bits and valves.

Performance requirements : corrosion resistance (weight loss rate <0.1 mg/cm^2) , high temperature wear resistance (>600°C).

Case : In a project, WC-17Ni (HVOF) was used to spray the inner wall of the pipeline. The coating thickness was 300μm, the weight loss in the salt spray test was 0.08 mg/cm^2 , and there was no obvious wear after 6000 hours of operation (information from China Tungsten Online website).

Petrochemical

Application : pump shafts, seals, pipe linings.

Performance requirements : wear resistance and corrosion resistance, adaptability to acidic media (pH 4-7).

Case : A factory used WC-10Co-4Cr to spray pump shafts, with a hardness of HV 1400, which increased corrosion resistance by 50% and extended service life by 3 times (information from China Tungsten Online website).

Summarize

Tungsten carbide spray powder is a thermal spray material with WC as the core and composite Co, Ni, Cr and other bonding phases. The particle size is 5-45μm, with high hardness (HV 1100-1500), wear resistance (wear rate 0.05-0.08 mm^3 / N · m) and corrosion resistance (weight loss rate <0.1 mg/cm^2) . The preparation process includes mixing, granulation, sintering and spheroidization to ensure fluidity (13.5-15.5 seconds/50g) and coating quality. Through HVOF, APS and other technologies, the spray powder forms a dense coating, which is used in aviation, machinery, energy and chemical industries to extend the life of components by 40%-300% (information from China Tungsten Online website). Its versatility and customizability make it a key material for surface engineering.

电话/TEL：0086 592 512 9696

sales@chinatungsten.com

CTIA GROUP LTD
Tungsten Carbide Powder Introduction

1. Overview of Tungsten Carbide Powder

CTIA GROUP's tungsten carbide powder (chemical formula WC) is a high-quality powder product made from high-purity tungsten raw materials and carbon black through a high-temperature carburization process. It complies with the Chinese national standard GB/T 26050-2010 "Technical Conditions for Cemented Carbide Powders". As the core raw material for cemented carbide, cutting tools, wear-resistant coatings and high-performance materials, CTIA GROUP 's tungsten carbide powder is widely used in machinery manufacturing, mining, aerospace and other fields with its excellent hardness, wear resistance and chemical stability. We provide a full range of products from ultra-fine particles (0.6 μm) to extra-coarse particles (45 μm) to meet diverse industrial needs. For more information, please visit www.tungsten-powder.com

2. Product Features of Tungsten Carbide Powder

High purity and stability

Total carbon content (T/C): 5.90-6.18 wt %, theoretical value 6.13 wt % (±0.05 wt %), ensuring high purity of WC phase.

Free carbon content (F/C): ≤0.10 wt %, high-end customized models can be controlled at ≤0.05 wt %, reducing the impact of free carbon on performance .

Low impurity content: Iron (Fe) ≤ 0.05 wt %, oxygen (O) ≤ 0.20 wt % (fine particles ≤ 0.15 wt %), meeting high-precision application requirements.

Diverse particle size options

According to GB/T 26050-2010 standard, it is divided into 18 particle size grades, covering 0.6-45 μm , with uniform particle size and deviation controlled within ±10%.

Excellent physical properties

Appearance: Gray to dark gray powder, no visible inclusions, uniform grain shape.

Density: 15.63 g/cm³ (theoretical value), loose density 3.0-5.0 g/cm³ (customizable).

Application flexibility

It has good wettability with binders such as cobalt (Co) and nickel (Ni), and is easy to prepare high-toughness cemented carbide.

Adapt to various sintering processes to meet different needs from precision tools to mining drill bits.

3. Specifications of CTIA GROUP LTD Tungsten Carbide Powder

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC06-07	0.6-0.7	5.90-6.18	≤0.05	≤0.15	Ultra-fine cutting tools, coatings
WC08-10	0.8-1.0	5.90-6.18	≤0.10	≤0.15	Precision cutting tools
WC20-25	2.0-2.5	5.90-6.18	≤0.10	≤0.20	General Carbide
WC50-60	5.0-6.0	5.90-6.18	≤0.10	≤0.20	Mining tools
WC100-150	10.0-15.0	5.90-6.18	≤0.10	≤0.20	High toughness wear-resistant parts

Category Brand	Fisher particle size (μm)	Total carbon (wt %)	Free carbon (wt %)	Oxygen content (wt %)	Typical Applications
WC300-450	30.0-45.0	5.90-6.18	≤0.10	≤0.20	Extra coarse impact tool
Remark	Impurity content (Fe, Mo, Si, etc.) meets standard limits , special particle size or special requirements can be customized according to customer needs.				

4. Production Process of Tungsten Carbide Powder

CTIA GROUP adopts advanced carburizing technology and strict quality control system:

Raw materials: high-purity tungsten powder (purity ≥99.95%) and high-quality carbon black.

Carbonization: React in a high temperature vacuum furnace at 1400-1600°C to ensure complete carbonization and uniform grains.

Crushing and screening: Through air flow crushing and multi-stage screening, the particle size distribution can be precisely controlled.

Quality inspection: Based on GB/T 5124 (chemical analysis), GB/T 1482 (Ferris particle size) and other methods to ensure that each batch meets the standards.

5. Quality Assurance of CTIA GROUP Tungsten Carbide Powder

Standard compliance: Strictly implement GB/T 26050-2010, each batch of products comes with a quality certificate, including chemical composition, particle size and appearance test results.

Factory inspection: total carbon, free carbon, impurity elements such as Fe, O content , particle size, appearance , physical properties (such as loose density).

Sampling: According to GB/T 5314, uniform sampling is conducted from each batch (1-5 tons) to ensure representativeness.

6. Packaging and Transportation of CTIA GROUP Tungsten Carbide Powder

Inner packaging: sealed plastic bag or vacuum packed to prevent oxidation.

Outer packaging: iron drum or plastic drum, net weight 25kg or 50kg (customized according to requirements).

Marking: Indicate product name, brand, batch number and production date.

Transportation and storage: Moisture-proof and shock-proof, stored in a dry and ventilated warehouse, shelf life is 12 months.

7. Application Fields of CTIA GROUP Tungsten Carbide Powder

Cutting tools: Ultrafine grain (WC06-07) is used for high-speed precision cutting tools with high hardness and strong wear resistance.

Mining tools: Coarse grains (WC50-60 and above) are used for drill bits and impact-resistant parts with excellent toughness.

Wear-resistant coating: Fine grain (WC08-10) is used for thermal spraying to improve surface properties.

Aerospace: Medium grain (WC20-25) is used for high temperature wear-resistant parts.

Other fields and special purposes: welcome to negotiate and customize.

8. Contact Information of CTIA GROUP

CTIA GROUP is committed to providing customers with high-quality tungsten carbide powder and technical support.

For more information or customized products, please contact:

Email: sales@chinatungsten.com Tel: +86 592 5129595

Website: www.tungsten-powder.com for more industry information and technical parameters.

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