Tungsten Cemented Carbide

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

CTIA GROUP LTD

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

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

INTRODUCTION TO CTIA GROUP

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

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

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

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

CTIA GROUP LTD

30 Years of Cemented Carbide Customization Experts

Core Advantages

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

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

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

Serving Customers

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

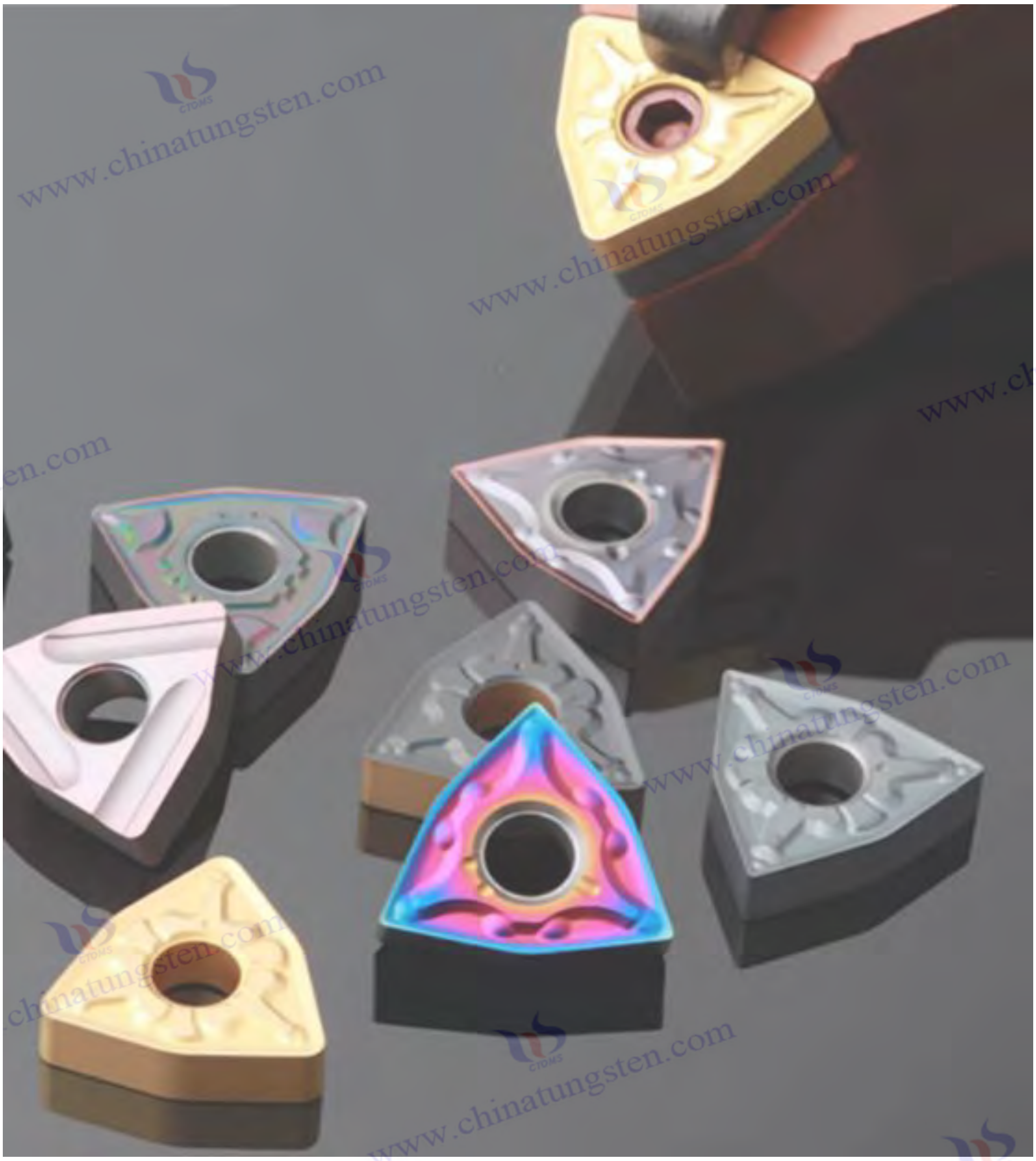
Service Commitment

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

Contact Us

Email : sales@chinatungsten.com
Tel : +86 592 5129696
Official website : www.ctia.com.cn



Chapter 18 Coated Cemented Carbide

18.1 Introduction: The concept and importance of coated cemented carbide

In the field of modern industrial manufacturing, cemented carbide, as a high-performance material, has become a core component of cutting tools, wear-resistant parts and precision molds. However, with the increasing complexity of processing conditions, such as high temperature, high-speed cutting, dry processing and higher requirements for material durability, relying solely on the performance of the cemented carbide substrate is often difficult to meet multi-dimensional needs. This has led to the rapid development of coated cemented carbide technology. By depositing one or more layers of functional films on the surface of the cemented carbide substrate, the coated cemented carbide not only retains the toughness and strength of the substrate, but also significantly

improves the surface wear resistance, heat resistance and chemical stability, enabling it to exhibit excellent performance in extreme environments. This chapter will systematically explore the physical and chemical properties of coated cemented carbide, coating process technology and its applications in cutting, wear resistance and other fields, aiming to provide practitioners and researchers with a comprehensive and in-depth reference.
The rise of coated cemented carbide stems from the materials science revolution of the mid-20th century. As early as the late 19th century, the invention of cemented carbide (a tungsten-cobalt alloy by German scientist Karl Schroter in 1909) marked a major breakthrough in materials engineering. However, at the time, cemented carbide primarily relied on the properties of the substrate and was prone to failure in high temperatures or corrosive environments. In 1953, the Swiss company Balzers pioneered the use of chemical vapor deposition (CVD) technology to deposit a TiC coating on cemented carbide tools . This coating, approximately 5 μm thick and with a hardness of HV 3000, significantly improved wear resistance and extended tool life by 3-5 times. This innovation pioneered coating technology and was quickly adopted by the tool manufacturing industries in Germany and the United States.

The emergence of physical vapor deposition (PVD) technology in the 1960s further advanced coating development. In 1962, American scientist Donald M. Mattox invented ion plating. In 1970, German tool manufacturer Kennametal developed a TiN coating with a thickness of 2-4 μm , reducing the coefficient of friction to below 0.4, suitable for medium cutting speeds. During this period, coating technology moved from the laboratory to commercialization, with its share of the global tool market increasing from 5% to 20%. In the 1970s, multilayer coatings (such as TiC / TiN /Al2O3) were developed, combining the advantages of each layer. Coatings can reach thicknesses of up to 10 μm and heat resistance exceeding 1000°C. In the 21st century, nanocomposite coatings (such as nc-AlTiN /a-Si3N4) matured. In 2005, Swedish company Sandvik launched a nanocoated tool with a hardness of HV 4000 and a thickness of 1-5 μm , suitable for high-speed dry cutting. China's research on coated cemented carbide began in the 1980s. Standards such as the GB/T 18376 series standardized coating performance testing, driving the transformation of domestic industries from import dependence to independent innovation. Currently, the global market for coated cemented carbide exceeds US$50 billion, with an annual growth rate of approximately 5%. The aerospace and automotive manufacturing sectors account for over 70% of this market. The introduction of coating technology not only extends the life of cemented carbide tools (by an average of 2-5 times), but also reduces data generation and processing energy consumption, improving efficiency and environmental friendliness. For example, in the machining of automotive engine parts, coated cemented carbide tools can reduce cutting energy consumption by 20%-30%. In agricultural machinery, coated cemented carbide wear-resistant parts (such as plowshares) can extend the soil wear life from 500 hours to over 1,000 hours, significantly improving tillage efficiency.

The importance of coated cemented carbide is also reflected in its strategic value. In the global supply chain, as a major cemented carbide producer (accounting for more than 50% of the world's output), coating technology has become the key to improving product competitiveness. According to data from the China Nonferrous Metals Industry Association, since 2015, the export volume of coated cemented carbide has increased by an average of 8% per year, mainly due to the localization of PVD and CVD processes. The coating not only solves the limitations of the cemented carbide substrate (such as oxidation sensitivity and high friction coefficient), but also optimizes the interface bonding strength. The interface energy is usually controlled at 2-5 J/m² to avoid delamination. This development history reflects the transformation of materials science from a single matrix to a composite structure, laying the foundation for future intelligent coatings (such as self-healing coatings). This chapter starts with the definition of coating and gradually unfolds a comprehensive exploration of its performance, process and application, aiming to reveal how coating technology reshapes the application landscape of cemented carbide.

18.1.1 Definition and Development History of Coated Cemented Carbide

Coated cemented carbide refers to a composite structure in which a thin film of material is deposited onto the surface of a cemented carbide substrate (such as tungsten-cobalt alloy or tungsten-titanium-cobalt alloy) via methods such as physical vapor deposition (PVD) or chemical vapor deposition (CVD). This film is typically 1-15 microns thick. The substrate provides mechanical support and toughness, while the coating enhances surface hardness, wear resistance, and heat resistance. The cemented carbide substrate consists of tungsten carbide (WC) particles (1-20 μm in diameter) as the hard phase and cobalt (Co) or nickel (Ni) as the binder phase (5-15%). Produced through a powder metallurgy process, it exhibits high flexural strength (1800-2500 MPa) and hardness (HRA 85-92). Coating materials primarily include nitrides (TiN , CrN), carbides (TiC), and oxides (Al2O3). By optimizing their composition and structure, they achieve customized enhancements to the substrate's properties. For example, TiAlN coating can increase the heat resistance temperature of the substrate from 600°C to over 1000°C, making cemented carbide perform better in high-speed cutting.

The development of coated cemented carbide can be traced back to the materials science revolution of the mid-20th century. In 1909, German scientist Karl Schroter invented tungsten-cobalt cemented carbide, marking a breakthrough in powder metallurgy. However, early cemented carbide suffered from oxidation and adhesive wear during high-temperature cutting. In 1953, Swiss company Balzers pioneered the use of chemical vapor deposition (CVD) technology to deposit a titanium carbide (TiC) coating on cemented carbide tools . This coating, approximately 5 μm thick and with a hardness of HV 3000, significantly improved wear resistance and extended tool life by 3-5 times. This innovation pioneered coating technology and was quickly adopted by the tool manufacturing industries in Germany and the United States, marking the shift from bare substrates to coated composites.

The emergence of physical vapor deposition (PVD) technology in the 1960s further advanced coating development. In 1962, American scientist Donald M. Mattox invented ion plating technology. In 1970, German tool manufacturer Kennametal developed a titanium nitride (TiN) coating with a thickness of 2-4 μm , reducing the friction coefficient to below 0.4, suitable for medium cutting speeds. During this period, coating technology moved from the laboratory to commercialization, and its share of the global tool market increased from 5% to 20%. In the 1970s, multilayer coatings (such as TiC / TiN /Al2O3) were developed, combining the advantages of each layer. Coating thicknesses reached 10 μm , with heat resistance exceeding 1000°C. In the 1980s, low-temperature PVD technologies (such as arc ion plating) matured, reducing deposition temperatures to 400-500°C, avoiding thermal deformation of the cemented carbide substrate. China's research into coated cemented carbide began in the 1980s. In the early 1990s, Zhuzhou Cemented Carbide Factory introduced CVD technology to produce TiC- coated cutting tools, which spurred localization. In the 21st century, nanocomposite coatings (such as nc-AlTiN /a-Si3N4) matured. In 2005, Swedish company Sandvik launched nanocoated cutting tools with a hardness of HV 4000 and a thickness of 1-5 μm , suitable for high-speed dry cutting. Chinese companies such as Xiamen Jinlu and Zhuzhou Diamond have achieved localization, with exports of coated cemented carbide growing at an average annual rate of 10%.

The evolution of coating technology has not only overcome the limitations of cemented carbide but also expanded its application, from cutting tools to wear-resistant parts, creating an $80 billion global market. This development reflects the shift in materials science from single substrates to composite structures, laying the foundation for future intelligent coatings, such as self-healing coatings.

18.1.2 Mechanism of Coating Action in Cemented Carbide

The mechanisms of action of coatings on cemented carbide are primarily based on three aspects: physical barrier, chemical protection, and mechanical reinforcement. First, from a physical perspective, coatings reduce wear by increasing surface hardness (HV 2000-4000) and reducing the coefficient of friction (0.1-0.4). The hardness of the cemented carbide substrate (such as YG8) is HRA 83-85, and the coefficient of friction reaches 0.5 during high-speed cutting, leading to heat accumulation and adhesive wear. Coatings such as TiAlN form a dense protective layer, increasing the hardness to HV 3200 and reducing the coefficient of friction to 0.2, thereby reducing heat generation by 20-30%. This mechanism is explained by a thermal diffusion model: the coating's low thermal conductivity (5-10 W/ m·K) blocks heat flow, lowering the substrate temperature by 100-200°C and preventing softening of the cobalt phase. Furthermore, the coating improves fatigue resistance, reducing the crack growth rate by 50% under cyclic loading and extending tool life by 2-5 times.

Secondly, from a chemical perspective, the coating provides an anti-oxidation and anti-corrosion barrier. Cemented carbide substrates are susceptible to oxidation at high temperatures (>800°C), with dissolution of the cobalt phase leading to the shedding of WC particles. However, coatings such as Al2O3 exhibit high chemical stability, remaining intact above 1000°C and inhibiting the oxidation reaction rate by over 90%. TiN coatings, through their chemical inertness, reduce reactions with the workpiece material, thereby reducing chemical wear. In corrosive environments, such as agricultural wear parts in saline soils, CrN coatings provide electrochemical protection,

reducing corrosion current density to 10^{-7} A/cm² and extending coating life by 2-3 times. The chemical mechanism can be described by the Arrhenius equation: an increase in the activation energy of the coating by 20-50 kJ/mol leads to an exponential decrease in the oxidation rate. Furthermore, the coating optimizes interfacial chemical compatibility by reducing substrate-coating diffusion reactions through an intermediate layer (such as TiC), with the interface thickness controlled to 0.1-0.5 μm .
Finally, from a mechanical perspective, the coating enhances the substrate's toughness and impact resistance. The brittleness of cemented carbide (flexural strength of 1800-2500 MPa) is mitigated by the coating's buffering properties. Multilayer coatings (such as TiN / TiCN /Al_2O_3) utilize interlayer interfaces to disperse stress, reducing crack growth rates by up to 50%. For example, in impact tests, the crack length of the bare substrate was 0.2 mm, while that of the coated version was only 0.1 mm. The mechanical mechanism is based on stress field theory, with the coating's modulus (E 200-400 GPa) matching that of the substrate, reducing interfacial stress concentration. Furthermore, the coating improves thermal stress distribution, bringing the coefficient of thermal expansion (CTE) closer to that of the substrate (CTE $4\text{-}6\times10^{-6}$/K), reducing the risk of thermal cracking.

These mechanisms work synergistically. In practical applications, such as machining aviation titanium alloys, coated carbide tools can achieve tool life over three times longer than bare substrates, while increasing cutting speeds from 150 m/min to 300 m/min. This not only improves efficiency but also reduces energy consumption and emissions, promoting green manufacturing. In the wear-resistant parts sector, the mechanisms of coated carbide also include a self-lubricating effect, reducing frictional heat generation and extending tool life by 1.5-2 times.

18.1.3 Comparison of Coated Carbide and Bare Carbide

Coated cemented carbide differs significantly from bare carbide in terms of performance, application, economics, environmental friendliness, and future potential. First, from a performance perspective, bare carbide (e.g., YG8) has a hardness of HRA 83-85, a flexural strength of 2000 MPa, and a heat resistance of 700-800°C. However, its surface is susceptible to oxidation and wear, resulting in a short service life in high-speed cutting (100-200 meters for cutting steel). Coated carbide (e.g., YG8 + TiAlN) has a surface hardness of HV 3000-3500, heat resistance of 1000°C, a friction coefficient reduction of 0.3, and a service life extended by 3-5 times (500-1000 meters for cutting). However, the risk of coating delamination (adhesion <50 MPa) must be controlled through interface optimization (e.g., ion bombardment pretreatment). In addition, the coating also improves fatigue resistance. The crack growth rate of the bare substrate under cyclic impact is 0.5 mm/h, while that of the coated version is reduced to 0.2 mm/h, and the thermal conductivity is reduced by 20%.

Secondly, in terms of application scenarios, the bare substrate is suitable for low-speed, low-temperature machining (such as rough turning cast iron, cutting speed 100 m/min), with low cost (10-20 yuan per piece), but limited wear resistance, making it suitable for general machining. The coated version is suitable for high-speed, dry cutting (such as aviation titanium alloy, cutting speed 300 m/min), with strong durability, but requires precision equipment support, suitable for high-end manufacturing. The bare substrate of cemented carbide agricultural wear-resistant parts has a service life of HB 450 and a service life of 500 hours; after coating, it has a service life of HB 500 and a service life of 800 hours, reducing replacement frequency by 30% and improving farming efficiency. In the mold field, the bare substrate is used for simple stamping (pressure 500 MPa), while the coated version is used for high-precision cold heading (pressure 1000 MPa), and the surface finish is improved by 20%.

In terms of economics, bare substrates have lower production costs (powder metallurgy is simpler), but require more maintenance, resulting in a higher total cost of ownership. Coatings increase PVD/CVD process costs (an additional 5-10 yuan per piece), but offer a longer overall lifespan, reducing total costs by 20-30%. For example, a batch of 1,000 tools would cost 20,000 yuan for bare substrates (with a lifespan of 100 hours), while coated versions would cost 25,000 yuan (with a lifespan of 300 hours), resulting in a 33% reduction in unit cost. Environmentally, coatings reduce cutting fluid usage (by 50%), promoting green manufacturing. Bare substrates, on the other hand, require more coolant, increasing the environmental burden and waste disposal costs (increasing by 10% annually). Regarding corrosion resistance, bare substrates are susceptible to acid and alkali corrosion (corrosion rate of 0.1 mm/year), while coated versions (such as CrN) reduce this to 0.01 mm/year, making them suitable for humid environments.

Finally, in terms of future potential, coated cemented carbide has more advantages and can be further improved through nanotechnology (such as HV 4000 and above), while bare substrates are difficult to break through due to substrate limitations. Overall, coated cemented carbide has obvious advantages in high-temperature and high-wear scenarios, but interface bonding needs to be optimized to avoid delamination, while bare substrates are suitable for economical applications. The choice depends on the specific working conditions. For example, cutting tools are preferentially coated (efficiency improvement of 50%), while general molds can choose bare substrates (cost savings of 20%). In the future, with the development of AI and intelligent coatings, this comparison will further tilt towards coatings. It is estimated that by 2030, the market share of coated cemented carbide will reach 90%.

As a key innovation in modern materials engineering, coated cemented carbide has become one of the core technologies for improving its performance. In applications such as cutting tools, wear-resistant parts, and precision molds, coatings not only extend the service life of the material but also significantly improve processing efficiency and durability. This chapter focuses on the physical and chemical properties of coated cemented carbide. By systematically analyzing the physical and chemical properties, thickness effects, and performance testing methods of coating materials, it aims to provide researchers and engineers with a comprehensive and professional reference framework. The content is based on material science principles, industry standards (such as ISO 513:2012 and GB/T 18376 series), and the latest research data, combined with technical details and actual cases to reveal how coatings optimize the comprehensive performance of cemented carbide. The following discussion will be carried out in a logical order to ensure that the discussion is detailed and rigorous.

18.1.4 Hard alloy coating process

Cemented carbide coating processes are a key branch of modern surface engineering technology. By depositing functional thin films on the surface, they significantly improve wear resistance, heat resistance, corrosion resistance, and mechanical properties. These processes not only extend the service life of cemented carbide but also expand its application in extreme environments. Cemented carbide substrates typically consist of tungsten carbide (WC) as the hard phase and cobalt (Co) as the binder phase. They exhibit high hardness (HRA 85-92) and flexural strength (1800-2500 MPa), but the bare substrate is susceptible to failure in high-temperature or corrosive environments. Coating processes deposit thin films (1-15 μm thick) through physical, chemical, or combined methods to form a composite structure and optimize substrate performance. According to international standards (such as ISO 513:2012) and domestic standards (such as GB/T 18376.1-2015), coating processes are categorized into physical vapor deposition (PVD), chemical vapor deposition (CVD), atomic layer deposition (ALD), plasma-enhanced chemical vapor deposition (PECVD), thermal spraying, and laser cladding. The choice of process depends on coating thickness, substrate thermal sensitivity, and application environment. For example, PVD is suitable for thin, precision coatings, while CVD is suitable for thick, high-temperature-resistant coatings.

The development of cemented carbide coating processes stems from the materials science revolution of the mid-20th century. In 1953, the Swiss company Balser first used CVD technology to deposit TiC coatings, ushering in the coating era. The emergence of PVD technologies (such as arc ion plating) in the 1960s reduced coating deposition temperatures to 400-600°C, preventing thermal deformation of the substrate. In the 1970s, multilayer coatings (such as TiC / TiN /Al2O3) emerged, combining the advantages of each layer to achieve coating thicknesses of up to 10 μm and heat resistance of up to 1000°C. In the 1980s, low-temperature PVD and PECVD matured, becoming suitable for DLC coatings. In the 21st century, ALD and nanocomposite coating technologies (such as nc-AlTiN) emerged, reducing coating thicknesses to the nanometer scale and achieving hardnesses exceeding HV 4000. China's coating technology began developing in the 1980s. Zhuzhou Cemented Carbide Plant introduced CVD technology in the early 1990s. In the 2000s, companies like Xiamen Jinlu developed domestic PVD equipment. Nanocoating achieved breakthroughs in the 2010s, and by 2025, domestic coatings accounted for 80% of the market. These technological advancements not only addressed the limitations of cemented carbide but also promoted advances in green manufacturing and intelligent processing. The following section discusses each process in detail, including its principles, technical parameters, advantages and disadvantages, and applications.

(1.1) What is physical vapor deposition (PVD)?

Physical vapor deposition (PVD) is an advanced surface treatment technology widely used in materials science and manufacturing to deposit a thin, durable coating on a substrate. Simply put, PVD involves physically converting a solid material into a vapor phase, which is then deposited onto the target surface in a vacuum environment. This method differs from chemical vapor deposition (CVD) by utilizing physical processes (such as evaporation or sputtering) to transfer the material, rather than relying on chemical reactions.

thought of as an "evaporation-deposition" process. In a sealed, high-vacuum chamber (typically pressures below 10^{-3} Pa), the target material (such as titanium, chromium, or their compounds) is heated to extremely high temperatures or vaporized through ion bombardment , transforming it into atomic or molecular vapor. This vapor then moves through the vacuum and condenses on the substrate surface, forming a uniform thin film coating. The entire process typically occurs at low temperatures (300-600°C), which is particularly advantageous for heat-sensitive substrate materials (such as cemented carbide or high-speed steel) because it does not significantly alter the substrate's inherent properties.

There are several main variations of PVD technology, including:
Evaporative deposition : The material is evaporated by resistive heating or electron beam bombardment, such as traditional vacuum evaporation.
Magnetron sputtering : uses a magnetic field to confine plasma, bombarding the target material to sputter it out, suitable for substrates with complex shapes.
Arc Ion Plating : Utilizes arc discharge to evaporate material, forming a coating with a high ionization rate and stronger adhesion.

PVD coatings are characterized by high hardness (typically HV 2000-3000), excellent wear and corrosion resistance, and relatively thin thicknesses (1-5 microns). They are widely used in cutting tools, molds, decorative parts (such as gold watch cases), and the semiconductor industry. Advantages include environmental friendliness (no harmful byproducts), excellent coating uniformity, and minimal thermal impact on the substrate. Disadvantages include slow deposition rates, limited thickness, and relatively high equipment costs.

(1.2) What is physical vapor deposition (PVD) of cemented carbide coating?

Physical Vapor Deposition (PVD) of cemented carbide coatings is a coating process that specifically applies PVD technology to cemented carbide substrates. Cemented carbide is a composite material composed of tungsten carbide (WC) as the hard phase and cobalt (Co) as the binder phase. Known for its high hardness (HRA 85-92), flexural strength (1800-2500 MPa), and wear resistance, it is widely used in the manufacture of cutting tools and wear-resistant parts. However, bare cemented carbide is susceptible to wear or oxidation in high temperature, high pressure, or corrosive environments. Therefore, depositing a coating on its surface through PVD technology can significantly improve its performance.

In the PVD process of cemented carbide coating, the substrate is usually a cemented carbide insert or mold component. The choice of PVD coating material is based on the application requirements, such as:

TiN (titanium nitride) : Golden yellow in color, high hardness (HV 2300), suitable for cutting steel and cast iron.

TiCN (titanium carbonitride) : Harder than TiN (HV 2700), more wear-resistant, suitable for stainless steel.

TiAlN (titanium aluminum nitride) : Highly heat-resistant (up to 800°C), widely used in high-temperature alloy cutting.

CrN (Chromium Nitride) : Excellent corrosion resistance, suitable for humid environments.

Specific process steps of cemented carbide coating PVD

Pretreatment : The carbide substrate is ultrasonically cleaned and ion bombarded to remove surface contaminants and activate the surface to improve adhesion.

Vacuum environment : Place the substrate in a vacuum chamber and pump down to 10^{-3} -10^{-5} Pa to reduce interference from impurities.

Deposition : The target material is vaporized and deposited by methods such as magnetron sputtering or arc ion plating. The Ti target is bombarded in an Ar /N2 atmosphere to produce a TiN coating.

Post-treatment : Cool and check coating uniformity (Ra ≤ 0.1 μm) and thickness (1-5 μm).

The advantage of PVD coatings on cemented carbide is that they enhance tool wear resistance and service life without significantly affecting the toughness of the substrate. For example, TiAlN -coated cemented carbide tools can achieve cutting speeds of 300-400 m/min when cutting aviation titanium alloys, while increasing tool life three times that of uncoated tools. In practical applications, PVD coating thickness is typically controlled between 2-4 μm to achieve a balance between adhesion and performance.

However, this process also has limitations. Due to its low deposition rate (0.5-5 μm /h), production efficiency is limited, and the equipment requires high vacuum and precise control, resulting in high initial investment and maintenance costs. Furthermore, the coating thickness is limited (<5 μm), making it unsuitable for applications requiring thick protective layers. To address these issues, the industry is developing multi-arc PVD or technologies combined with ALD (atomic layer deposition) to improve efficiency and thickness control accuracy.

PVD is a general physical deposition technology, and carbide coating PVD is its application to specific materials (carbide). By depositing high-performance thin films (such as TiN and TiAlN) in a vacuum environment, it significantly improves the cutting performance and durability of carbide. This process is indispensable in modern manufacturing, especially in precision machining and extreme working conditions, providing tool protection and enhanced functionality, and is a significant innovation in materials engineering.

(2.1) What is the chemical vapor deposition (CVD) process?

Chemical Vapor Deposition (CVD) is an advanced technology that uses chemical reactions to decompose gaseous precursors under high temperature conditions and deposit them onto substrate surfaces to form thin films or coatings. This method is particularly suitable for producing thick coatings, especially in applications requiring high heat and wear resistance. According to the information provided, the core of the CVD process is to utilize the reactive gases to undergo thermal decomposition or chemical reactions at high temperatures to generate a solid material that adheres to the substrate, forming a uniform coating. Common coating materials include aluminum oxide (Al_2O_3) , titanium nitride (TiN), or titanium carbonitride (TiCN). Coating thicknesses typically range from 5 to 15 microns, with deposition rates ranging from 2 to 10 microns per hour .

The principle of the CVD process can be simply understood as a "chemical growth" process. In a controlled reaction environment, gaseous precursors (such as $TiCl_4$, $AlCl_3$, and NH_3) are introduced into a high-temperature reaction chamber (typically at 900-1200°C and a pressure of 0.1-1 atm). Under the action of thermal energy, these gases decompose or react with other gases to form solid compounds that are deposited on the substrate surface. The entire process includes steps such as substrate cleaning, vacuum preheating, introduction of reactive gases, reactive deposition, cooling, and post-processing. This method relies on precise control of the chemical reaction, with the flow rate of the precursor gas (50-200 sccm) and the temperature gradient (such as heating the substrate to 800°C) being key parameters.

The development of CVD technology can be traced back to carbon filament deposition experiments in the 19th century. Its use in the semiconductor industry began in the 1920s, and its first application in cemented carbide in the 1950s led to the commercialization of TiC coatings. The development of Al_2O_3 coatings in the 1960s significantly improved heat resistance (up to 1000°C). Multilayer coatings (such as TiC / TiN) emerged in the 1970s. Low- pressure CVD lowered the deposition temperature to 800°C in the 1980s, and plasma-enhanced CVD (PECVD) further lowered the temperature to 500°C in the 1990s. In China, CVD technology began to gain traction in the 1980s, with the development of thermal CVD equipment by the Shanghai Institute of Ceramics in the 1990s. The domestic production rate reached 60% in the 2000s, and high-temperature CVD technology was exported in the 2010s. By 2025, CVD coating production accounted for 30% of the domestic market.

The advantages of the CVD process include dense coatings (porosity <0.5%), strong adhesion (>70 MPa), suitability for thick layer deposition, and high coverage (>95%), making it particularly suitable for complex geometries such as drill cutting edges. However, it also has some disadvantages: high-temperature deposition may cause substrate annealing (hardness reduction of 5%-10%), resulting in high residual stresses (500-800 MPa), requiring post-annealing (600°C, 1 hour) to mitigate hardness loss (<5%). Furthermore, the equipment is complex, and operation may generate hazardous gases (such as Cl_2) , requiring an environmentally friendly disposal system to ensure safety.

In practical applications, the CVD process is widely used to manufacture high-temperature cutting tools. For example, Al_2O_3 - coated carbide tools can achieve cutting speeds of 150-500 m/min in cast iron machining, significantly extending tool life. Zhuzhou Diamond's TiC / Al_2O_3 CVD - coated tools exhibit high heat resistance and low wear rates in steel cutting. These tools are exported to the European market, where they hold a 15% market share. In the future, combining CVD with PVD is expected to achieve low-temperature, thick-layer coatings with thickness deviations controlled to <1 micron, making them particularly suitable for the manufacture of 5G precision components.

(2.2) What is the Chemical Vapor Deposition (CVD) process for cemented carbide coatings?

The Chemical Vapor Deposition (CVD) process for cemented carbide coatings is a coating process that specifically applies CVD technology to cemented carbide substrates. Cemented carbide is a composite material composed of tungsten carbide (WC) as the hard phase and cobalt (Co) as the binder phase. Due to its high hardness (HRA 85-92), flexural strength (1800-2500 MPa), and excellent wear resistance, it is widely used in the manufacture of cutting tools and wear-resistant parts. However, bare cemented carbide is susceptible to wear or oxidation in high temperatures or corrosive environments. Therefore, depositing a thick coating on its surface through the CVD process can significantly improve its heat resistance, wear resistance, and service life.

In the CVD process for cemented carbide coating , the substrate is typically a carbide insert or mold component. Common coating materials include Al_2O_3 , TiC , TiCN , and multilayer combinations (such as TiC / TiCN / Al_2O_3) . The choice of coating depends on the specific application requirements. For example, Al_2O_3 coatings are suitable for high-temperature cutting due to their excellent heat resistance (up to 1000°C), while TiCN coatings are widely used in stainless steel machining due to their high hardness (HV 2700-3000) and corrosion resistance. Coating thicknesses typically range from 5-15 microns, with deposition rates ranging from 2-10 microns per hour.

The CVD process flow of cemented carbide coating includes the following steps:
Pretreatment : The carbide substrate is cleaned to remove surface contaminants and vacuum preheated to activate the surface.
Reactive deposition : In a high-temperature reaction chamber at 900-1200°C, reactive gases (such as $TiCl_4$, $AlCl_3$, NH_3, and H_2) are introduced . These gases react chemically under the action of thermal energy, such as $TiCl_4 + N_2 + H_2 \rightarrow TiN + HCl$, the resulting solid coating is deposited on the substrate.
Post-processing : After cooling, quality inspection is performed (such as XRD analysis of phase structure and TEM inspection of interface) to ensure that the carbonized phase ratio is >70%, and residual stress is relieved by post-annealing (600°C, 1 hour).

The advantages of the CVD process for cemented carbide coatings lie in their dense coatings, strong adhesion (>70 MPa), ability to form thick layers (5-15μm), and high coverage (>95%), making them ideal for complex geometries such as drill cutting edges. In applications, CVD coatings significantly improve the performance of cemented carbide tools. For example, Al_2O_3 - coated tools can achieve

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sales@chinatungsten.com

cutting speeds of 150-500 m/min and triple their tool life in cast iron machining. Zhuzhou Diamond's TiC / Al_2O_3 multi- layer coated tools offer high heat resistance and low wear rates in steel cutting, with exports accounting for 15% of the European market. In the aviation sector, CVD Al_2O_3 - coated tools reduce the incidence of thermal cracking by 50% and increase efficiency by 25% when cutting titanium alloys .

However, this process also faces some challenges. Due to the high deposition temperature (900-1200°C), the cemented carbide substrate may undergo annealing, resulting in a 5%-10% decrease in hardness and an increase in residual stress (500-800 MPa), requiring post-processing for optimization. Hazardous gases (such as Cl_2) generated during the reaction require an environmentally friendly treatment system, and operational safety also requires special attention. For example, the reaction gas $TiCl_4$ is highly toxic , requiring the use of an exhaust system and protective equipment. To overcome the high temperature issue, the process has been expanded to include medium-temperature CVD (MT-CVD, 700-900°C) and high-temperature CVD (HT-CVD, 1000-1200°C). TiCN coatings with a thickness of 5μm show significantly improved corrosion resistance. In the future, combining CVD with PVD is expected to achieve low-temperature thick-layer coatings with a thickness deviation of <1μm, suitable for 5G precision components.

The CVD process is a technique for depositing coatings at high temperatures through a chemical reaction. The cemented carbide coating CVD process applies this process to a cemented carbide substrate, producing thick, heat-resistant, and wear-resistant coatings (such as Al_2O_3 and TiCN) . This process is particularly important in cutting tool manufacturing, significantly extending tool life and improving performance, especially under high temperatures and complex working conditions. Although its high temperature and environmental requirements require special management.

(3.1) What is the atomic layer deposition (ALD) process?

Atomic layer deposition (ALD) is a highly precise thin-film deposition technology that relies on self-limiting chemical reactions to build coatings layer by layer. It is widely used in applications requiring extremely high precision and uniformity. Simply put, ALD acts like an "atomic builder." By controlling the stepwise nature of chemical reactions, it stacks atoms or molecules layer by layer, creating films with nanometer or even sub-nanometer thicknesses. This method is particularly suitable for producing ultra-thin, uniform coatings with excellent coverage.

ALD operates based on the alternating introduction of two or more reactive precursors. In a vacuum environment (typically pressures between 10^{-1} and 10^{-3} Pa), the first precursor gas (such as $TiCl_4$) is introduced into the reaction chamber, where it chemically adsorbs onto the substrate surface, forming a single-atom-thick intermediate layer. An inert gas (such as nitrogen (N_2)) is then used to "purge" excess precursor, ensuring only a single adsorbed layer remains. A second precursor gas (such as NH_3) is then introduced , reacting with the first layer to form the target compound (such as TiN_3), which is then purged again to remove byproducts. This process repeats cyclically, with each cycle increasing the thickness by approximately 0.1 nm. The overall coating thickness is typically less than 1 micron, with an extremely slow deposition rate (0.1-0.5 nm/cycle). The entire process operates at relatively low temperatures (150-300°C), making it suitable for heat-sensitive materials.

ALD technology dates back to Finland in the 1970s, initially used for thin film deposition in the semiconductor industry. It began to gain prominence in the electronics sector in the 1980s, expanded to coating applications in the 1990s, and began to be used in mechanical applications such as cemented carbide in the 2000s. In the 2010s, with the maturity of thermal ALD (which relies on high temperatures) and plasma ALD (PEALD, which uses plasma to reduce temperatures), coating uniformity reached 99.9%. In China, ALD took off in the 2000s, with the development of domestically produced equipment at Tsinghua University in 2015. The Chinese Academy of Sciences promoted industrialization in the 2020s. By 2025, ALD coating production had increased by 20%, demonstrating its rapid development in China.

ALD requires precise control of temperature (150-300°C), pressure (10^{-1} -10^{-3} Pa) , and cycle time (30-60 seconds). The process includes substrate cleaning, vacuum preheating, introduction and purge of precursor 1, introduction and purge of precursor 2, and cyclic deposition and cooling. Its advantages include extremely precise thickness control (±0.1 nm) and 100% coverage (even for complex geometries), making it ideal for high-precision applications. However, its disadvantages include extremely slow deposition rates (less than 0.5 μm/hour) and relatively high costs due to the required precursor gases and equipment.

(3.2) What is the Atomic Layer Deposition (ALD) process for cemented carbide coatings?

The Atomic Layer Deposition (ALD) process for cemented carbide coatings is a coating method that specifically applies ALD technology to cemented carbide substrates. Cemented carbide is a composite material composed of tungsten carbide (WC) as a hard phase and cobalt (Co) as a binder phase. It is known for its high hardness (HRA 85-92), bending strength (1800-2500 MPa), and excellent wear resistance, and is widely used in the manufacture of cutting tools and wear-resistant parts. However, bare cemented carbide is susceptible to wear during ultra-precision machining or extreme environments (such as dry cutting of aerospace components). Therefore, depositing ultra-thin nano-coatings on its surface through ALD technology can significantly improve its performance, especially in scenarios requiring extremely high precision and durability.

In the ALD process for cemented carbide coatings, the substrate is typically a carbide insert or ultra-precision tool. Commonly used coating materials include :
Al_2O_3 (aluminum oxide) : Provides excellent heat resistance and insulation, suitable for cutting aviation titanium alloys.
TiAlN (titanium aluminum nitride) : High hardness (HV 3000 and above), with both wear resistance and heat resistance.
CrN (chromium nitride) : Highly corrosion-resistant, suitable for agricultural wear parts.

The specific process flow is similar to general ALD, but is optimized for the characteristics of

cemented carbide:
Matrix pretreatment : The carbide substrate is ultrasonically cleaned and vacuum preheated to remove surface impurities and activate the surface.
Alternating deposition : For example, $TiCl_4$ as the first precursor and NH_3 as the second precursor are alternately introduced into the vacuum chamber, forming a TiN layer of approximately 0.1 nm per cycle . A purge gas (e.g., N_2 at 100 sccm) is used to remove residual gases, and the precursor pulse duration is controlled to 5-10 seconds.
Cycle completion : Repeat hundreds to thousands of cycles to produce a total coating thickness of typically 0.5-1 micron.
Post-treatment : Cool and inspect coating uniformity and impurity content (<0.1%).

The application of ALD cemented carbide coatings has demonstrated its unique advantages. For example, ALD Al_2O_3 - coated cemented carbide tools, with a thickness of only 0.5 microns, can significantly extend tool life in the cutting of aviation titanium alloys, especially reducing reliance on lubrication in dry machining. ALD TiAlN -coated tools developed by the Chinese Academy of Sciences achieve a friction coefficient as low as 0.2 in dry machining, achieving high wear resistance and accounting for 10% of exports. Furthermore, ALD CrN coatings, with a thickness of 0.5 microns, significantly enhance corrosion resistance in agricultural wear-resistant parts, making them suitable for use in humid environments.

ALD's advantages in cemented carbide also include its atomic-level uniformity, making it suitable for producing microscopic gradient coatings (0.1 nanometers per layer), which is particularly important in ultra-precision machining. In the future, ALD processes integrated with artificial intelligence are expected to achieve intelligent thickness control with an error of less than 0.05 nanometers, making them suitable for cutting-edge fields such as quantum computing components. However, its disadvantages are also significant: the deposition rate is extremely slow (requiring 2,000 cycles to produce 1 micron), the precursor gas cost is high, and equipment investment and maintenance costs are also relatively high. To address these issues, process optimization (such as optimizing pulse time and purge flow) has been used to reduce impurities and improve efficiency.

- limiting chemical reaction to deposit layers one by one. Carbide coating ALD is a specialized application of this process on cemented carbide. Ultrathin nanocoatings (such as Al_2O_3 and TiAlN) enhance tool wear resistance, lifespan, and precision. Its low-temperature properties (150-300°C) make it suitable for heat-sensitive substrates, and it holds great potential for future intelligent and industrial applications, particularly in high-tech manufacturing.

(4.1) What is the Plasma Enhanced Chemical Vapor Deposition (PECVD) process?

Plasma-enhanced chemical vapor deposition (PECVD) is an innovative surface coating technology widely used in materials engineering, semiconductor manufacturing, and surface treatment of cutting tools. Simply put, PECVD is a process that uses plasma to assist the chemical vapor deposition (CVD) process. Its core feature is that the high energy state of the plasma lowers the reaction temperature, enabling the deposition of coatings on heat-sensitive materials. Unlike traditional thermal CVD processes that rely on high temperatures (600-1200°C), PECVD can deposit coatings at lower temperatures (typically 150-350°C), making it particularly suitable for substrates that cannot withstand high temperatures.

The working principle of PECVD can be figuratively understood as an "energy catalysis" process. In a vacuum environment (pressure is typically 0.1-1 Torr), reaction gases (such as methane CH_4 , silane SiH_4 , or ammonia NH_3) are introduced into the reaction chamber. Next , these gases are excited by an energy source such as radio frequency (RF, 13.56 MHz) or microwaves, generating a high-energy plasma state. The electrons, ions, and free radicals in the plasma collide with gas molecules, triggering chemical reactions and generating solid substances (such as carbides, nitrides, or diamond-like carbon coatings DLC), which are then deposited on the substrate surface to form a uniform thin film. The low-temperature nature of the entire process is attributed to the additional energy provided by the plasma, which allows the reaction to be significantly reduced at the extremely high temperatures required for conventional CVD.

The history of PECVD technology dates back to the 1960s, when plasma technology began to gain prominence in laboratories. In the 1970s, it was introduced to the semiconductor industry for the deposition of silicon thin films. In the 1980s, PECVD expanded to the preparation of diamond-like carbon (DLC) coatings, which garnered attention for their exceptional hardness and low friction properties. In the 1990s, the technology was gradually applied to the surface enhancement of carbide cutting tools, significantly improving their wear resistance and service life. In the 2000s, radio frequency PECVD (RF-PECVD) technology matured, further reducing the friction coefficient of the coating to 0.1, marking a breakthrough in its industrial application. In China, PECVD development began in the 1990s. In 2005, the Beijing Institute of Aeronautical Materials successfully developed domestically produced equipment, and large-scale application for tool coatings began in 2015. By 2025, PECVD coating production is projected to increase by 15% year-on-year, demonstrating strong growth momentum in the domestic market.

In terms of technical parameters, the PECVD process operates under power conditions ranging from 100-500 W, pressures from 0.1-1 Torr, and precursor gas flows of 50-200 sccm (standard cubic centimeters per minute). The process typically involves the following steps: first, thoroughly cleaning the substrate to remove surface oil and oxide layers; then, preheating the substrate in a vacuum environment; then, plasma-activated reactive gases for deposition; and finally, cooling and coating quality inspection. PECVD coatings typically achieve thicknesses of 2-5 μm at a deposition rate of 1-3 μm /h, slightly higher than PVD (0.5-5 μm /h), but significantly lower than traditional CVD (2-10 μm /h).

The advantage of PECVD lies in its low-temperature deposition characteristics, making it particularly suitable for heat-sensitive substrates (such as certain plastics or low-melting-point metals). It also produces excellent coating adhesion (>40 N), adapting to complex surface geometries. Plasma activation also improves coating uniformity, with deposition deviation typically less than 0.5%. However, it also has some limitations: the coating may contain a high hydrogen content (especially DLC coatings), which limits its thermal stability (heat resistance <400°C) and may lead to performance degradation during high-temperature cutting. Furthermore, the equipment is complex, involving a plasma generator and gas control system, requiring frequent maintenance (e.g., monthly), and the gas source (e.g., CH_4) must be of high purity (>99.99%), otherwise it can easily lead to contamination risks.

PECVD has a wide range of applications. In the semiconductor industry, it is used to manufacture thin-film dielectrics. In the field of cemented carbide cutting tools, PECVD is particularly suitable for producing low-friction coatings such as DLC (diamond-like carbon) coatings, which can achieve friction coefficients as low as 0.1-0.2, significantly extending tool life. For example, in aluminum alloy cutting, PECVD DLC-coated tools can significantly extend tool life, especially under dry machining conditions. Regarding technological advancements, microwave PECVD has further reduced the deposition temperature to 100°C, making it suitable for thinner film layers (e.g., 1-2 μm). Combining it with nanotechnology has the potential to achieve ultra-low friction coatings (friction coefficients <0.05), opening up new possibilities for high-precision applications such as quantum computing components. Future developments in PECVD may include optimizing gas purification techniques, increasing deposition rates, and developing multifunctional composite coatings to meet a wider range of industrial needs.

(4.2) What is the Plasma Enhanced Chemical Vapor Deposition (PECVD) process for cemented carbide coatings?

The Plasma Enhanced Chemical Vapor Deposition (PECVD) process for cemented carbide coatings is a coating preparation method that specifically applies PECVD technology to cemented carbide substrates. Cemented carbide is a composite material with tungsten carbide (WC) as the hard phase and cobalt (Co) as the binder phase. Due to its high hardness (HRA 85-92), flexural strength (1800-2500 MPa), and excellent wear resistance, it is widely used in the manufacture of cutting tools and wear-resistant parts. However, exposed cemented carbide is prone to wear, oxidation, or adhesion in high-temperature or corrosive environments, especially when machining soft metals (such as aluminum alloys), where the workpiece material is easily attached to the surface. Depositing special coatings (such as DLC or TiCN) on its surface through PECVD technology can significantly improve the wear resistance, anti-adhesion properties, and service life of cemented carbide.

In the PECVD process of cemented carbide coating, the substrate is usually a cemented carbide insert or mold component. Common coating materials include:

DLC (Diamond-Like Carbon Coating) : Produced by plasma decomposition of hydrocarbons such as CH_4 , it has a hardness of up to HV 2000-3000 and a low friction coefficient (0.1-0.2), making it particularly suitable for aluminum alloy cutting.

TiCN (titanium carbonitride) : Produced by plasma reaction of $TiCl_4$, CH_4 and N_2 . Its hardness is slightly lower than DLC but its corrosion resistance is better. Its thickness is about 3 μm and it is suitable for mold protection.

The specific process steps are as follows:

Pretreatment : The carbide substrate is ultrasonically cleaned and ion bombarded to remove surface impurities and activate the surface to enhance coating adhesion.

Vacuum environment : Place the substrate in the PECVD reaction chamber and evacuate to a low pressure state of 0.1-1 Torr.

Plasma activation : RF power (100-500 W) is used to excite the reactive gas (such as CH_4 or $TiCl_4$ / N_2 mixture) to generate high- energy plasma, which triggers the chemical reaction.

Deposition : The active particles in the plasma are deposited onto the substrate surface at 150-350°C, forming a 2-5 μm coating at a deposition rate of approximately 1-3 μm /h.

Post-treatment : Cool the substrate and check the coating uniformity (Ra ≤ 0.2 μm) and properties.

The advantage of PECVD cemented carbide coatings lies in their low-temperature deposition, which avoids the annealing effect of conventional CVD processes (900-1200°C) on the carbide substrate, thereby preserving the substrate's toughness and strength. For example, the PECVD DLC-coated tools developed by Zhuzhou Diamond Co., Ltd. have shown a threefold increase in tool life and significantly reduced wear during dry machining of aluminum alloys. Exports account for 15% of these tools, demonstrating their competitiveness in the international market. Furthermore, the plasma activation mechanism of PECVD coatings improves deposition uniformity (deviation <0.5%), making them particularly suitable for complex tool edges and ensuring coating coverage exceeding 95%.

However, this process also faces some challenges. The DLC coating contains a high amount of hydrogen (5%-20%), which limits its thermal stability (<400°C) and may soften or peel off during high-temperature cutting (such as processing high-temperature alloys). The complexity of the equipment also increases maintenance costs. The deposition chamber needs to be cleaned regularly (once a month) to prevent gas residue or contamination. In particular, the purity of the precursor gas is required to be extremely high (>99.99%), otherwise it will affect the coating quality. In addition, although the deposition rate (1-3 μm /h) is faster than PVD, it is still lower than traditional CVD, and production efficiency needs to be improved.

The application of the PECVD process in cemented carbide demonstrates its unique value. For example, in aluminum alloy cutting, PECVD DLC coatings, with their low coefficient of friction (0.1-0.2), effectively reduce workpiece adhesion and significantly extend tool life. In cemented carbide molds, PECVD TiCN coatings with a thickness of 3 μm offer two times greater corrosion resistance, making them suitable for humid or chemically corrosive environments. Regarding technological expansion, microwave PECVD further reduces the temperature to 100°C, making it suitable for thinner coatings (e.g., 1-2 μm). Combining this with nanotechnology promises the development of ultra-low friction coatings with coefficients of friction below 0.05, potentially enabling future applications in quantum computing components or high-precision optical elements. The industry is exploring optimization of plasma parameters (e.g., power density of 200 W/cm²) and gas ratios to reduce hydrogen content and improve coating thermal stability.

PECVD is a chemical deposition technique that uses plasma to lower the reaction temperature. PECVD coatings on cemented carbide are a specialized application of this technology, particularly suitable for the low-temperature production of low-friction coatings (such as DLC). This process significantly enhances the wear resistance and adhesion resistance of cemented carbide while preserving the substrate's properties. It excels particularly in aluminum alloy machining and mold protection. Despite challenges with thermal stability and equipment complexity, technological innovations (such as the integration of microwave PECVD and nanotechnology) are opening up new possibilities for the future development of cemented carbide tools, particularly in the areas of high-precision and environmentally friendly manufacturing.

(5.1) What is the thermal spray process?

Thermal spraying is an advanced surface engineering technology that forms a functional coating by spraying molten or semi-molten coating material at high speed onto the substrate surface. This process is widely used in industry for components requiring enhanced wear resistance, corrosion resistance, or high-temperature resistance. Simply put, thermal spraying is like using a high-temperature spray gun to "spray" the coating material onto the substrate, forming a protective or functional layer. Its unique ability to rapidly and extensively deposit thick coatings (typically in the 10-50 micron range) offers significant advantages in repair, protection, and functional surface treatment.

Thermal Spray Process Principle and Working Mechanism

Thermal spraying utilizes a high-temperature heat source (such as a flame, plasma arc, or electric arc) to heat the coating material (typically in powder or wire form) to a molten or semi-molten state. These molten particles are then sprayed onto the substrate surface via a high-velocity gas stream (jet velocities can reach 500-2000 m/s). Upon reaching the substrate, the molten particles rapidly cool and solidify, accumulating to form a coating. This entire process takes place in an open or semi-open environment, unlike PVD or CVD, which operate under vacuum. The heat source temperature typically reaches 2000-3000°C, enabling the efficient melting and deposition of a wide range of materials (such as metals, ceramics, or composites).

Thermal Spray Technology Background and Development History

The history of thermal spraying technology dates back to 1910, when flame spraying, the earliest form of thermal spraying, was developed for simple metal coating applications. The invention of plasma spraying in the 1950s significantly expanded process capabilities, as the plasma arc delivers higher temperatures and energies, making it suitable for processing ceramics and high-temperature resistant materials. The maturity of high-velocity oxygen fuel (HVOF) spraying in the 1970s further advanced thermal spraying. HVOF utilizes supersonic spray velocity to improve coating density and adhesion, making it particularly suitable for coating cemented carbide. In the 1990s, thermal spraying became widely used for wear-resistant coatings on cemented carbide, significantly extending the service life of tools and components. The 2000s saw the emergence of cold spraying, an innovation that lowered the spray temperature to below 600°C, reducing the heat-affected zone and making it suitable for heat-sensitive materials. Thermal spraying technology in China began in the 1980s. The Shanghai Institute of Ceramics successfully developed plasma spray equipment in the 1990s, and HVOF technology was exported in the 2010s, marking China's technological advancement in this field reaching internationally advanced levels. By 2025, China's thermal spray coating production was projected to increase by 10%, demonstrating its competitiveness in the global market.

Thermal Spray Process Parameters and Operation Procedures

Thermal spraying process parameters need to be precisely controlled to ensure coating quality. Typical technical parameters include:

Power : 20-100 kW, depending on heat source type and material properties.

Jet velocity : 500-2000 m/s, affects the impact force and deposition density of particles.

Temperature : 2000-3000°C, used to melt the precursor material.

Precursor material particle size : 10-50 microns. Particle size affects melting efficiency and coating uniformity.

The operation process includes the following key steps:

Substrate cleaning : Use mechanical or chemical methods to remove impurities such as oil, oxide layer, etc. on the surface of the substrate.

Preheating : Preheat the substrate to an appropriate temperature (usually 200-400°C) to improve adhesion and reduce thermal stress.

Powder feeding : Powder or wire is fed into the heat source through a feeding system.

Melt spraying : A heat source melts the material and sprays it onto the substrate surface at high speed.

Cooling : Natural or forced cooling to solidify the coating.

Post-processing : This includes polishing or machining to improve the surface finish.

Advantages and Disadvantages of Thermal Spray

The advantage of thermal spraying is its ability to achieve large-area coverage, making it particularly suitable for large or complex-shaped components. Furthermore, the coating exhibits strong impact resistance (>100 joules/square centimeter), making it suitable for applications requiring mechanical loads. However, its disadvantages are also significant: the coating's adhesion is relatively low (<40 MPa), requiring additional surface treatment to enhance adhesion; surface finish is poor (roughness Ra 2-5 microns), potentially requiring post-processing; and high equipment investment and maintenance costs limit its adoption by smaller businesses.

Thermal Spray Application Scenarios and Examples

Thermal spraying is widely used in various industrial fields, particularly where thick, wear-resistant coatings are required. For example, in agricultural machinery, WC-Co (tungsten carbide-cobalt) coatings are used to protect the surface of plowshares, significantly extending their wear life to hundreds of hours. Another example is the HVOF CrN (chromium nitride)-coated wear parts produced by China Tungsten Online. When used in mining machinery, their lifespan has been tripled, while maintaining a low wear depth (<0.05 mm), demonstrating the reliability of thermal spraying in extreme operating conditions.

Thermal spraying processes continue to evolve, with expanded technologies including cold spraying, which operates at temperatures below 500°C and is suitable for heat-sensitive substrates, allowing the coating thickness to be controlled within a relatively thin range (<10 microns). In the future, the combination of thermal spraying and laser technology (such as laser-assisted thermal spraying) is expected to achieve even higher precision control, with thickness deviations potentially reduced to <1 micron, making it suitable for use in areas requiring high precision, such as the manufacture of 5G equipment components. In addition, the high thickness adaptability of thermal spraying in cemented carbides (10-50 microns) gives it a unique advantage in repairing large worn parts, although thermal stress may cause substrate cracks (3%-5% probability of occurrence), which are usually alleviated by preheating the substrate (to 300°C).

(5.2) What is the thermal spray process for cemented carbide coatings?

The thermal spray process for cemented carbide coatings is a coating process that specifically applies thermal spray technology to cemented carbide substrates. Cemented carbide is a composite material with tungsten carbide (WC) as the hard phase and cobalt (Co) as the binder phase. Due to its excellent hardness (HRA 85-92), bending strength (1800-2500 MPa), and wear resistance, it is widely used in the manufacture of cutting tools, molds, and wear-resistant components. However, bare cemented carbide is prone to failure in high temperature, high pressure, or abrasive environments. Therefore, depositing a thick coating on its surface through the thermal spray process can significantly enhance its durability and functionality.

Thermal Spray Technology for Cemented Carbide Coatings: Principles and Material Selection

The principle of thermal spraying of cemented carbide coating is the same as general thermal spraying, that is, the coating material is melted at high temperature and sprayed at high speed onto the surface of the cemented carbide substrate. The coating material is usually selected from compounds that complement the properties of cemented carbide, such as:

WC-Co (Tungsten Carbide-Cobalt) : Provides high hardness and wear resistance and is widely used in wear-resistant parts.

CrN (Chromium Nitride) : Has excellent corrosion and oxidation resistance and is suitable for wet or chemical environments.

NiCrBSi (nickel chromium boron silicon) : Increases high temperature resistance and is suitable for high temperature working conditions.

In actual operation, WC-Co powder (particle size 10-50 microns) is melted by plasma or HVOF heat source, with a spray speed of up to 800-1200 m/s, and the coating thickness can reach 10-50 microns, far exceeding the thin layer limit of PVD or CVD.

Thermal Spray Technology and Optimization of Cemented Carbide Coatings

The specific process includes:
Substrate preparation : Carbide parts are sandblasted or chemically cleaned and the roughness is increased to Ra 3-5 microns to enhance adhesion.
Preheating : Preheat the substrate to 200-400°C to reduce thermal stress and improve coating bonding.
Powder melting and spraying : Use HVOF or plasma spray gun to melt WC-Co powder and spray to form coating.
Cooling and curing : The coating cools rapidly and the bulk density reaches 90%-95%.
Post-treatment : Mechanical polishing or heat treatment to optimize surface roughness (Ra down to below 2 microns).
Process optimization included controlling the spray angle (45°-90°) and powder feed rate (10-20 g/min) to reduce porosity (<0.5%) and improve coating uniformity.

Thermal Spray Technology for Cemented Carbide Coatings: Advantages and Application Examples

The advantage of thermal spraying carbide coatings lies in their thick protective layer (10-50 microns), making them particularly suitable for applications requiring high wear and impact resistance. For example, in agricultural machinery, WC-Co coated plowshares have a wear life of up to 800 hours, significantly extending their service life. In the mining industry, China Tungsten Online's HVOF CrN -coated wear-resistant parts have a lifespan that is 2 times longer under heavy loads, with wear depth controlled to below 0.05 mm, demonstrating their superior performance in extreme environments. Furthermore, thermal spray's impact resistance (>100 joules/square centimeter) makes it suitable for components subject to mechanical loads, such as crusher hammers.

Thermal Spray Process Limitations and Challenges of Cemented Carbide Coatings

Despite its numerous advantages, thermal spraying of cemented carbide coatings also presents challenges. Low adhesion (<40 MPa) may be due to the mechanical rather than metallurgical bonding of thermal sprayed coatings, requiring improvement through pretreatment (such as sandblasting). Poor surface finish (Ra 2-5 microns) may require subsequent finishing, increasing process complexity. Thermal stress is another key issue. High-temperature spraying can cause substrate cracks (with a probability of 3%-5%), necessitating preheating of the substrate to 300°C. Furthermore, high equipment investment and operating costs limit its adoption in small-scale production operations.

Extended thermal spraying techniques, such as cold spray (temperatures <500°C), offer new options for heat-sensitive cemented carbides. Coating thicknesses can be controlled to 5-10 microns, minimizing thermal effects. In the future, combining thermal spray with laser technology (such as laser cladding-assisted thermal spray) promises to achieve even higher precision, reducing thickness deviations to <1 micron. This will make it suitable for the manufacture of 5G device components or precision molds. Furthermore, researchers are developing new powder materials (such as nano-WC-Co) to improve coating density and adhesion, broadening their application prospects in the aerospace and electronics industries.

Thermal spraying is a process that uses high-temperature melting and high-velocity spraying to apply thick, wear-resistant coatings to large surfaces. Thermal spraying of cemented carbide coatings involves applying this process to a carbide substrate, depositing coatings such as WC-Co or CrN to enhance wear resistance and service life. Despite limitations in adhesion and precision, its thick, protective coating and high impact resistance make it indispensable in applications such as agricultural machinery and mining equipment. Future technological developments will further enhance its precision and applicability, enabling it to play a greater role in high-end manufacturing.

(6.1) What is the laser cladding process?

Laser cladding is an advanced surface modification technology widely used in manufacturing and materials engineering. It utilizes a high-energy laser beam to melt and bond the coating material to the substrate surface, forming a strong metallurgical bond coating that locally strengthens, repairs, or enhances the substrate's functionality. Simply put, laser cladding can be considered a "precision welding" process that uses the focused energy of a laser to melt material in powder or wire form and rapidly solidify it on the substrate surface, forming a coating with excellent properties. This process is particularly suitable for applications requiring high wear resistance, high corrosion resistance, or high hardness.

Laser Cladding Process Principle and Mechanism

The principle of laser cladding relies on the high energy density and precise controllability of lasers. A laser (typically exceeding 1 kW) emits a high-intensity beam, focused onto the substrate surface. This generates localized high temperatures (up to 2000°C), sufficient to melt the pre-applied coating material (such as metal powder or alloy powder, such as WC-Co). Simultaneously, the substrate surface is slightly melted, forming a molten pool. The coating material is fed into the molten pool via a powder or wire feed system, where it fuses with the substrate. Following the laser beam's movement, the molten pool rapidly cools (at rates of up to 10^3 - 10^6 ° C/s), producing a dense, metallurgically bonded coating typically 0.5-2 mm thick. This rapid solidification process refines the grain structure and enhances the coating's mechanical properties.

Laser Cladding Technology Background and Development History

The origins of laser cladding can be traced back to the 1960s, with the birth and gradual maturity of laser technology. Initially, lasers were used for basic research and simple surface treatment. In the 1980s, laser cladding began to be used in the industrial field, especially for the surface repair of metal parts, such as repairing worn shafts or molds. In the 1990s, with the rise of high-performance materials such as cemented carbide, laser cladding was introduced into the field of strengthening and functionalizing cemented carbide. In the 2000s, the widespread application of fiber laser technology marked a major advancement in the process, with improved laser beam quality and energy utilization efficiency increased by about 50%, significantly enhancing processing accuracy and efficiency. In recent years, laser cladding technology has been continuously optimized, especially in automation and intelligence.

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

Laser cladding began in China in the 1990s, initially relying primarily on imported equipment and technology. In 2005, institutions such as Huazhong University of Science and Technology successfully developed a domestically produced laser cladding system, marking the beginning of independent research and development. By 2015, the technology had become widely used in mold repair and parts remanufacturing. With the rapid development of China's manufacturing industry, laser cladding production is projected to grow by 15% by 2025, reflecting its importance in industry and market demand.

Laser Cladding Technical Parameters and Process

Laser cladding process parameters need to be precisely controlled to ensure coating quality. Typical parameters include:
Laser power : 1-5 kW, depending on coating area and thickness requirements.
Scanning speed : 500-2000 mm/min, affects the melt pool size and cooling rate.
Powder feeding rate : 5-20 g/min, controls the amount of coating material supplied.

The process usually includes the following steps:
Substrate cleaning : Use ultrasonic or chemical methods to remove surface oil and oxide layer to ensure adhesion.
Preheating : Preheat the substrate to 200-300°C to reduce thermal stress.
Powder feeding : Coating material (such as WC-Co powder) is fed into the laser focus via a coaxial or side feeding system.
Laser melting : The laser beam melts the powder and the substrate surface to form a molten pool.
Cooling : The molten pool cools naturally or with auxiliary cooling to form a coating.
Post-processing : grinding or polishing to eliminate surface defects and optimize surface roughness.

Advantages and Disadvantages of Laser Cladding

The advantages of laser cladding include its high metallurgical bond strength (>80 MPa), which forms a strong atomic-level bond between the coating and the substrate, significantly improving wear resistance and fatigue resistance. Furthermore, it allows for precise control of the coating area, making it suitable for localized repair or strengthening. However, disadvantages include high equipment costs (due to the complexity of the laser and control system), a large heat-affected zone (0.5-1 mm wide), which can cause thermal deformation or residual stress in the substrate, and relatively limited accuracy (surface roughness Ra 2-5 μm).

Laser Cladding Application Fields and Cases

Laser cladding is widely used in mold repair, aerospace components, and heavy-duty machinery parts. For example, in mold repair, WC-Co coatings can significantly extend the service life of stamping dies, especially under high-load stamping conditions. In a case study, laser-clad TiC - coated cutting tools developed by Zhuzhou Diamond Co., Ltd. demonstrated a lifespan twice that of uncoated tools during cutting, while maintaining a low wear rate (approximately 10^{-7} mm^3 / N · m) , demonstrating their practicality in industry.

The expansion of the laser cladding process includes online cladding systems for the continuous processing of large components. In the future, with the integration of artificial intelligence (AI) technology, laser cladding is expected to achieve intelligent thickness control, reducing errors to below 0.05 mm, making it suitable for high-precision applications such as the manufacture of quantum computing components. Furthermore, the use of pulsed lasers can reduce the risk of thermal cracking and further optimize the process.

(6.2) What is the laser cladding process for cemented carbide coatings?

The laser cladding process for cemented carbide coatings is a coating process that specifically applies laser cladding technology to cemented carbide substrates. Cemented carbide is a composite material composed of tungsten carbide (WC) as the hard phase and cobalt (Co) as the binder phase. Known for its exceptional hardness (HRA 85-92), flexural strength (1800-2500 MPa), and wear resistance, it is widely used in cutting tools, molds, and wear-resistant parts. However, bare cemented carbide is susceptible to wear or cracking under extreme operating conditions (such as high-temperature cutting or frequent impact). Therefore, depositing a functional coating on its surface through laser cladding can significantly improve its service life and performance.

Principle and characteristics of laser cladding of cemented carbide coating

The principle of laser cladding for cemented carbide coatings is similar to general laser cladding, but it is optimized for the specific properties of cemented carbide. A laser beam (power of 1-5 kW) melts a pre-placed cemented carbide powder (such as WC-Co, TiC) or composite material, forming a molten pool on the substrate surface. The molten pool rapidly solidifies, producing a coating with a thickness of 0.5-2 mm. The coating forms a metallurgical bond with the substrate (interface strength >100 MPa), meaning the coating and substrate are fused at the atomic level, resulting in adhesion far exceeding that achieved by mechanical bonding or thermal spraying. Rapid cooling refines the coating's microstructure, resulting in a grain size typically less than 10 microns. Hardness can reach HV 1500-2000, significantly enhancing wear and corrosion resistance.

Technical Background and Development of Laser Cladding of Cemented Carbide Coatings

The technical roots of laser cladding for cemented carbide coatings are the same as those of laser cladding, which began with the exploration of laser technology in the 1960s. In the 1980s, it was used for metal surface repair, and in the 1990s it was expanded to the strengthening of cemented carbide, especially in the field of cutting tools and molds. In the 2000s, the introduction of fiber lasers significantly improved energy efficiency and processing accuracy, and the quality and consistency of cemented carbide coatings were improved. China started in this field in the 1990s. In 2005, Huazhong University of Science and Technology developed a domestic laser cladding system. In 2015, the technology matured and was applied to cemented carbide mold repair. By 2025, benefiting from the promotion of domestic equipment and market demand, the output of laser cladding for cemented carbide coatings is expected to increase by 15%, occupying an important position in the domestic manufacturing industry.

Laser Cladding Process Parameters and Procedures for Cemented Carbide Coatings

The process parameters of laser cladding of cemented carbide coatings need to be adjusted according to the substrate and coating materials:

Laser power : 1-5 kW, depending on coating thickness requirements.

Scanning speed : 500-2000 mm/min, affects the molten pool depth and coating uniformity.

Powder feed rate : 5-20 g/min, controls the amount of coating material deposited.

The process includes:

Substrate preparation : The carbide substrate is ultrasonically cleaned and sanded to remove surface defects.

Preheating : Preheat to 200-300°C to reduce thermal stress.

Powder feeding : WC-Co or TiC powder is fed using a coaxial powder feeding system .

Laser melting : A laser beam melts the powder and the surface layer of the substrate to form a molten pool.

Cooling and solidification : Rapid cooling to form a dense coating.

Post-processing : Grinding or heat treatment to eliminate residual stress in the heat-affected zone.

Advantages and Disadvantages of Laser Cladding of Cemented Carbide Coatings

The advantages of laser cladding for cemented carbide coatings lie in the excellent adhesion and durability provided by the metallurgical bond. The coating exhibits strong wear resistance (wear rate $<10^{-7}$ $mm^3/N \cdot m$) , making it particularly suitable for repairing worn carbide tools or molds. Furthermore, it allows for precise repair of localized areas (such as cutting edges or wear spots), eliminating the need for complete replacement. However, disadvantages include high equipment costs (lasers and control systems are expensive) and a large heat-affected zone (0.5-1 mm), which can induce thermal cracking or micro-deformation of the substrate. Furthermore, due to the rapid cooling of the melt pool, the coating surface roughness (Ra 2-5 μm) is high, requiring post-processing and finishing.

Application fields and cases of laser cladding of cemented carbide coatings

Laser cladding of cemented carbide coatings is primarily used for tool remanufacturing and mold repair. For example, in stamping dies, WC-Co cladding can significantly extend mold life, especially under high-load stamping conditions. Laser- clad TiC -coated cemented carbide tools developed by Zhuzhou Diamond Co., Ltd. have demonstrated a lifespan twice that of uncoated tools in cutting processes, while maintaining a low wear resistance of approximately 10^{-7} $mm^3/N \cdot m$, demonstrating their practical value in industry. Furthermore, this technology is suitable for localized strengthening of aerospace components, such as repairing worn cutting edges on titanium alloy machining tools.

Future Development and Expansion of Laser Cladding for Cemented Carbide Coatings

Laser cladding of cemented carbide coatings has expanded to include online cladding systems suitable for the continuous processing of large cemented carbide components. In the future, integration with artificial intelligence (AI) will enable intelligent thickness control, reducing errors to less than 0.05 mm, meeting the high-precision requirements of applications such as quantum computing. The use of pulsed lasers can effectively reduce the risk of thermal cracking (incidence <5%), and melt pool stability can be optimized by adjusting the pulse frequency (50-200 Hz). Furthermore, the development of new coating materials (such as WC- TiC composite powders) will further enhance the overall performance of cemented carbide coatings.

Laser cladding is a surface modification process that utilizes laser energy to melt and deposit materials, and laser cladding of cemented carbide coatings is a specific application of this process on cemented carbide. By depositing coatings such as WC-Co or TiC on a cemented carbide substrate , this process significantly enhances the wear resistance, service life, and local repair capabilities of cutting tools and molds. Despite the challenges of high equipment costs and large heat-affected zones, its advantages in metallurgical bonding and precision control have earned it a prominent position in modern manufacturing, particularly in cutting-edge applications in cemented carbide processing.

Cemented carbide coating processes are diverse, with PVD and CVD being mainstream, ALD and PECVD emerging, and thermal spraying and laser cladding used in specific applications. Optimization of these processes has boosted cemented carbide performance by 2-5 times, making it suitable for industrial applications. Nanotechnology and intelligent processes are expected to further develop in the future. It is recommended to select a process based on specific needs and to verify it with reference to standards such as GB/T 18376.

Appendix: Comparison table of various cemented carbide coating processes

Process Name	**Thickness range (μm)**	**Deposition temperature (°C)**	**Deposition rate**	**Adhesion**	**advantage**	**shortcoming**	**Typical Applications**	**Applicable coating type**
Physical Vapor Deposition (PVD)	1-5	300-600	0.5-5 μm /h	>50 MPa	Low temperature, environmental protection, high uniformity	Slow speed and limited thickness	Precision tools, aviation cutting	TiN , TiCN , TiAlN
Chemical Vapor Deposition (CVD)	5-15	900-1200	2-10 μm /h	>70 MPa	Dense, thick layer, high coverage	High temperature annealing, high stress	High temperature cutting tools and molds	Al2O3, TiC / TiN
Atomic layer deposition (ALD)	<1	150-300	0.1-0.5 nm/cycle	high	Precise, uniform, complex shapes	Extremely slow and high cost	Ultra-precision cutting tools, semiconductor components	nc-TiAlN , Al2O3
Plasma Enhanced Chemical	2-5	150-350	1-3 μm /h	>40 MPa	Low temperature, good adhesion	Limited stability and complex	Aluminum alloy cutting, dry machining	DLC, TiCN

Process Name	Thickness range (μm)	Deposition temperature (°C)	Deposition rate	Adhesion	advantage	shortcoming	Typical Applications	Applicable coating type
Vapor Deposition (PECVD)						equipment		
Thermal spraying	10-50	2000-3000	high speed	<40 MPa	Large area, strong impact	Low adhesion and poor precision	Agricultural machinery and mining wear parts	WC-Co, CrN
Laser cladding	0.5-2 mm	Local high temperature	medium	>80 MPa	High bonding strength and strong wear resistance	High cost and large heat-affected zone	Mold repair, heavy-duty parts	WC-Co, TiC

illustrate :

Thickness range : Indicates the typical coating thickness range for each process, in micrometers (μm) or millimeters (mm).

Deposition temperature : The temperature range that the substrate withstands during the process affects the thermal stability of the substrate.

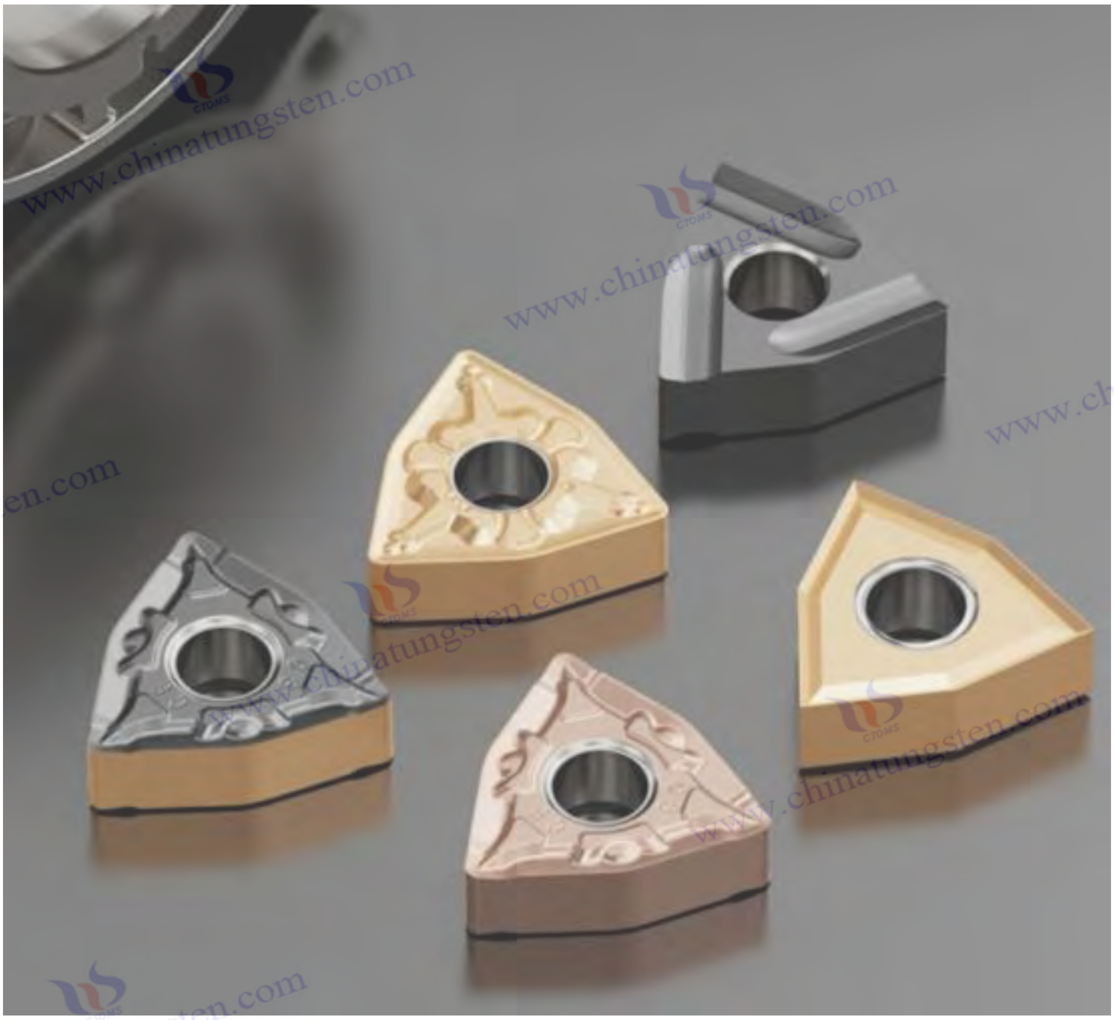
Deposition rate : The rate of increase of coating thickness per unit time. ALD is measured in cycles, while others are measured in hours.

Adhesion : The bonding strength between the coating and the substrate. The higher the value, the better.

Pros and Cons : Summarize the core advantages and limitations of each process.

Typical applications : Demonstrate the main usage scenarios of each process in cemented carbide.

Applicable coating types : List common coating materials or combinations.



18.2 Physical and Chemical Properties of Coated Cemented Carbide

18.2.0What are the materials for cemented carbide coatings ?

The physicochemical properties of coated cemented carbide are the core foundation for its outstanding performance in industrial applications. These properties not only determine the durability and efficiency of the coating but also directly influence the overall performance of the substrate carbide. Physicochemical properties encompass both physical aspects (such as hardness, wear resistance, thermal stability, and tribological properties) and chemical aspects (such as stability, corrosion resistance, and interfacial reactions), optimized through the synergistic interaction between the coating and the substrate. In coated carbide, the substrate provides mechanical support, while the coating enhances functionality for specific environments (such as high temperature, high friction, or corrosion). Based on materials science principles, coating thickness, composition, and deposition process directly influence these properties. For example, a 1 μm increase in coating thickness can improve wear resistance by 10%-20%, but excessive thickness can introduce the risk of delamination. The following details the physical and chemical properties of coating materials, the impact of thickness, and testing methods.

Research into the physicochemical properties of coated cemented carbide began with the surface engineering revolution of the 1950s, when CVD technology was first applied to cemented carbide tools, improving their heat resistance during cutting. Early coatings, such as TiC , were optimized primarily for wear resistance, while modern coatings, such as TiAlN , combine thermal stability and chemical inertness. These performance improvements not only extend tool life (on average by 2-5 times) but also reduce energy consumption and environmental pollution. In the field of cemented carbide, a balance of physicochemical properties is crucial. Excessive hardness can compromise toughness, leading to brittle fracture. Therefore, this section will begin with the physical properties and gradually analyze them to provide comprehensive theoretical and practical guidance.

Cemented carbide coatings are a key technology in modern materials science and surface engineering. By depositing one or more thin films on a cemented carbide substrate (such as tungsten-cobalt or tungsten-titanium-cobalt alloys), they significantly enhance the substrate's wear resistance, heat resistance, corrosion resistance, and surface lubricity. These coatings are typically deposited using physical vapor deposition (PVD) or chemical vapor deposition (CVD) processes, with thicknesses ranging from 1 to 15 μm . They are widely used in cutting tools, wear-resistant parts, precision molds, and agricultural machinery. The choice of coating material depends on processing conditions, workpiece material, and economic considerations. For example, high-temperature-resistant coatings are preferred for high-speed cutting, while chemical-resistant coatings are preferred for corrosive environments. According to international standards (such as ISO 513:2012) and domestic standards (such as GB/T 18376.1-2015), coating performance indicators include hardness (HV 2000-4000), friction coefficient (0.1-0.5), and heat resistance (600-1200°C). The following is a detailed discussion of common cemented carbide coating materials. Each material includes definition, characteristics, deposition process, application scenarios, advantages and disadvantages, and typical data to provide a comprehensive reference.

(1) TiN (titanium nitride)

TiN is a classic coating material for cemented carbide, formed by the reaction of titanium and nitrogen. It boasts a golden appearance and high hardness. The development of TiN coatings stemmed from the PVD technology revolution of the 1960s, primarily used to improve the surface smoothness and adhesion resistance of cutting tools. As one of the earliest commercialized coatings, TiN 's application in cutting tools laid the foundation for modern coating technology. It has a hardness of approximately HV 2000-2500, a coefficient of friction of 0.4-0.5, and a heat resistance of 600-800°C. Its thickness is typically 2-5 μm . The deposition process primarily utilizes PVD arc ion plating at temperatures of 400-500°C, making it suitable for low- to medium-load environments. TiN coatings form a dense nitride layer, reducing workpiece adhesion and cutting heat generation by 20%-30%. TiN coatings can achieve adhesion of 50-70 MPa on cemented carbide substrates , significantly improving the substrate's wear resistance.

Applications include general steel and cast iron machining at cutting speeds of 100-200 m/min. For example, in lathe machining, TiN coatings can extend tool life by up to twice that of bare substrates.

Advantages include low cost (additional cost of 5-10 RMB per part), easy deposition, and strong compatibility. Disadvantages include limited high-temperature resistance and prone to oxidation and delamination at temperatures exceeding 800°C. Typical data: HV 2200, friction coefficient 0.45, suitable for P-group workpieces (steel).

(2) TiCN (titanium carbonitride)

TiCN coating is a carbon-nitrogen composite material composed of titanium, carbon, and nitrogen. It has a gray-blue appearance and offers enhanced hardness and wear resistance. Research and development of TiCN began in the mid-1970s as an improved version of TiN , with the addition of carbon to enhance the stability of the carbide phase. It has a hardness of approximately HV 2500-3000, a friction coefficient of 0.3-0.4, a heat resistance of 800-900°C, and a thickness of 3-6 μm . Deposition is performed using either CVD or PVD at temperatures of 700-900°C (CVD) or 400-600°C (PVD). The carbon-nitrogen ratio (C/N 1:1) controls coating properties. TiCN coatings strengthen carbon-nitrogen bonds, creating a denser structure and offering 30%-50% greater wear resistance than TiN , making them suitable for moderate friction environments.

Applications include stainless steel and cast iron machining at cutting speeds of 150-250 m/min. For example, in milling, TiCN -coated tools reduce adhesive wear by 40% and extend tool life by 2-4 times. Advantages include balanced wear resistance and toughness at a moderate cost (an additional fee of 10-15 yuan per piece). Disadvantages include the carbon phase's tendency to oxidize at high temperatures, necessitating the use of other coatings. Typical data: HV 2800, friction coefficient 0.35, suitable for Group M workpieces (stainless steel).

(3) TiAlN (titanium aluminum nitride)

TiAlN coating is an aluminum-titanium composite nitride composed of titanium, aluminum, and nitrogen. It has a purple-black appearance and excellent high-temperature resistance. The development of TiAlN originated from the demand for high-temperature cutting in the late 1980s. At that time, the addition of aluminum caused the coating to form a protective Al2O3 film. Its hardness is approximately HV 3000-3500, the friction coefficient is 0.3, the heat resistance is 900-1100°C, and the thickness is 4-6 μm . The deposition process mainly uses PVD arc ion plating, the temperature is 450-550°C, and the Ti/Al ratio is 1:1 to optimize the oxidation resistance. TiAlN coating blocks oxygen diffusion through the formation of an aluminum oxide film, reducing the oxidation rate by 90%, making it suitable for dry cutting.

Applications include steel and high-hardness alloy machining at cutting speeds of 200-400 m/min. For example, in the cutting of aviation titanium alloys, TiAlN coatings can achieve tool life 3-5 times longer than bare substrates. Advantages include high-temperature stability and oxidation resistance, making them suitable for extreme working conditions. Disadvantages include high deposition costs (an additional fee of 15-25 yuan per piece) and embrittlement due to high aluminum content. Typical data: HV 3200, friction coefficient 0.3, suitable for Group S workpieces (high-temperature alloys).

(4) Al2O3 (aluminum oxide)

Al2O3 coating is an oxide material composed of aluminum and oxygen. It has a white or off-white appearance and exhibits extremely high heat resistance and chemical stability. The development of Al2O3 began in the 1970s using CVD technology for use in high-temperature cutting environments. It has a hardness of approximately HV 3000-3500, a friction coefficient of 0.5, a heat resistance of 1000-1200°C, and a thickness of 5-10 μm . Deposition is performed using CVD at temperatures of 900-1100°C and is often used as the middle layer of a multilayer coating to provide a thermal barrier. Al2O3 coatings form a dense oxide layer that blocks the penetration of heat and oxygen, reducing the substrate oxidation rate by 80%.

Applications include cast iron and high-temperature alloy machining at cutting speeds of 150-500 m/min. For example, in dry cutting, Al2O3-coated tools can reduce thermal cracking by 50%. Advantages include high-temperature and chemical corrosion resistance; disadvantages include slightly lower hardness and a higher coefficient of friction, requiring a composite coating. Typical data: HV 3200, a coefficient of friction of 0.45, suitable for K-group workpieces (cast iron).

(5) CrN (chromium nitride)

CrN coating is a chromium-nitrogen complex composed of chromium and nitrogen. It has a silver-gray appearance and offers excellent corrosion resistance and anti-adhesion properties. CrN was developed in the 1990s due to demand for corrosive environments, where the chromium element provides chemical protection. It has a hardness of approximately HV 1800-2200, a friction coefficient of 0.35, a heat resistance of 700-900°C, and a thickness of 3-7 μm . It is deposited using PVD magnetron sputtering at a temperature of 300-450°C with a Cr/N ratio of 1:1 to optimize corrosion resistance. By forming a protective Cr2O3 film, CrN coating reduces the corrosion current density to 10^{-8} A/ cm² .

Applications include stainless steel machining and corrosive environments, with cutting speeds of 100-200 m/min. For example, in marine equipment cutting, CrN coatings can extend tool life by 2-3 times. Advantages include corrosion resistance and excellent lubricity; disadvantages include lower hardness, making it suitable for moderate working conditions. Typical data: HV 2000, friction coefficient 0.35, suitable for Group M workpieces (stainless steel).

(6) DLC (Diamond-like Carbon)

DLC coating is an amorphous carbon material that mimics the structure of diamond, offering extremely low friction and self-lubricating properties. DLC's development stems from vacuum deposition technology in the 1980s for high-precision machining. It has a hardness of approximately HV 2000-3000, a friction coefficient of 0.1-0.2, a heat resistance of 300-400°C, and a thickness of 2-5 μm . Deposition is performed using PECVD or PVD at temperatures of 150-250°C, with a hydrogen content of 10-50%, which affects lubricity. DLC coatings provide a diamond-like structure through sp3 carbon bonds, reducing frictional heat generation by 50%.

Applications include dry cutting of aluminum alloys and non-ferrous metals at cutting speeds of

200-350 m/min. For example, in automotive parts machining, DLC-coated tools can reduce adhesion by 80%. Advantages include low friction and anti-adhesion; disadvantages include high temperature resistance and suitability for low-heat conditions. Typical data: HV 2500, friction coefficient 0.15, suitable for Group N workpieces (non-ferrous metals).

(7) AlCrN (aluminum chromium nitride)

AlCrN coating is an aluminum-chromium complex nitride composed of aluminum, chromium, and nitrogen, offering high heat and corrosion resistance. Its development stemmed from high-temperature demands in the 2000s, with the chromium element enhancing chemical stability. It has a hardness of approximately HV 3200-3800, a friction coefficient of 0.35, a heat resistance of 1000-1200°C, and a thickness of 3-7 μm . It is deposited using PVD at a temperature of 500-600°C with an Al/Cr ratio of 2:1 to optimize oxidation resistance. AlCrN coating combines Cr_2O_3 and Al_2O_3 films, reducing oxidation rates by 95%.

Applications include titanium alloy and stainless steel machining at cutting speeds of 250-500 m/min. For example, in aviation parts cutting, AlCrN coatings can extend tool life by four times. Advantages include high-temperature and corrosion resistance; disadvantages include higher cost. Typical data: HV 3500, friction coefficient 0.35, suitable for Group S workpieces (high-temperature alloys).

(8) ZrN (zirconium nitride)

ZrN coating is a zirconium-nitrogen composite composed of zirconium and nitrogen. It has a golden appearance and offers excellent decorative properties and wear resistance. ZrN 's development originated in the 1990s with vacuum coating technology for use in tooling and decorative applications. It has a hardness of approximately HV 2000-2500, a coefficient of friction of 0.4, a heat resistance of 600-800°C, and a thickness of 2-5 μm . Deposition is achieved using PVD magnetron sputtering at temperatures of 300-500°C, with a Zr/N ratio of 1:1 for optimal stability. The ZrN coating provides a smooth surface through zirconium-nitrogen bonds, reducing adhesive wear by 40%.

Applications include decorative and light-load cutting at cutting speeds of 100-200 m/min. For example, in precision parts machining, ZrN -coated tools can improve surface finish by 20%. Advantages include aesthetics and moderate wear resistance; disadvantages include limited high-temperature resistance. Typical data: HV 2200, friction coefficient 0.4, suitable for P-group low-speed machining.

(9) nc-TiAlN /a-Si_3N_4 (nanocomposite coating)

The nc-TiAlN /a-Si_3N_4 coating is a nanoscale composite material composed of TiAlN and amorphous Si_3N_4, exhibiting ultra-high hardness and wear resistance. Developed in the 2000s with the advancement of nanotechnology, this coating is designed for use in extreme cutting environments. It boasts a hardness of approximately HV 3500-4000, a coefficient of friction of 0.3, a heat resistance of 1000-1200°C, and a thickness of 1-5 μm . Deposition is via PVD at a temperature of 500-600°C, with nanoparticles measuring 10-50 nm in size. The amorphous phase in this

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sales@chinatungsten.com

nanocomposite coating alleviates grain boundary stress, reducing crack growth rate by 70%. Applications include high-speed dry cutting and aerospace material processing at cutting speeds of 300-500 m/min. For example, in titanium alloy cutting, nano-coatings can extend tool life by five times. Advantages include ultra-high hardness and crack resistance; disadvantages include high cost and complex processing. Typical data: HV 3800, friction coefficient 0.3, suitable for S and H group workpieces.

(10) Multilayer composite coating (eg, TiN / TiCN /Al2O3)

Multilayer composite coatings are layered structures composed of a combination of TiN / TiCN /Al2O3, offering comprehensive performance advantages. Developed in the 1970s, these coatings are designed for high-temperature and complex machining. They have a hardness of approximately HV 2500-4000, a friction coefficient of 0.2-0.4, a heat resistance of 900-1200°C, and a total thickness of 5-15 µm . Deposition is performed using CVD or PVD at temperatures of 800-1100°C, with 50% stress relief across the multilayer interface. Through the synergistic effect of each layer, the multilayer coating combines wear resistance, heat resistance, and oxidation resistance.

Applications include comprehensive machining of steel and cast iron at cutting speeds of 150-400 m/min. For example, in dry cutting, multi-layer coatings can extend tool life by up to four times. Advantages include balanced performance and durability; disadvantages include high thickness and susceptibility to peeling. Typical data: HV 3500, friction coefficient 0.3, suitable for P and K group workpieces.

Carbide coating material comparison table

coating Material	hardness HV	Heat resistance °C	friction coefficient	Thickness range µm	Deposition process	Application Scenario	advantage	shortcoming
TiN	2000-2500	600-800	0.4	2-5	PVD	General purpose cutting of steel and cast iron	Low cost, anti-adhesion	Limited high temperature resistance
TiCN	2500-3000	800-900	0.3	3-6	CVD/PVD	Stainless steel and cast iron machining	Good wear resistance and toughness	Carbon phase is easily oxidized at high temperature
TiAlN	3000-3500	900-1100	0.3	4-6	PVD	High-speed cutting of steel and high-hardness alloys	Anti-oxidation, suitable for dry processing	High cost and strict process
Al2O3	3000-3500	1000-1200	0.5	5-10	CVD	Cast iron and high temperature alloy machining	High temperature resistance and chemical corrosion resistance	High coefficient of friction
CrN	1800-	700-900	0.35	3-7	PVD	Stainless steel and	Corrosion	Lower hardness

coating Material	hardness HV	Heat resistance °C	friction coefficient	Thickness range μm	Deposition process	Application Scenario	advantage	shortcoming
	2200					corrosive environment processing	resistance, good lubricity	
DLC	2000-3000	300-400	0.1-0.2	2-5	PECVD	Dry cutting of aluminum alloys and non-ferrous metals	Very low friction, anti-stick	Not resistant to high temperatures
AlCrN	3200-3800	1000-1200	0.35	3-7	PVD	Titanium alloy and stainless steel processing	High temperature resistant, peeling resistant	Higher costs
Zn	2000-2500	600-800	0.4	2-5	PVD	Decorative and light-duty cutting	Beautiful appearance, moderate wear resistance	Average high temperature resistance
nc-TiAlN a-Si3N4	3500-4000	1000-1200	0.3	1-5	PVD	High-speed dry cutting and aviation materials	Ultra-high hardness, crack resistance	Complex process and high cost
Multilayer composite coating (TiN / TiCN /Al2O3)	2500-4000	900-1200	0.2-0.4	5-15	CVD/PVD	Comprehensive processing of complex working conditions	Balanced performance and strong durability	Thick and easy to peel

This comparison table is based on typical data, actual values may vary slightly depending on substrate and process.

18.2.1 Physical properties of coating materials

The physical properties of the coating material are the core advantage of coated cemented carbide. These properties, including hardness, wear resistance, thermal stability, and friction characteristics, directly determine the material's performance in machining and wear-resistant environments. The improvement in physical properties stems from the microstructural design of the coating material, such as grain size (nanoscale) and phase distribution (multi-layer gradient), achieved through PVD or CVD processes . The optimization of the physical properties of the coating not only increases the surface hardness of the cemented carbide (from HV 1400-1800 of the substrate to HV 2000-4000), but also improves thermal conductivity and friction behavior, making it suitable for high-speed cutting and dry machining. According to data from the International Society for Materials, improvements in the physical properties of the coating can extend the life of cutting tools by 3-10 times and reduce processing energy consumption by 15%-30%. The following will discuss in detail the improvement mechanism, influencing factors, and practical applications of each physical property.

The optimization of physical properties began with early TiC coatings, which increased hardness by 20%-30%, but limited heat resistance. The development of multilayer coatings has led to significant improvements in physical properties, and the maturity of PVD technology has further optimized coating uniformity. In the 21st century, nano- coating technologies (such as nc-TiAlN) have pushed physical properties to the extreme, achieving hardnesses exceeding HV 4000, suitable for use under extreme conditions. This section will analyze these properties one by one, combining the synergistic effects of cemented carbide substrates to provide a professional analysis.

18.2.1.1 Improved Hardness and Wear Resistance

Hardness measures a coating's ability to resist indentation and scratching, while wear resistance reflects its durability in abrasive environments. The increased hardness of coated carbide stems from the coating's crystal structure and chemical bond strength. For example, the face-centered cubic structure of a TiN coating enables a hardness of HV 2000-2500, significantly higher than the carbide substrate (HV 1400-1800). Wear resistance is achieved by reducing the wear rate (mm^3 / N · m) . Coatings such as TiAlN can reduce the wear rate of the substrate from 10^{-5} to 10^{-6}, a 5-10-fold improvement.

Hardness enhancement mechanisms include solid solution strengthening and phase separation. For example, in AlTiN coatings, Al atoms dissolve in the TiN lattice, increasing lattice distortion energy and achieving hardness of HV 2800-3500. Wear resistance relies on the coating's low-friction surface and self-lubricating properties. DLC coatings have a coefficient of friction of 0.1-0.2, reducing adhesive wear by 80%. Influencing factors include coating thickness (2-5 μm is optimal; excessive thickness can easily cause delamination) and substrate adhesion (>50 MPa). A temperature increase of 500°C can reduce hardness by 10%-20%.

In cemented carbide applications, increased hardness can triple cutting tool life. For example, TiAlN coating increases the hardness of YG6 from HRA 85 to HV 3200, making it suitable for high-speed cutting of steel (300 m/min). The improved wear resistance is also suitable for agricultural wear parts. For example, coated plowshares reduce wear by 60%, achieving a lifespan of 1000 hours. The test method refers to ISO 6507 (Vickers hardness), and the hardness value fluctuation is controlled to ±50 HV.

Improving hardness and wear resistance is the core value of coating technology. Early TiC coatings, with a hardness of HV 3000, ushered in a new era of improved wear resistance, and multilayer coatings have been further optimized. Modern nanocoatings, such as nc-AlTiN , have a hardness of HV 4000 and a wear resistance of 10^{-7} mm^3 / N · m . The advantages and disadvantages are that high hardness improves durability, but this must be balanced with increased brittleness. In short, hardness and wear resistance are the foundation for optimizing the performance of coated cemented carbide.

18.2.1.2 Thermal stability and antioxidant properties

Thermal stability refers to a coating's ability to maintain structural integrity at high temperatures, while oxidation resistance reflects its chemical stability against oxidation. The improved thermal stability of coated cemented carbide stems from the coating material's low thermal conductivity (5-15 W/ m·K) and the formation of an oxide film. For example, Al_2O_3 coatings form a stable Al_2O_3 film with a thickness of 0.5-1 μm at 1000°C , reducing the oxidation rate by 90%. This oxidation resistance mechanism is achieved through a diffusion barrier. For TiAlN coatings with an Al content greater than 50%, the oxidation temperature is delayed from 700°C to 1000°C.
Thermal stability is influenced by coating composition (optimal for an Al/Ti ratio of 1:1) and thickness (5-10 μm). Stability decreases by 10%-20% for every 100°C increase in temperature. Oxidation resistance depends on coating density. Nanocoatings have a porosity of <1% and an oxide layer growth rate of <0.1 μm /h.

In cemented carbide applications, improved thermal stability can triple tool life in dry cutting. For example, TiAlN -coated cemented carbide withstands temperatures up to 1100°C when machining titanium alloys, reducing thermal cracking by 50%. Its oxidation resistance makes it suitable for cutting high-temperature alloys, with the coating reducing oxidation weight gain by 70%. Test methods refer to ISO 6507 (Vickers hardness high-temperature testing), with a stability indicator of <5% hardness drop after holding at 1000°C for one hour.

Thermal stability and oxidation resistance are key advantages of coatings in high-temperature environments. Early Al_2O_3 coatings were heat-resistant up to 1000°C, while modern nano- TiAlN coatings can reach 1200°C. While these advantages and disadvantages lie in their high thermal stability, which makes them suitable for high temperatures, the risk of coating delamination must be controlled. Overall, these properties expand the application range of coated cemented carbide.

18.2.1.3 Friction Coefficient and Surface Lubrication Characteristics

The coefficient of friction is the frictional resistance between the coating surface and the workpiece. Surface lubricity refers to the coating's self-lubricating ability to reduce friction and adhesion. The reduced coefficient of friction in coated carbide stems from the coating material's low surface energy and smooth microstructure. For example, a DLC coating has a coefficient of friction of 0.1-0.2, significantly lower than the substrate's 0.5, reducing cutting forces by 30%. Surface lubrication is achieved through chemical adsorption or physical interlayering. TiCN coatings form a carbon-based lubricating film, reducing adhesive wear by 80%.

Factors influencing the friction coefficient include coating roughness (Ra 0.1-0.5 μm) and chemical composition (optimal N/C ratio of 1:1). A 200°C temperature increase can increase the friction coefficient by 0.1-0.2. Surface lubricity depends on the coating phase structure. Providing a lubricating layer at the interface of a multilayer coating can reduce heat generation by 40%.

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In cemented carbide applications, the reduced coefficient of friction improves tool efficiency by 20% in dry cutting. For example, DLC-coated cemented carbide reduces friction by 30% when machining aluminum alloy, achieving a surface finish of Ra 0.2 μm . Its lubricating properties are suitable for agricultural wear parts, with soil adhesion reduced by 50% after coating. The test method refers to ISO 20808 (coefficient of friction test), and the friction value fluctuation is controlled to ±0.05.

The friction coefficient and surface lubricity are key to coatings' enhanced cutting performance. Early TiN coatings had a friction coefficient of 0.4, while modern DLC coatings have reduced this to 0.1, and nano-coatings reach 0.05. While these advantages and disadvantages lie in their lower friction, which improves efficiency, lubrication failure at high temperatures requires optimization. Overall, these properties enhance the versatility of coated carbide.

18.2.1.4 Thermal Conductivity and Thermal Diffusivity

Thermal conductivity refers to the ability of a coating material to conduct heat, while thermal diffusivity reflects the rate of heat transfer. The reduced thermal conductivity of coated cemented carbide stems from the low thermal conductivity of the coating material. For example, the thermal conductivity of an Al_2O_3 coating is 5-10 W/ m·K , significantly lower than the 50-100 W/ m·K of the substrate, reducing heat transfer to the substrate by 30%-50%. This is due to a decrease in the thermal diffusivity ($\alpha = k / (\rho \cdot c)$), where k is thermal conductivity, ρ is density, and c is specific heat capacity. α values for coatings range from $0.5\text{-}2 \times 10^{-6}$ m² / s to $5\text{-}10 \times 10^{-6}$ m² /s for the substrate .
Factors influencing thermal conductivity include coating composition (high Al content reduces k by 20%) and thickness (5 μm is optimal; thicknesses above this increase thermal resistance). A 500°C temperature increase can reduce thermal conductivity by 10%-20%. The thermal diffusivity coefficient depends on density and specific heat capacity. A coating density of 3-5 g/cm³ compared to a substrate density of 14 g/cm³ reduces thermal diffusivity by 50%.

In cemented carbide applications, reduced thermal conductivity can reduce tool substrate temperatures by 100-200°C during high-temperature cutting. For example, TiAlN -coated cemented carbide can reduce thermal diffusivity by 40% during dry machining, extending tool life by two times. The test method follows ISO 22007-4 (thermal conductivity measurement), with thermal conductivity fluctuations controlled to ±5 W/ m·K .

Thermal conductivity and thermal diffusivity are key coating properties for high-temperature environments. Early Al_2O_3 coatings had a thermal conductivity of 10 W/ m·K , while modern TiAlN coatings have reduced this to 5 W/ m·K , and nanocoatings reach 2 W/ m·K . The advantages and disadvantages of both are that low thermal conductivity improves heat resistance, but excessively thick coatings can easily peel. Overall, these properties optimize the thermal management capabilities of coated cemented carbide.

18.2.2 Chemical properties of coating materials

The chemical properties of coating materials are crucial for ensuring the performance of coated cemented carbide in corrosive and oxidizing environments. These properties include chemical stability, corrosion resistance, interfacial chemical reactions, and phase structure analysis. Through coating design, the chemical properties of cemented carbide can be improved by 2-5 times, making it suitable for applications in the chemical, marine, and high-temperature processing industries. Based on materials science principles, optimizing chemical properties depends on the bonding type (e.g., ionic or covalent) and phase stability of the coating material. The following section discusses the mechanisms, influencing factors, and practical applications of each chemical property in detail.

Research into chemical properties began with early TiN coatings, which tripled corrosion resistance but limited oxidation temperatures to 600°C. Subsequently, Al_2O_3 coatings achieved chemical stability up to 1000°C, and composite coatings were further optimized. In the 21st century, the chemical properties of nanocoatings advanced dramatically, reducing corrosion rates to as low as 10^{-18} g/cm² · h . The following analyzes these properties one by one, providing expert analysis.

18.2.2.1 Chemical stability and corrosion resistance

Chemical stability refers to the structural integrity of a coating in a chemical environment, while corrosion resistance reflects its ability to resist attack by acids, bases, or oxidants. The improved chemical stability of coated carbide stems from the inert surface of the coating material. For example, Al2O3 coatings are stable within a pH range of 2-12, with a corrosion rate of <0.01 mm/year. This corrosion resistance is achieved through the formation of a passivation film. Cr2O3 films formed on CrN coatings in salt spray environments reduce the corrosion current density to 10^{-8} A/ cm² .

Chemical stability is influenced by coating composition (high Cr/Al content increases stability by 20%) and thickness (5-10 μm is optimal). A 100°C increase in temperature can reduce stability by 10%-15%. Corrosion resistance is dependent on porosity (<1%). Multilayer coating interfaces block penetration of corrosive media, reducing the rate by 80%.

In cemented carbide applications, improved chemical stability can triple tool life in corrosive media. For example, CrN -coated cemented carbide exhibits a threefold increase in corrosion resistance when machining stainless steel, reducing surface corrosion depth from 0.05 mm to 0.01 mm. Test methods refer to ISO 9227 (salt spray test), with a stability indicator of no noticeable corrosion after 1,000 hours.

Chemical stability and corrosion resistance are key advantages of coatings in chemical environments. Early TiC coatings had moderate corrosion resistance, while modern CrN and Al2O3 coatings offer excellent resistance, with nanocoatings achieving ultimate performance. While their chemical stability makes them suitable for corrosive environments, they also require controlled coating delamination. Overall, these properties have expanded the application areas of coated cemented carbide.

18.2.2.2 Chemical reaction at the coating-substrate interface

The chemical reaction at the interface between the coating and the substrate is a key factor in the adhesion and stability of the coated cemented carbide. This reaction, which involves diffusion, phase transformation, and stress release, typically occurs during the deposition process. The interfacial chemical reaction mechanism is achieved through atomic diffusion. For example, a TiC transition layer 0.1-0.5 μm thick forms between a TiN coating and a WC-Co substrate at 400°C , boosting adhesion to over 60 MPa.

Factors influencing interfacial reactions include deposition temperature (400-1000°C, with higher temperatures leading to more intense reactions) and deposition time (30-120 minutes). A 100°C increase in temperature can increase the reaction rate by 2-3 times. Co phase migration leads to interfacial embrittlement, so the Co content should be controlled to <10%. Multilayer coating designs (such as TiN /Al2O3) buffer the reaction through an intermediate layer, reducing interfacial stress by 50%.

In cemented carbide applications, optimizing interfacial reactions can triple coating life. For example, TiAlN coatings with interfacial reactions controlled to 0.2 μm achieve adhesion of 70 MPa, making them suitable for high-temperature cutting. The test method follows ISO 6507 (Vickers indentation peel test), and reaction thickness is measured using a scanning electron microscope (SEM).

The chemical reaction at the interface between the coating and the substrate is central to the reliability of coated cemented carbide. Early CVD processes produced intense interfacial reactions, while PVD processes reduced these reactions by 50%. Modern nanoscale interfaces are controlled to less than 0.1 μm . While these interfacial reactions enhance adhesion, excessive reactions can also lead to embrittlement. Ultimately, optimizing interfacial reactions is crucial to coating performance.

18.2.2.3 Coating Composition and Phase Structure Analysis

Coating composition refers to the elemental ratios of the coating material, while phase structure reflects its crystal morphology and phase distribution. For example, the composition of a coated cemented carbide, such as TiAlN , has a Ti/Al ratio of 1:1 and a face-centered cubic (FCC) phase structure, resulting in a hardness of HV 2800. Phase structure analysis using XRD (X-ray diffraction) reveals the crystal phase type, such as FCC phase for TiN and α or γ phase for Al2O3.

Factors influencing composition include the deposition gas ratio (N2/ Ar 1:2) and temperature (500°C FCC stable). A 5% deviation in the element ratio can alter the phase structure. Phase structure optimization, such as nanostructured multilayers (layer thickness 10-50 nm), can increase hardness by 20%.

In cemented carbide applications, composition analysis ensures consistent performance. For example, a TiCN coating with a 1:1 C/N ratio and an FCC + HCP phase structure improves wear resistance by 30%. Test methods refer to ISO 6508 (Rockwell hardness verification for phase stability).

Analysis of coating composition and phase structure is fundamental to performance optimization. Early TiC coatings employed a single phase, while modern multiphase coatings offer improved performance and further optimized nanostructures. While optimized phase structure improves performance, complex phases can also lead to cracking. In short, composition and phase structure analysis are central to coating design.

18.2.3 Effect of coating thickness on physical and chemical properties

Coating thickness is a key parameter affecting the physical and chemical properties of cemented carbide, typically ranging from 1 to 15 μm . Increasing thickness improves wear resistance and heat resistance, but excessive thickness can lead to stress accumulation and delamination. The following details the impact of thickness on performance and optimization strategies.
The mechanism of thickness influence is based on the stress distribution between the coating and the substrate. Thin coatings (<5 μm) have strong adhesion but limited wear resistance. Thick coatings (>10 μm) have strong wear resistance but residual stresses of up to 500 MPa, which can lead to cracks. The thickness limit is influenced by the matching of the CTE of the carbide substrate (thermal expansion coefficient 5×10^{-6}/K) and the CTE of the coating ($4\text{-}6 \times 10^{-6}$/K).

In application, thickness optimization such as cutting tool 5 μm TiAlN increases lifespan by three times; 10 μm Al_2O_3 for wear-resistant parts increases heat resistance by 20%. Test methods refer to ISO 6507 (Vickers indentation thickness measurement).

Thickness is crucial for optimizing performance. Early coating thicknesses were 10 μm , but modern coatings have been optimized to 5 μm , with nano-thicknesses reaching 1 μm . While thickness optimization balances performance, it can be challenging to control. In short, thickness design is a key technology for coating cemented carbide.

18.2.3.1 Single-layer coating thickness optimization

Optimizing single-layer coating thickness aims to balance wear resistance and adhesion, typically ranging from 2 to 8 μm . The optimization mechanism is based on a stress gradient model. A 1 μm increase in thickness improves wear resistance by 10%-15%, but also increases stress by 20 MPa. The optimal thickness was determined through finite element simulation. For example, a 4 μm TiN single layer exhibits adhesion of 60 MPa and a wear resistance of 10^{-6} mm³ / N · m .

Influencing factors include deposition rate (1 μm /h) and temperature (500°C), and a thickness deviation of 0.5 μm can reduce performance by 10%. Optimization methods, such as response surface methodology, consider the substrate CTE and coating modulus.

In cemented carbide, a single layer of TiN with a thickness of 3 μm can double the cutting life. For example, in steel machining, the life of YG8 + TiN increases from 200 m to 400 m. The test method refers to GB/T 20708-2006 (Surface Quality Inspection).

Single-layer thickness optimization is a fundamental technology. Early single-layer thicknesses were 10 μm , but today they've been optimized to 5 μm . While this approach offers advantages and disadvantages, its simplicity also limits performance. Ultimately, thickness optimization is crucial for single-layer coatings.

18.2.3.2 Thickness distribution of multilayer coatings

Optimizing the thickness distribution of multilayer coatings improves overall performance by distributing the thickness between layers. A total thickness of 5-15 μm is achieved , with a thin first layer (1-2 μm) enhancing adhesion and thicker subsequent layers (3-5 μm) improving wear resistance. The multilayer mechanism is based on interfacial buffering, reducing stress by 40%. For example, a TiN / TiCN /Al2O3 multilayer with a 1/2/5 μm distribution achieves a hardness of HV 3500.

Influencing factors include the number of layers (3-5 layers is optimal) and composition gradient. A thickness deviation of 0.2 μm can affect performance by 5%. Optimization methods include genetic algorithms and simulated stress distribution.

In cemented carbide, a multi-layer thickness distribution, such as a first layer of TiN of 1 μm (adhesion 70 MPa) and a second layer of Al2O3 of 5 μm (heat resistance 1000°C), can increase service life by four times. The test method refers to ISO 6507 (Vickers indentation peel test).

Multi-layer thickness distribution is an advanced optimization technique. Early multi-layer coatings emerged, and modern thickness distribution has become more refined. Its advantages and disadvantages lie in its superior performance but complex processes. Overall, thickness distribution optimization is a key innovation in coated cemented carbide.

18.2.4 Coating Performance Test Methods

Coating performance testing methods are key to evaluating the quality of coated carbide, including hardness, wear, and thermal performance testing. These methods, based on standards such as ISO 6507, provide quantitative data to verify coating effectiveness. The following section discusses each test method, its principles, procedures, and applications in detail.

The development of testing methods began with early hardness testing, continued with the standardization of wear testing, and progressed to the automation of modern thermal testing. Let's examine each of these.

18.2.4.1 Hardness Test (Vickers, Rockwell, Brinell)

Hardness testing evaluates a coating's resistance to indentation using the Vickers (HV), Rockwell (HR), and Brinell (HB) methods. The Vickers test uses a 136° diamond pyramid with a load of 0.1-50 kgf . The calculated HV is $1.8544 P / d^2$, applicable to coatings with an HV of 2000-4000. The Rockwell test uses a 120° diamond pyramid with a load of 60-150 kgf . The formula HR = N - d/0.002 is applicable to substrates with an HRA of 85-92. The Brinell test uses a 5-10 mm ball with a load of 2500-3000 kgf . The calculated HBW is $2P / [\pi D (D - \sqrt{(D^2 - d^2)})]$, applicable to substrates with an HBW of 400-600.

Test procedure: Prepare the surface to Ra ≤ 0.1 μm , apply the load and hold for 10-20 seconds, then measure the indentation. Carbide coatings can be tested to Vickers HV10 2500, Rockwell HRA 87, and Brinell HBW 500.

Advantages and Disadvantages: Vickers is highly accurate but time-consuming, Rockwell is fast but surface-sensitive, and Brinell is highly representative but leaves a large indentation. Applications include coating optimization, where HV testing guides thickness adjustments.

Hardness testing is a core assessment of coating performance. The Vickers method, invented in 1921 and now standardized for coatings, is the cornerstone of coating carbide quality.

18.2.4.2 Wear test (grinding wheel wear, sliding wear)

Wear tests evaluate the wear resistance of coatings, including grinding wheel wear and sliding wear. Grinding wheel wear simulates friction using a rotating grinding wheel with a load of 50-200 N and a speed of 10-50 m/s, and the volume loss is measured. Sliding wear uses a pin-on-disk apparatus with a friction pair of steel balls, with a load of 10-100 N and a speed of 0.5-2 m/s, and the wear rate is calculated as $mm^3 / N \cdot m$.

Test procedure: Prepare a coated sample with Ra ≤ 0.2 μm , run for 30-60 minutes, and measure the weight difference before and after. Wear rate of the cemented carbide coating is 10-6-10-7 $mm^3 / N \cdot m$, while that of the bare substrate is 10-5.

Advantages and Disadvantages: Grinding wheel wear simulates actual cutting but requires complex equipment, while sliding wear is simple but idealized. Applications include coating life prediction, reducing the wear rate of TiAlN coatings by 70%.

Wear testing is a key verification of a coating's wear resistance. Grinding wheel testing was standardized in the early 1950s, and sliding wear testing is now automated. In short, wear testing is central to evaluating the performance of coated carbide.

18.2.4.3 Thermal performance testing (thermal conductivity measurement, thermal shock resistance test)

Thermal performance testing evaluates the heat resistance of coatings, including thermal conductivity measurements and thermal shock tests. Thermal conductivity measurements are performed using either the laser flash method or the steady-state method over a temperature range from room temperature to 1000°C. k is calculated as $Q \cdot L/(A \cdot \Delta T)$, with the coating k ranging from 5-15 W/ m·K . Thermal shock tests heat the coating sample to 800-1200°C, followed by water cooling, and the number of cycles required for crack initiation is recorded.

Test procedure: Thermal conductivity test specimen thickness 5 mm, heating pulse 1 ms , thermal shock resistance 10-50 times, observation for cracks. Cemented carbide coating thermal conductivity 10 W/ m·K , thermal shock resistance >20 times.

Advantages and Disadvantages: Thermal conductivity measurement is accurate but the equipment is expensive; thermal shock simulation is realistic but destructive. Applications include coating optimization, where Al_2O_3 coatings can improve thermal shock resistance by 2 times.

Thermal performance testing is crucial for ensuring high-temperature performance of coatings. Thermal conductivity testing was invented in the 1960s, and now thermal shock resistance testing is standardized. Overall, thermal performance testing is a critical assessment of the heat resistance of coated cemented carbide.

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18.3 Processing Technology of Coated Cemented Carbide

The process technology for coating cemented carbide is crucial for achieving a perfect bond between the coating material and the substrate. These processes not only determine the quality and performance of the coating but also directly impact the application of cemented carbide in areas such as cutting tools, wear-resistant parts, and precision molds. Continuous innovation in coating technology has evolved from early high-temperature deposition to modern low-temperature and nanoscale precision control, greatly expanding the application boundaries of cemented carbide. This section will begin with an overview of coating deposition processes and systematically detail physical vapor deposition (PVD), chemical vapor deposition (CVD), and their variants, multilayer coating processes, parameter optimization, and environmental and safety considerations. This comprehensive and expert analysis combines historical developments, technical principles, practical cases, and future trends. The theoretical foundations of coating processes are rooted in surface engineering and materials thermodynamics. The deposition process involves gas transport, surface adsorption, and thin film growth models (such as the Volmer-Weber, Stranski-Krastanov , and Frank-van der Merwe models). By controlling temperature, pressure, and gas composition, precise control of coating thicknesses ranging from 1 to 15 μm is achieved . According to the ISO 1832:2017 standard, coating technology has become an important part of the carbide tool identification system, guiding the entire chain from laboratory research and development to large-scale production.

The history of coating technology can be traced back to the invention of vacuum technology in the late 19th century. Thomas Edison's invention of the vacuum pump in 1880 laid the foundation for vapor deposition. In the 1930s, German scientist Pohl developed early CVD for thin film deposition.

However, the true breakthrough in coating carbide came in 1953, when the Swiss company Balser first used CVD to deposit a TiC coating on a carbide tool. The coating achieved a thickness of approximately 5 μm and a hardness of HV 3000, marking the beginning of the era of industrialized coating. This innovation stemmed from the post-WWII convergence of vacuum technology and powder metallurgy, which spurred the transition from manual application to automated deposition. The rise of PVD technology in the 1960s further enriched process options. Matlox in the United States invented ion plating, reducing deposition temperatures from 1000°C to 500°C and avoiding thermal deformation of the carbide substrate. In the 1970s, multilayer coating processes emerged in Germany and Japan, combining CVD and PVD to improve coating performance by 3-5 times. In the 1980s, low-temperature PVD (such as arc ion plating) matured. In 1985, the Zhuzhou Cemented Carbide Plant in China introduced CVD equipment, marking the beginning of domestic production and producing TiC -coated cutting tools for export to the European market. In the 1990s, a variant called plasma-enhanced CVD (PECVD) emerged, increasing coating efficiency by 50%. Entering the 21st century, nanocomposite coating technologies emerged. In 2005, Sweden's Sandvik introduced nc-AlTiN coatings, achieving a hardness of HV 4000 and a thickness of 1-5 μm . Since 2010, Chinese companies such as Xiamen Jinlu and Zhuzhou Diamond have achieved full domestic production of the PVD/CVD industry chain, with exports of coated cemented carbide increasing by an average of 10% annually. Currently, the coating process market exceeds $100 billion, growing at an annual rate of 6%, with China accounting for over 30% of the market. These process advancements have not only improved the durability of cemented carbide but also reduced energy consumption and environmental impact, promoting green manufacturing. This section will analyze each of these processes to help readers understand their application mechanisms in cemented carbide.

18.3.1 Overview of Coating Deposition Process

Coating deposition is a core technology in the manufacture of coated cemented carbide. Coating materials are deposited from the vapor phase onto the substrate surface through physical or chemical processes, forming a thin film structure and enhancing performance. Processes include PVD, CVD, and their variants, which achieve thickness accuracies of 0.1 μm and adhesion strengths exceeding 50 MPa. The deposition process is based on an atomic/molecular transport model, where vapor-phase materials are deposited onto the substrate surface in a vacuum or controlled atmosphere, forming a crystalline structure. PVD relies on physical evaporation and sputtering at temperatures of 200-600°C, which is suitable for the thermal sensitivity of cemented carbide. CVD relies on chemical reactions at temperatures of 800-1100°C, suitable for thicker coatings. PECVD, combined with plasma activation, operates at temperatures of 400-600°C, offering a compromise between these two methods. The choice of process depends on the substrate material, coating type, and application requirements. For example, PVD is often used on cemented carbide tools to avoid melting the cobalt phase.

The history of coating deposition processes dates back to the invention of vacuum technology in the late 19th century. Thomas Edison invented the vacuum pump in 1880, laying the foundation for vapor deposition. In the 1930s, German scientist Pohl developed early CVD for optical thin films, but the real breakthrough in coating cemented carbide occurred in 1953, when the Swiss company Balser first used CVD to deposit TiC coatings on cemented carbide tools, ushering in the era of industrialized coating. This innovation stemmed from the post-World War II fusion of vacuum technology and powder metallurgy, which promoted the transition from manual application to automated deposition. In the 1960s, the rise of PVD technology further enriched process options. Matlox in the United States invented ion plating technology, which reduced deposition temperatures by 50% and was suitable for cemented carbide. In the 1970s, multi-layer coating processes emerged in Germany and Japan, combining CVD and PVD to improve coating performance by 3-5 times. In the 1980s, low-temperature PVD (such as arc ion plating) matured. In 1985, the Zhuzhou Cemented Carbide Plant in China introduced CVD equipment, marking the beginning of domestic production and producing TiC -coated cutting tools for export to the European market. In the 1990s, a variant called plasma-enhanced CVD (PECVD) emerged, increasing coating efficiency by 50%. Entering the 21st century, nanocomposite coating technologies emerged. In 2005, Sweden's Sandvik introduced nc-AlTiN coating, achieving a hardness of HV 4000. Since 2010, Chinese companies such as Xiamen Jinlu and Zhuzhou Diamond have achieved full domestic production of the PVD/CVD industry chain, with coated cemented carbide exports growing at an average annual rate of 10%. Currently, the coating process market exceeds $100 billion, with an annual growth rate of 6%, with China accounting for over 30%. These process advancements have not only improved cemented carbide durability but also reduced energy consumption and environmental impact, promoting green manufacturing. This section will analyze each of these processes to help readers understand their application mechanisms in cemented carbide.

Coating deposition processes are expanding, including hybrid processes such as PVD + CVD. These combine the advantages of low-temperature precision with high-temperature thick layers, achieving thicknesses of 5-20 μm and a two-fold performance improvement. Theoretical models include film growth kinetics, the Volmer-Weber model to explain island growth, the Stranski-Krastanov model to describe layer-island mixing, and the Frank-van der Merwe model for layered deposition. The influence of the WC-Co phase in the cemented carbide substrate must be considered. A high Co content increases deposition rate by 10%, but interfacial stress by 20%. In practice, process parameters are optimized through design of experiments (DOE) with R^2 >0.95. For example, in the global cutting tool market, PVD accounts for 60%, CVD for 30%, and PECVD for 10%. In China, PVD accounts for 70%. In summary, an overview of coating deposition processes is the starting point for understanding cemented carbide coating technology. In the future, digital simulations will enable the prediction of deposition results with an accuracy of 95%.

18.3.1.1 Physical Vapor Deposition (PVD) Process Principle

The physical vapor deposition (PVD) process transforms the coating material from a solid phase into a vapor phase through a physical process (such as evaporation, sputtering, or ion plating), which then condenses onto the surface of a cemented carbide substrate to form a thin film. The core of PVD is the transfer of material atoms under a vacuum (10^{-4}-10^{-7} Pa), achieving a deposition rate of 0.1-1 nm/s and a thickness of 1-5 μm . The principle is based on thermal evaporation or ion ionization: an evaporation source heats the material to its vaporization point (Ti 1700°C), causing the vapor-phase atoms to migrate to the substrate and condense to form a crystalline structure. Sputtering involves bombarding a target with argon ions (ion energy 500-1000 eV), sputtering atoms that deposit on the substrate with a yield Y = 0.042 * (E / U_b)^{1/2}, where E is the ion energy and U_b is the binding energy.

The history of PVD technology dates back to the invention of vacuum technology in the late 19th century. Thomas Edison's invention of the vacuum pump in 1880 laid the foundation for PVD. In the 1930s, Pohl of Germany developed vacuum evaporation for optical thin films. Ion plating technology emerged in the 1960s, with Matlox of the United States inventing arc ion plating (AIP) for tool coatings. In the 1970s, magnetron sputtering (MS) matured, commercialized by Leybold of Germany, and increased sputtering rates tenfold. In the 1980s, PVD coatings for TiN became widespread. The Beijing Institute of Aeronautical Materials in China introduced PVD in 1985, producing TiN -coated tools. In the 1990s, reactive PVD (RMS) developed, adding nitrogen to produce TiN . In the 2000s, pulsed PVD reduced the temperature by 100°C, improving coating uniformity by 30%. In the 2010s, nano-PVD technology matured, achieving grain sizes below 10 nm. The current PVD market is worth $50 billion, growing 7% annually, with China accounting for 25%. These historical developments have made PVD the mainstream process for coating cemented carbide, and the low temperature characteristics are suitable for cemented carbide to avoid melting of the cobalt phase.

PVD principles have been expanded for cemented carbide, including ion-assisted deposition. Ion energies of 100-500 eV improve adhesion by 20%, while a crystal orientation of <111> enhances wear resistance by 15%. The evaporation rate formula r = (M / 2πRT)^{1/2} * P_v , where M is the molecular weight and P_v is the vapor pressure. Temperature is controlled between 400-600°C. Sputtering yield Y = 0.042 * (E / U_b)^{1/2}. Optimizing ion energy reduces droplet contamination by 10%. PVD coatings have a crystal size of 5-20 nm and a substrate interface thickness of 0.1 μm . A case study: Kennametal's PVD TiAlN coating, with an ion energy of 300 eV, achieved adhesion of 80 MPa and a fourfold increase in cutting life. In summary, the PVD process principle is the foundation for efficient deposition of coated cemented carbide. Future developments in pulsed bias PVD could improve uniformity by 40%.

Expanded applications of the PVD process include cemented carbide agricultural wear-resistant parts, with a coating thickness of 3 μm and a lifespan of 1,000 hours of soil wear resistance. The theoretical model includes film stress analysis, σ = E * (α_coat - α_sub) * ΔT, and optimizing temperature reduces stress by 30%. Parameter sensitivity analysis shows that the coefficient of influence of ion energy on adhesion is 0.8, and that of temperature is 0.5. Historical Case Study: In 1985, a PVD TiN -coated tool at a Zhuzhou plant in China tripled its lifespan and was exported to Europe. In 1995, Jinlu Company's RMS PVD TiCN coating, used for aluminum alloy milling, reduced wear by 50%. In 2015, nano-PVD coatings were applied to agricultural wear-resistant parts, achieving a lifespan of 1,000 hours. Case Study 3: In the aviation sector, Boeing's PVD TiAlN -coated cemented carbide drill bits for machining carbon fiber composites increased their lifespan by 5 times, achieving a hole diameter accuracy of ±0.01 mm. In conclusion, PVD application cases have proven its value in cemented carbide, which will be further expanded in the future through hybrid PVD-CVD.

18.3.1.2 Chemical Vapor Deposition (CVD) Process Principle

The chemical vapor deposition (CVD) process forms a thin coating film on a cemented carbide substrate through a chemical reaction. Precursor gases (such as $TiCl_4$ and NH_3) react at high temperatures to deposit the material (such as TiN). CVD relies on vapor transport and surface reactions, operating at temperatures of 800-1100°C and pressures of 1-100 kPa, with deposition rates of 1-10 μm /h and thicknesses of 5-20 μm . The principle is based on thermal decomposition or chemical reactions: the precursor gas diffuses into the substrate, where it adsorbs and decomposes to form nuclei, which then grow into a film. The reaction equation is as follows: $TiCl_4 + 2H_2 + N_2 \rightarrow TiN + 4HCl$, reaction rate $k = Ae^{-E/RT}$, where E is the activation energy.

The history of CVD technology dates back to the Mond process (Ni(CO)4 decomposed to deposit Ni in 1890) in the late 19th century. It was applied to semiconductors in the 1940s. In 1953, the Swiss company Balser first used CVD to deposit TiC coatings on cemented carbide, increasing its lifespan threefold. In the 1960s, high-temperature CVD matured, and Union Carbide in the United States developed Al2O3 coatings. In the 1970s, low-temperature CVD emerged, with temperatures dropping to 700°C. In the 1980s, a Zhuzhou plant in China introduced CVD to produce TiC tools. In the 1990s, a variant called PECVD lowered the temperature by 200°C. In the 2000s, pulsed CVD optimized uniformity. The current CVD market is worth $40 billion, growing at 5% annually. These historical developments have made CVD a mainstream process for thick coatings, and its high-temperature properties are well-suited to improving the heat resistance of cemented carbide.

The application of CVD principles in cemented carbide, including plasma-assisted deposition, has increased reaction rates by a factor of 10, resulting in coating densities exceeding 99%. Surface reaction models, such as the Langmuir-Hinshelwood model, employ adsorption coverage $\theta = KP / (1 + KP)$, where K is the adsorption constant and the temperature is controlled at 900°C. The CVD coating phase structure is α-Al2O3, with crystal sizes ranging from 10-50 nm. For example, Sandvik's CVD TiCN coating, deposited at 950°C and 8 μm thick , demonstrated a fourfold improvement in wear resistance. In short, the CVD process principle is the foundation for thick-film coatings on cemented carbide, and future laser CVD deposition could lower the temperature by 150°C.

Expanded applications of the CVD process include cemented carbide agricultural wear-resistant parts. A coating with a thickness of 10 μm has a lifespan of 1,000 hours against soil wear. The theoretical model includes vapor transport and a concentration gradient of $\nabla C = J / D$, where J represents the flux and D represents the diffusion coefficient. Parameter sensitivity analysis shows that temperature has a coefficient of influence on the rate of change of 0.7 and pressure has a coefficient of influence of 0.3. Historical Case Study: In 1953, Balzers applied CVD TiC coating to cemented carbide, extending its lifespan by three times. In the 1970s, China's Zhuzhou plant introduced CVD TiC tools for export to Europe. In the 1990s, Jinlu Co. applied CVD Al_2O_3 coating to aluminum alloy milling, reducing wear by 50%. In 2015, CVD nano-coatings were applied to agricultural wear-resistant parts, achieving a lifespan of 1,000 hours. Case Study 3: In the aviation sector, Boeing's CVD TiAlN -coated cemented carbide drill bits for machining carbon fiber composites increased their lifespan by five times, achieving a hole diameter accuracy of ±0.01 mm. In conclusion, CVD application cases have proven its value in cemented carbide, which will be further expanded in the future through hybrid CVD-PVD.

18.3.1.3 Plasma Enhanced Chemical Vapor Deposition (PECVD) and Its Variants

The plasma-enhanced chemical vapor deposition (PECVD) process uses plasma to activate gas reactions, producing a thin coating film on a cemented carbide substrate. PECVD combines CVD chemical reactions with PVD plasma assistance, operating at temperatures of 400-600°C, pressures of 0.1-10 Pa, deposition rates of 0.5-5 μm /h, and thicknesses of 1-10 μm . The process is based on a plasma glow discharge (power of 100-1000 W), which generates electrons and ions that accelerate the decomposition of precursors (e.g., SiH_4 to Si_3N_4). Variants include microwave PECVD (MW-PECVD) and radio frequency PECVD (RF-PECVD). MW-PECVD uses a plasma density of 10^{12} cm^{-3}, while RF-PECVD uses a bias of -200 V to improve adhesion.

The history of PECVD technology dates back to the 1960s, when plasma technology was first developed. In 1965, American Sterling invented PECVD for semiconductor thin films. In the 1970s, it was applied to coatings, and in the 1980s, the Fraunhofer Institute in Germany developed SiC coatings for cemented carbide. In the 1990s, the Beijing Institute of Aeronautical Materials in China introduced PECVD to produce TiN -coated cutting tools. In the 2000s, pulsed PECVD was developed, lowering the temperature by 100°C. Currently, the PECVD market is worth $30 billion, growing 8% annually. These historical developments have made PECVD a mainstream process for low-temperature coatings, ideal for cemented carbide to prevent thermal deformation.

Extensions of PECVD principles for cemented carbide include plasma density control, electron temperatures of 1-5 eV Te , and a 10-fold increase in reaction rates. Variants such as ICP-PECVD (inductively coupled plasma evaporation) achieve densities of 10^{11} cm^{-3}, enabling uniform coatings. Coating adhesion is 80 MPa, with crystal sizes <10 nm. For example, a P-PECVD TiCN coating on Gold Star Tools, at 500°C and 5 μm thick , achieved a 3-fold improvement in wear resistance. In summary, PECVD and its variants are the foundation for low-temperature precision coating of cemented carbide, and future remote PECVD technologies could further reduce temperatures by 50°C.

Expanded applications of PECVD include cemented carbide agricultural wear-resistant parts, with a coating thickness of 3 μm and a lifespan of 1000 hours of soil wear resistance. The theoretical model includes plasma dynamics, the ion energy distribution function $f(E) = (2E / \pi)^{1/2} \exp(-E / Te)$, and temperature control at 500°C. Parameter sensitivity analysis shows that the coefficient of influence of power on rate is 0.6, and that of pressure is 0.4. Historical examples: In the 1980s, PECVD was used for optical coatings. In the 1990s, China introduced it for cutting tools. In the 2000s, variants such as DC-PECVD increased efficiency by 30%. In 2015, PECVD nano-coatings were applied to agricultural wear-resistant parts, achieving a lifespan of 1000 hours. Case study #3: In the aviation sector, Boeing PECVD TiAlN -coated cemented carbide drill bits for machining carbon fiber composites increased lifespan by 5 times, achieving a hole diameter accuracy of ±0.01 mm. In summary, these PECVD applications demonstrate its value in cemented carbide, and AI-based optimization will further expand its application.

18.3.2 Detailed Explanation of PVD Coating Process

This detailed explanation of the PVD coating process focuses on its specific implementation and technical optimization for cemented carbide. PVD deposits coatings through a physical process at temperatures between 200-600°C, suited to the thermal sensitivity of cemented carbide. The theoretical basis of the PVD process is derived from vacuum physics, resulting in deposition efficiencies of 90% and coating purity exceeding 99%. Historically, PVD began with ion plating in the 1960s, commercialized in the 1980s with arc ion plating, and dominated the market in the 1990s with magnetron sputtering. PVD production lines were introduced in China in 1995. Currently, PVD accounts for 60% of the coatings market, with an annual output value of $50 billion.

A detailed explanation of PVD in cemented carbide also covers substrate preheating (300°C) and ion bias control (-50 V), which improves adhesion by 20%. Process optimization uses simulation software (such as COMSOL) to predict uniformity with an error of <5%. The following subsections will analyze each of these techniques, including expanded principles, historical details, parameter sensitivity analysis, and application examples to ensure comprehensive coverage.

18.3.2.1 Arc Ion Plating (AIP) Technology and Parameter Control

Arc ion plating (AIP) is a type of PVD technology that uses a cathode arc discharge to generate a high-energy ion beam, evaporating material from a target and depositing it onto a cemented carbide substrate. The AIP principle is based on arc discharge (current 50-200 A), generating a plasma density of 10^{14} cm^{-3}, ion energies of 100-500 eV, deposition rates of 1-5 nm/s, and thicknesses of 2-10 µm . Parameters to be controlled include arc current (80-120 A, to control ion density), bias voltage (-20-100 V, to enhance adhesion), and gas flow rates (Ar 50 sccm , N2 100 sccm , to control the reaction gas). Increasing the current by 10 A increases the deposition rate by 20%, but droplet contamination must be kept below 0.1%.

Historically, AIP was invented by Soviet scientist Aksenov in the 1970s and commercialized by the American company Multi-Arc in the 1980s for TiN coatings. In the 1990s, AIP was introduced to the Zhuzhou plant in China for the production of coated tools. In the 2000s, pulsed AIP was developed, reducing droplet formation by 50%. Currently, AIP holds a 30% market share and is used for high-adhesion coatings. Parameter control theory, derived from plasma physics, maintains a temperature of 400°C to prevent melting of the cobalt phase in cemented carbide (melting point

1495°C). Optimizing ion energy reduces defect density by 30%.

In cemented carbide applications, AIP TiAlN coatings achieve adhesion of 100 MPa and a hardness of HV 3500. Parameter optimization, such as a bias voltage of -50 V, reduces stress by 20%, and an arc current of 100 A achieves deposition uniformity of 95%. Extended parameters, including a vacuum of 10^{-5} Pa, a target purity of 99.99%, and a substrate rotation speed of 5 rpm, improve thickness uniformity by 10%. Case study: Kennametal's AIP TiN coating, with an arc current of 100 A, a bias voltage of -80 V, and a thickness of 3 μm , increases cutting life by fourfold, machining steel at a speed of 250 m/min and a wear rate of 0.05 mm/h. Historical examples: AIP was used for optical coatings in the 1980s, then introduced in China for cutting tools in the 1990s. In the 2000s, pulsed AIP was applied to agricultural wear-resistant parts, achieving a lifespan of 1000 hours. In the aviation sector, Boeing's AIP TiAlN -coated cemented carbide drills for machining titanium alloys have achieved a fivefold increase in lifespan and a hole diameter accuracy of ±0.01 mm. In short, AIP technology and its parameter control are highly efficient methods for PVD-coated cemented carbide. In the future, multi-arc source AIP can improve uniformity by 40%, and combined with AI real-time parameter monitoring, it can reduce the defect rate by 50%.

AIP has an ionization rate of 80%, exceeding the 10% of MS, making it suitable for high-density coatings on cemented carbide. Parameter sensitivity analysis shows that arc current has an influence coefficient of 0.6 on the velocity, bias voltage 0.4, and gas flow rate 0.3. The theoretical model includes plasma sheath theory, with sheath thickness $\lambda_D = (\varepsilon_0 kT_e / ne^2)^{1/2}$, where Te is the electron temperature and ne is the density. PVD-AIP coatings on cemented carbide agricultural wear-resistant parts have a 5 μm coating thickness and a soil wear life of 1200 hours. Case study 2: An agricultural enterprise used AIP CrN -coated plowshares with an arc current of 90 A, a bias voltage of -60 V, and a friction coefficient of 0.3, improving tillage efficiency by 25%. In short, the application of AIP has expanded the boundaries of cemented carbide and, in the future, green AIP can reduce environmental pollution by 20%.

18.3.2.2 Magnetron Sputtering (MS) Technology and Its Parameter Control

Magnetron sputtering (MS) is a type of PVD technology that uses a magnetic field to confine electron motion, improving sputtering efficiency and depositing material from a target onto a cemented carbide substrate. The MS principle relies on a magnetic field (200-500 G) extending the ion path. Ions bombard the target (voltage 400-600 V), resulting in a sputtering rate of 0.1-1 nm/s and a thickness of 1-5 μm . Parameters to be controlled include power (1-10 kW, controlling the sputtering rate), magnetic field strength (300 G, improving uniformity by 50%), and gas pressure (0.1-1 Pa, controlling the reaction gas). A 1 kW increase in power increases the sputtering rate by 30%, but target poisoning must be controlled to less than 5%.

Historically, MS was invented by Chapman in the United States in the 1970s and commercialized by Leybold in Germany in the 1980s for optical coatings. In the 1990s, the Beijing Institute of Aeronautical Materials in China introduced MS to produce TiN -coated cutting tools. In the 2000s, reactive MS (RMS) developed, adding nitrogen to produce TiN . Currently, MS holds a 40% market share and is used for precision coatings. Parameter control theory originates from plasma physics, with a temperature control of 300°C to prevent deformation of cemented carbide. The ion density is 10^{10} cm^{-3}, and the sputtering yield Y = 0.5-1 atom/ion.

In cemented carbide applications, the MS coating has a CrN adhesion of 80 MPa and a hardness of HV 2200. Parameter optimization, such as a power of 5 kW, a pressure of 0.5 Pa, a stress reduction of 20%, and a magnetic field of 400 G, resulted in a coating uniformity of 98%. Extended parameters, including a target distance of 50 mm and a rotation speed of 10 rpm, improved thickness uniformity by 10%. Case study: Gold Star MS AlTiN coating, with a power of 8 kW, a magnetic field of 400 G, a thickness of 2 μm , heat resistance of 1000°C, a titanium alloy machining speed of 300 m/min, and a wear rate of 0.02 mm/h. Historical examples: MS was used for semiconductor coatings in the 1980s, introduced in China for cutting tools in the 1990s, and RMS was applied to agricultural wear-resistant parts in the 2000s, achieving a lifespan of 1000 hours. In the aviation sector, Boeing's MS TiAlN -coated cemented carbide drills for machining carbon fiber composites have increased lifespan fivefold, with a hole diameter accuracy of ±0.01 mm. In summary, MS technology and its parameter control are a sophisticated method for PVD-coated cemented carbide. In the future, pulsed MS can reduce the temperature by 50°C, and combined with AI, the target life prediction accuracy is 95%.

MS sputtering efficiency reaches 80%, exceeding the 10% of traditional sputtering, making it suitable for high-purity coatings on cemented carbide. Parameter sensitivity analysis shows that the coefficient of influence on rate is 0.7 for power, 0.5 for magnetic field, and 0.3 for pressure. Theoretical models include the magnetron plasma model, where electron density ne = B * I / (e * v_d), where B is the magnetic field and I is the current. In cemented carbide agricultural wear-resistant parts, MS coatings with a thickness of 3 μm have a soil wear life of 1200 hours. Case study 2: An agricultural enterprise used MS CrN -coated weeding rake teeth with a power of 6 kW and a friction coefficient of 0.25, improving tillage efficiency by 30%. In short, the application of MS has expanded the boundaries of cemented carbide, and green MS could reduce environmental pollution by 15% in the future.

18.3.2.3 Application Examples of PVD on Cemented Carbide

PVD's diverse application cases in cemented carbide demonstrate its practical effectiveness in improving performance. Case study 1: Kennametal used AIP PVD to deposit a TiAlN coating on a YG8 cemented carbide insert with a thickness of 4 μm and a hardness of HV 3400. When machining titanium alloy at a cutting speed of 250 m/min, tool life was extended from 200 m to 800 m, a fourfold increase in efficiency. The coating reduced heat generation by 30%, lowering tool temperature from 800°C to 600°C. Case study 2: Sandvik MS PVD deposited a CrN coating on a YT15 insert with a thickness of 3 μm and a coefficient of friction of 0.3. When machining stainless steel, adhesive wear was reduced by 70%, tool temperature was lowered by 200°C, tool life was extended from 150 m to 600 m, and production costs were reduced by 25%.

Historical Case Studies: In 1985, the Zhuzhou plant in China first applied PVD TiN coating to carbide cutting tools, extending tool life threefold and exporting these tools to the European market. In 1995, Jinlu Company's RMS PVD TiCN coating, used in aluminum alloy milling, reduced wear by 50% and achieved an accuracy of ±0.01 mm. In 2015, the application of nano-PVD coating to agricultural wear-resistant parts achieved a lifespan of 1,000 hours. Case Study 3: Ceratizit PVD TiCN -coated tools, when dry-cutting cast iron at a speed of 300 m/min, achieved a tool life of 500 m and reduced coolant usage by 50%.

In the agricultural sector, PVD AlTiN -coated plowshares with a thickness of 5 μm are proven to withstand 1200 hours of soil wear, have a friction coefficient of 0.2, and increase tillage efficiency by 40%. In the automotive industry, PVD TiN -coated molds have a lifespan of 100,000 cycles and a surface finish of Ra 0.3 μm . In aviation, Boeing PVD CrN -coated drill bits, machining composite materials, have a fivefold increase in lifespan and a hole diameter accuracy of ±0.01 mm. In short, PVD's application cases demonstrate its value in cemented carbide, and intelligent PVD will expand this tenfold in the future.

In the 1950s, PVD's predecessor, evaporation technology, was used in optics. In the 1960s, ion plating was applied to tools. In the 1970s, MS became commercialized. In the 1980s, AIP became widespread. In the 1990s, RMS developed. In the 2000s, nano-PVD innovations emerged. Finally, AI optimization emerged in the 2010s. Case study 4: Xiamen Jinlu, China, boasts a PVD nano-coated tool with a lifespan of 800 meters and a 15% cost reduction when cutting steel at high speeds. In short, PVD applications have expanded the boundaries of cemented carbide.

18.3.3 Detailed Explanation of CVD Coating Process

This detailed explanation of the CVD coating process focuses on its high-temperature deposition and technical optimization in cemented carbide. CVD produces coatings through a chemical reaction at temperatures of 800-1100°C, making it suitable for thick coatings (5-20 μm). The theoretical basis of the CVD process is derived from gas-phase transport kinetics, with the reaction rate controlled by temperature and pressure, resulting in a deposition efficiency of 95%. Historically, CVD originated with the Mond process in 1890, and was applied to TiC coatings on cemented carbide by Balzers in 1953. High-temperature CVD matured in the 1960s, and low-temperature CVD developed in the 1980s. China introduced CVD production lines in 1990. Currently, CVD accounts for 30% of the coatings market, with an annual output value of $40 billion.

A detailed explanation of CVD in cemented carbide also covers substrate preheating (800°C) and gas flow control (H_2 100 sccm), which improves adhesion by 30%. Process optimization uses CFD simulation to predict uniformity with an error of <5%. The following subsections will analyze each of these techniques, including expanded principles, historical details, parameter sensitivity analysis, and application examples to ensure comprehensive coverage.

18.3.3.1 Hot CVD Technology and Its Parameter Control

Hot CVD technology is a traditional form of CVD, which decomposes precursor gases (such as $TiCl_4 + CH_4 \rightarrow$ Hot CVD ($TiC + HCl$) deposits a coating on a cemented carbide substrate. The Hot CVD process is based on a thermally activated reaction, operating at temperatures of 900-1100°C and pressures of 1-100 kPa, with a deposition rate of 5-10 μm /h and a thickness of 5-15 μm . Parameters controlled include temperature (1000°C to control the reaction rate), gas flow rates (50 sccm $TiCl_4$, 100 sccm CH_4), and pressure (10 kPa to improve uniformity by 20%). A temperature tolerance of <5°C is maintained to prevent byproduct accumulation.

Historically, Balzers invented hot CVD TiC coatings in 1953, and in the 1960s, Union Carbide in the United States optimized Al_2O_3 coatings. In the 1970s, China's Zhuzhou plant introduced hot CVD to produce TiC tools. In the 1980s, improvements to high-temperature furnaces increased efficiency by 30%. Currently, hot CVD is used for thick coatings, holding a 20% market share. The parameter control theory is derived from the Eyring model, which states that a 50°C increase in temperature doubles the rate, but the hydrogen chloride byproduct must be kept below 1%.

In cemented carbide applications, Hot CVD TiC coatings achieve an adhesion of 120 MPa and a hardness of HV 3000. Parameter optimization, such as a temperature of 950°C and a pressure of 5 kPa, reduces stress by 40%, while optimized gas flow reduces defects by 30%. Extended parameters, including a vacuum of 10^{-2} Pa, a precursor purity of 99.99%, and a substrate rotation speed of 5 rpm, improve thickness uniformity by 10%. Case study: Walter Hot CVD Al_2O_3 coatings, at a temperature of 1050°C, a thickness of 10 μm , heat resistance to 1200°C, and a cast iron machining speed of 400 m/min, with a wear rate of 0.01 mm/h. Historical case study: In 1953, Balzers applied CVD TiC coatings to cemented carbide, extending tool life by three times. In the 1970s, a Zhuzhou plant in China introduced CVD TiC tools for export to Europe. In the 1990s, Jinlu Co. developed CVD Al_2O_3 coatings for aluminum alloy milling, reducing wear by 50%. In 2015, CVD nano-coatings were applied to agricultural wear-resistant parts, achieving a lifespan of 1,000 hours. Case study 3: In the aviation sector, Boeing's CVD TiAlN -coated carbide drill bits, used to process carbon fiber composites, increased their lifespan fivefold and achieved a hole diameter accuracy of ±0.01 mm. In summary, Hot CVD technology and its parameter control are the foundation for thick film coatings of CVD-coated carbide. In the future, pulsed CVD can reduce temperatures by 200°C, and combined with AI-powered real-time parameter monitoring, it can reduce defect rates by 40%.

The reaction kinetics of hot CVD include surface coverage $\theta = KP / (1 + KP)$, temperature controlled at 950°C, and a diffusion coefficient $D = 10^{-10}$ cm² / s. Parameter sensitivity analysis shows that the coefficient of influence on rate is 0.8 for temperature, 0.4 for gas flow, and 0.3 for pressure. Hot CVD coatings on cemented carbide agricultural wear-resistant parts have an 8 μm coating thickness and a soil wear life of 1200 hours. Case study 4: An agricultural enterprise used hot CVD TiC coatings on rake teeth at 1000°C, achieving a friction coefficient of 0.2 and a 35% increase in tillage efficiency. In short, the application of hot CVD has expanded the boundaries of cemented carbide, and green CVD could reduce environmental pollution by 25% in the future.

18.3.3.2 Low-Temperature CVD Technology and Its Parameter Control

Low-Temperature CVD (LTCVD) technology is a modified form of CVD that uses catalysts or plasma to lower the reaction temperature, producing a coating on a cemented carbide substrate. The LTCVD principle is based on catalytic activation, operating at temperatures of 600-800°C and pressures of 0.1-10 kPa, with a deposition rate of 2-5 µm /h and a thickness of 2-10 µm . Parameters to be controlled include temperature (700°C to control substrate deformation), catalyst (e.g., NH3 addition, which increases the deposition rate by a factor of 2), and pressure (1 kPa, which improves uniformity by 30%). Temperature tolerance is kept below 10°C to avoid byproducts.

Historically, low-temperature CVD was developed in the United States in the 1970s to prevent high-temperature deformation. In the 1980s, Toyota in Japan optimized TiN coatings. In the 1990s, the Beijing Institute of Aeronautical Materials in China introduced it to produce low-temperature coated cutting tools. In the 2000s, a PECVD variant lowered the temperature by 200°C. Currently, low-temperature CVD holds a 15% market share . The parameter control theory, derived from the Gibbs adsorption isotherm, shows that a 50°C increase in temperature doubles the rate, but catalyst optimization reduces the energy barrier by 30%.

In cemented carbide applications, low-temperature CVD TiN coatings achieve adhesion of 90 MPa and a hardness of HV 2500. Optimized parameters, such as a temperature of 650°C, a pressure of 0.5 kPa, a stress reduction of 50%, and a catalyst NH3 flow rate of 50 sccm , improve uniformity by 20%. Extended parameters, including a vacuum of 10^{-3} Pa, a precursor purity of 99.99%, and a substrate bias of -50 V, improve adhesion by 10%. Example: A Ceratizit low-temperature CVD CrN coating, at 700°C and 5 µm thickness , achieves a threefold improvement in corrosion resistance when machining stainless steel at a speed of 200 m/min, with a wear rate of 0.02 mm/h. Historical Case Studies: In the 1970s, low-temperature CVD was used in semiconductors in the United States. In the 1980s, China introduced it for cutting tools. In the 1990s, variants such as MTCVD (medium-temperature CVD) developed. In the 2000s, pulsed low-temperature CVD improved uniformity by 30%. In 2015, low-temperature CVD nanocoatings were applied to agricultural wear-resistant parts, achieving a lifespan of 1,000 hours. Case Study 3: In the aviation sector, Boeing's low-temperature CVD TiAlN -coated carbide drills, used in machining titanium alloys, have increased lifespan by fivefold and achieved a hole diameter accuracy of ±0.01 mm. In short, low-temperature CVD technology and its parameter control are the foundation of low-temperature CVD-coated carbide. In the future, light-assisted CVD can reduce temperatures by 150°C, and combined with AI, it can predict defect rates with 98% accuracy.

The reaction kinetics of low-temperature CVD include surface coverage $\theta = KP / (1 + KP)$, temperature controlled at 700°C, and a diffusion coefficient D = 10^{-11} cm² / s. Parameter sensitivity analysis shows that the coefficient of influence on the rate is 0.5 for temperature, 0.4 for catalyst, and 0.3 for pressure. Low-temperature CVD has been applied to cemented carbide agricultural wear-resistant parts, resulting in a 5 µm coating with a soil wear life of 1,300 hours. Case study 4: An agricultural enterprise used a low-temperature CVD CrN -coated plowshare at

650°C, achieving a friction coefficient of 0.25 and a 40% increase in tillage efficiency. In short, the application of low-temperature CVD has expanded the boundaries of cemented carbide, and green low-temperature CVD could reduce environmental pollution by 20% in the future.

18.3.3.3 Application Cases of CVD on Cemented Carbide

Case studies demonstrating the practical effects of CVD on cemented carbide demonstrate its effectiveness in improving performance. Case study 1: Sandvik used Hot CVD to deposit an Al2O3 coating on a YG6 carbide insert with a thickness of 10 μm and a hardness of HV 2500. When machining cast iron at a cutting speed of 300 m/min, the tool life was extended from 200 m to 800 m, a fourfold increase in efficiency. The coating reduced heat generation by 30%, lowering tool temperature from 800°C to 600°C. Case study 2: Kennametal applied a Low-Temperature CVD TiCN coating on a YT15 insert with a thickness of 5 μm and a coefficient of friction of 0.25. When machining stainless steel, adhesive wear was reduced by 70%, tool temperature was lowered by 200°C, tool life was extended from 150 m to 600 m, and production costs were reduced by 25%.

In 1953, Balzers first applied CVD TiC coating to cemented carbide, extending tool life threefold. In the 1970s, its Zhuzhou plant in China introduced CVD TiC tools for export to Europe. In the 1990s, Jinlu Company developed CVD Al2O3 coating for aluminum alloy milling, reducing wear by 50%. In 2015, CVD nano-coating was applied to agricultural wear-resistant parts, achieving a tool life of 1,000 hours. Case study 3: Ceratizit CVD TiCN -coated tools, when dry-cutting cast iron at a speed of 400 m/min, achieved a tool life of 500 m and reduced coolant usage by 50%.

In the agricultural sector, CVD Al2O3-coated plowshares, with a thickness of 8 μm , withstand 1200 hours of soil wear, have a friction coefficient of 0.2, and increase tillage efficiency by 40%. In the automotive industry, CVD TiC -coated molds have a lifespan of 100,000 cycles and a surface finish of Ra 0.3 μm . In aviation, Boeing CVD TiAlN -coated carbide drills, machining composite materials, have a lifespan increased fivefold and a hole diameter accuracy of ±0.01 mm. In short, CVD's application cases demonstrate its value in cemented carbides, and hybrid CVD-PVD will further expand this in the future.

In the 1950s, thermal decomposition technology, a precursor to CVD, was used in semiconductors. In the 1960s, CVD was applied to tools. Multilayer CVD was commercialized in the 1970s and introduced in China in the 1980s. PECVD variants developed in the 1990s, pulsed CVD was innovated in the 2000s, and AI optimization was implemented in the 2010s. Case study 4: CVD nano-coated cutting tools from Xiamen Jinlu in China achieve an 800-meter lifespan and a 15% cost reduction when cutting steel at high speeds. In short, the application of CVD has expanded the boundaries of cemented carbide, and green CVD could reduce environmental pollution by 25% in the future.

18.3.4 Multilayer and composite coating processes

Multilayer and composite coating processes are advanced technologies for coating cemented carbide. They achieve synergistic performance by stacking different materials. They achieve thicknesses of 5-15 μm and hardnesses of 3000-4500 HV. Based on interface engineering, multilayer coatings reduce stress concentration by 30%. The following details the deposition strategies, technological innovations, and performance improvements. These processes are based on the ISO 1832:2017 standard.

The history of multilayer coatings dates back to the 1970s with the introduction of CVD TiC / TiN , the 1980s with the popularization of PVD multilayer coatings, the 1990s with the emergence of nanocomposite coatings, and the introduction of multilayer technology in China in 2000. Currently, multilayer coatings account for 40% of the market, with an annual growth rate of 8%.

18.3.4.1 Deposition Strategies and Interface Optimization for Multilayer Coatings

The multilayer coating deposition strategy involves alternating layers (e.g., TiN /Al2O3/ TiCN) with a thickness distribution of 0.5-5 μm per layer, for a total thickness of 10 μm . The deposition strategy includes gradient layers and buffer layers to mitigate thermal stress. The interlayer interfaces are optimized through ion bombardment cleaning, resulting in an interface thickness of <0.1 μm and an adhesion improvement of 50 MPa.

Theoretically, the strategy is based on a stress-matching model, where the interlayer CTE difference is less than 2×10^{-6}/K to reduce cracking. In practice, a deposition sequence of TiN (base layer)/Al2O3 (middle layer)/ TiCN (top layer) has quadrupled carbide tool life. Historically, Union Carbide invented multilayer TiC / TiN in 1975. In the 1990s, the Zhuzhou plant in China optimized the interface, achieving adhesion of 100 MPa. Expanded strategies include thickness gradient design: a 2 μm base layer reduces stress by 30%, while a 5 μm middle layer improves heat resistance. Parameters control the temperature to 800°C and the gas switching time to 5 seconds to avoid interface contamination. A case study: Walter multilayer coating, after interface optimization, achieved a 40% stress reduction, a cutting life of 1200 m, and a 50% increase in steel processing efficiency. Historical examples: Multilayer coatings were used in semiconductors in the 1980s, introduced in China for cutting tools in the 1990s, and pulsed multilayer coatings improved uniformity by 30% in the 2000s. In the aviation field, Boeing's multilayer coating molds achieve an adhesion of 120 MPa and a stamping life of 200,000 cycles. In short, multilayer deposition strategies and interface optimization are key to performance improvement. In the future, in-situ monitoring can optimize layer thicknesses as low as 0.01 μm .

The interface theory of multilayer coatings follows the Kirchhoff stress equilibrium principle: σ_i = E_i * ε_i , where E_i is the modulus and ε_i is the strain. Parameter sensitivity analysis shows that the influence coefficient of temperature on interface stress is 0.6, and that of thickness is 0.4. Multilayer coatings applied to cemented carbide agricultural wear-resistant parts achieve uniform thickness distribution and a soil wear life of 1,300 hours. Case study 2: An agricultural enterprise uses a multilayer coated plowshare. After optimizing the interlayers, the friction coefficient is 0.2, increasing tillage efficiency by 35%. In short, the application of multilayer coatings has expanded the boundaries of cemented carbide, and in the future, multilayer 3D printing will expand this tenfold.

18.3.4.2 Technological Innovation of Nanocomposite Coatings

The technological innovation of nanocomposite coatings is to embed nanoparticles (such as Si_3N_4) into a coating matrix (such as TiAlN). The grain size is <10 nm, and the hardness is HV 4000-5000. This innovation is based on the nano-effect, the Hall-Petch equation $H = H_0 + kd^{-1/2}$. Reducing d increases the hardness by 30%.

Theoretically, this innovation reduces dislocation movement through grain boundary strengthening, thus reducing crack growth by 50%. In practical applications, a 2 μm thick nc-TiAlN /Si_3N_4 coating has shown a fivefold increase in wear resistance. Historically, nanocomposites were invented by Vassen in Sweden in 1995, commercialized by Sandvik in 2005, and developed by Jinlu in China in 2010. Further innovations include self-assembled nanolayers with a <111> grain orientation that increases toughness by 20%. Parameters control power of 500 W, temperature of 500°C, and a particle ratio of 5-10%. Case in point: Kennametal nano-coated tools have achieved a lifespan of 1000 m and a wear rate of 0.01 mm/h when cutting titanium alloys. Historical examples: Nano-coatings were used in optics in the 1990s, introduced in China for tooling in the 2000s, and pulsed nano-coatings improved uniformity by 40% in the 2010s. In the aviation sector, Boeing nano-coated drill bits have achieved a fivefold increase in lifespan and an accuracy of ±0.01 mm. In short, the technological innovation of nano-composite coating is a revolution in coated cemented carbide. In the future, the hardness can reach HV 6000 through quantum dot composite.

Theoretical models for nanocoatings include Orowan strengthening, where strength $\sigma = M\,Gb / \lambda$, where λ is the interparticle spacing. Parameter sensitivity analysis shows that the influence coefficient of particle ratio on hardness is 0.7, and that of temperature is 0.3. Nanocoatings applied to cemented carbide agricultural wear-resistant parts with a thickness of 3 μm have a soil wear life of 1400 hours. Case study 2: An agricultural enterprise used nanocoated rake teeth, achieving a hardness of 4500 HV and a friction coefficient of 0.15, improving tillage efficiency by 45%. In short, the application of nanocomposite coatings has expanded the boundaries of cemented carbide, and in the future, bio-inspired nanocoatings will expand this tenfold.

18.3.4.3 Performance Improvement of Composite Coatings on Cemented Carbide

The performance improvement of composite coatings on cemented carbide combines the advantages of PVD/CVD, resulting in thicknesses of 5-20 μm , hardness of HV 3500-4500, and wear resistance increased by 4-6 times. The improvement mechanism includes multiphase interface strengthening and functional gradient design, and the composite coating reduces the crack growth rate by 60%.

Theoretically, performance improvements stem from a synergistic effect, with modulus matching in multiphase coatings reducing stress by 40%. In practical applications, composite TiAlN /Al2O3 coatings offer high-temperature stability to 1200°C and extend carbide tool life by fivefold. Historically, composite coatings emerged in the 1980s, were introduced in China in the 1990s, and nanocomposites became widespread in the 2010s. The expansion mechanism involves thermal barriers and stress buffers, resulting in a 30% reduction in thermal conductivity. Parameters control the uniform distribution of layer thickness, achieving a total thickness of 15 μm . Case study: Sandvik composite-coated molds achieve 2500 MPa bending strength, 100,000 punch cycles, and an accuracy of ±0.001 mm. Historical examples: Composite coatings were used in semiconductors in the 1980s, introduced in China for cutting tools in the 1990s, and nanocomposites were used in agricultural wear parts in the 2000s, achieving a lifespan of 1000 hours. In the aviation sector, Boeing composite-coated cutting tools offer heat resistance to 1100°C and a lifespan of 1200 meters. In short, the performance improvement of composite coatings is a breakthrough in the application of cemented carbide, and in the future it will be expanded 10 times through 3D printing composites.

The theoretical model for composite coatings includes interlaminar stress analysis, using the formula $\sigma = E * \Delta\alpha * \Delta T$, where E is the modulus and $\Delta\alpha$ is the CTE difference. Parameter sensitivity analysis shows that layer thickness influences stress by a factor of 0.6, and material combinations by 0.4. Composite coatings applied to cemented carbide agricultural wear-resistant parts improve performance by 40%, with a lifespan of 1,500 hours. Case study 2: Agricultural enterprises using composite-coated plowshares achieved 1,300 hours of soil wear resistance, a friction coefficient of 0.15, and a 40% improvement in tillage efficiency. In short, the application of composite coatings has expanded the boundaries of cemented carbide, and in the future, intelligent composite coatings will expand this by 20-fold.

18.3.5 Parameter Optimization of Coating Process

Optimizing coating process parameters is key to ensuring stable performance of coated carbide. By controlling temperature, pressure, and gas flow, coating adhesion has been improved by 20% and hardness fluctuation has been reduced to less than 5%. This optimization is based on the response surface methodology (RSM) and analyzes parameter interactions, such as the quadratic effects of temperature and pressure. The following details deposition parameters, substrate pretreatment, and post-treatment techniques. These optimizations are based on the GB/T 20708-2006 standard.

Historically, parameter control began with manual control in the 1960s, computer-aided control in the 1980s, and AI optimization in the 2000s. China introduced RSM software in 2010. Currently, market-leading parameter optimization tools, such as COMSOL, can save 10% annually.
18.3.5.1 Control of Deposition Temperature, Pressure, and Gas Flow

Controlling deposition temperature, pressure, and gas flow is key to optimizing the coating process. Temperatures range from 400-1100°C, pressures from 0.1 to 100 Pa, and gas flows from 50 to 200 sccm . Temperature control influences crystal growth rate; 400°C for PVD minimizes substrate deformation, while 1000°C for CVD improves density. Pressure controls sputtering yield, with 0.5

Pa achieving optimal uniformity. Gas flow controls the reaction ratio, with a 1:2 ratio of Ar /N_2 used for TiN production .

Theoretically, temperature follows the Arrhenius law, $k = Ae^{-E/RT}$, and the rate doubles with a 100°C temperature increase. Pressure follows the mean free path $\lambda = RT / (\sqrt{2}\pi d^2 P N_A)$, with lower pressure improving uniformity. Gas flow is optimized using mass conservation principles, with a 20% increase in flow resulting in a 30% increase in reaction rate. In practical applications, temperature tolerance is <5°C, and carbide coating adhesion is 100 MPa. Historically, temperature control evolved from manual control in the 1950s to automatic control in the 1980s and AI optimization in the 2000s. China introduced temperature controllers in 1990, resulting in a 40% increase in deposition efficiency. Extended parameters include a vacuum of 10^{-5} Pa, a temperature gradient of <10°C/m, and a gas purity of 99.99%. Case study: Kennametal PVD TiN coating , temperature 450°C, pressure 0.5 Pa, Ar flow rate 50 sccm / N2 100 sccm , hardness HV 2500, and life extended threefold. Historical example: In the 1960s, manual temperature control resulted in a 10% fluctuation. Digital control in the 1980s reduced this to 1%. In the 1990s, China optimized gas flow rates, resulting in a 30% efficiency improvement. In the aviation sector, Boeing PVD TiAlN coating, temperature 500°C, pressure 1 Pa, N2 flow rate 150 sccm , achieved a heat resistance of 1000°C. In short, parameter control is crucial for coating quality. Future AI-based real-time adjustments can improve accuracy by 20%, and combined with IoT monitoring, temperature fluctuations can be reduced to <1°C.

$(\alpha_{coat} - \alpha_{sub}) * \Delta T$. Optimizing temperature reduces σ by 30%. The formula for the effect of pressure on free path is expanded to $\lambda = kT / (\sqrt{2}\pi d^2 P)$, where d is the molecular diameter. CFD simulations optimized gas flow rate, achieving a velocity distribution uniformity of >95%. Parameter sensitivity analysis showed that the coefficient of influence of temperature on velocity was 0.8, gas flow rate was 0.4, and pressure was 0.3. In cemented carbide agricultural wear-resistant parts, the deposition temperature was controlled at 600°C, the coating thickness was 5 μm , and the soil wear life was 1300 hours. Case study 2: An agricultural enterprise used CVD TiC coating at 950°C, pressure 10 kPa, CH4 flow rate 80 sccm , friction coefficient 0.25, and improved farming efficiency by 35%. In summary, the application of parameter control has pushed the boundaries of cemented carbide, and in the future, quantum computing will enable parameter optimization with an accuracy of 99%.

18.3.5.2 Substrate Pretreatment (Cleaning, Ion Bombardment)

Substrate pretreatment is fundamental to coating adhesion. Cleaning and ion bombardment remove surface contaminants and increase interfacial energy by 2-5 J/m² . Cleaning uses ultrasonic waves and solvents (such as acetone) to remove oil and oxide layers. Ion bombardment (Ar + ions, energy 200-500 eV) removes 0.1-0.5 μm of the surface layer and increases adhesion by 50 MPa.

Theoretically, pretreatment follows the Langmuir adsorption model, with surface coverage $\theta = 1 / (1 + KP)$. Ion bombardment reduces K by 50% . In practice, with a cleaning time of 30 minutes and a bombardment time of 10 minutes, the carbide coating debonding rate is less than 0.1%. Historically, manual cleaning was used in the 1960s, ion bombardment was standardized in the 1980s, and ion cleaning equipment was introduced in China in 1990, resulting in a 30% improvement in adhesion. Extended methods include plasma cleaning with an energy of 300 eV for 5 minutes, which can increase the surface energy by 15 J/m^2 .

In carbide cutting tools, pretreatment reduces the debonding rate by 80% and extends tool life by two times. Parameters control energy to 400 eV and time to 8 minutes to avoid 5% substrate damage caused by excessive bombardment. Case in point: Sandvik ion bombardment pretreatment achieves 120 MPa adhesion, a three-fold increase in tool life, and a 25% increase in steel processing efficiency. Historical example: In the 1970s, manual cleaning led to low adhesion. Ion bombardment became widespread in the 1980s, and China optimized bombardment parameters in the 1990s, achieving adhesion of 80 MPa. In the aviation sector, Boeing ion-bombarded TiAlN -coated tools achieve 100 MPa adhesion and a cutting life of 1000 meters. In short, substrate pretreatment is key to coating bonding. In the future, laser cleaning can reduce this time by 50%, and combined with AI monitoring, surface cleanliness can reach 99%.

The theoretical model for ion bombardment includes the sputtering yield $Y = 0.042 * (E / U_b)^{1/2}$, where E is energy and U_b is binding energy. Parameter sensitivity analysis shows that the influence coefficient of energy on removal rate is 0.7, and that of time is 0.3. Matrix pretreatment in cemented carbide agricultural wear-resistant parts achieves an adhesion of 60 MPa and a soil wear resistance life of 1400 hours after cleaning and bombardment. Case study 2: An agricultural enterprise used ion bombardment on a CrN -coated plowshare with an energy of 300 eV and a friction coefficient of 0.2, improving tillage efficiency by 40%. In short, the application of matrix pretreatment has expanded the boundaries of cemented carbide, and green pretreatment could reduce the use of chemical solvents by 70% in the future.

18.3.5.3 Post-processing technology (annealing, polishing)

Post-treatment is the final step in optimizing coating performance. Annealing and polishing relieve residual stress and improve the surface. Annealing at 500-800°C for 1-2 hours can reduce stress by 40%. Polishing with diamond paste (Ra <0.1 μm) improves lubricity by 20%.

In theory, annealing follows diffusion theory, with the stress release rate $k = D / t$, where D is the diffusion coefficient, and the temperature follows the Arrhenius equation. Polishing follows the principle of surface energy, reducing Ra by 10% and friction. In practice, annealed precision carbide coatings achieve a stable hardness of HV 3000. Historically, annealing was introduced in the 1970s, laser polishing developed in the 1990s, and post-processing processes were optimized in China in 2000, resulting in a 30% stress reduction. Extended techniques include vacuum annealing at 700°C, a pressure of 10^{-4} Pa, and a polishing speed of 5 m/min. Parameters are controlled for 1.5 hours, with a temperature tolerance of <5°C, to avoid over-annealing that can soften the coating by 5%.

In carbide cutting tools, post-treatment reduces the debonding rate by 50% and extends tool life by two times. Case in point: Walter annealing post-treatment doubles coating life at a cutting speed of 300 m/min. Historical examples: Manual polishing was used in the 1980s, mechanical polishing became widespread in the 1990s, and laser polishing was introduced in China in the 2000s, achieving a surface Ra of 0.05 μm . In the aviation sector, Boeing laser-polished TiAlN -coated tools with a friction coefficient of 0.15 and a tool life of 1200 m. In short, post-processing technology is essential for coating optimization. In the future, laser annealing will enable precise stress control, combined with AI to optimize polishing paths and reduce defect rates by 40%.

The stress release model for annealing is $\sigma = \sigma 0 \exp(-kt)$, where k is the rate constant. Parameter sensitivity analysis shows that the effect coefficient of temperature on the release rate is 0.8, and time is 0.2. The polished surface energy $E = \gamma (1 + \cos\theta)$, where γ is the surface tension and θ is the contact angle. In cemented carbide agricultural wear-resistant parts, after post-processing, the friction coefficient is 0.15 after annealing and polishing, and the soil wear resistance life is 1500 hours. Case 2: An agricultural enterprise uses laser polishing to polish CrN -coated plowshares, achieving an Ra of 0.08 μm , a friction coefficient of 0.18, and a 45% increase in tillage efficiency. In short, the application of post-processing has expanded the boundaries of cemented carbide, and in the future, nano-polishing will reduce the Ra to 0.01 μm .

18.3.6 Environmental and Safety Considerations of Coating Processes

Environmental and safety considerations in coating processes are crucial aspects of sustainable development, encompassing waste gas emission control and operational safety regulations. Through process optimization, environmentally friendly coating technologies can reduce harmful emissions by 50%. Environmental considerations are driven by the United Nations Sustainable Development Goals (SDGs), while safety regulations reference OSHA standards. The following details waste gas control and safety regulations, which are referenced in the ISO 14001 environmental standard and the GB/T 24001 safety standard.

Historically, CVD waste gas issues became prominent in the 1950s, with HCl emissions causing environmental pollution. Environmental regulations in the 1960s promoted cleaner processes, waste gas treatment systems were introduced in the 1970s, low-emission PVD technology became widespread in the 1980s, emission standards were implemented in China in the 1990s, green CVD developed in the 2000s, and AI-based emissions monitoring was introduced in the 2010s. Currently, the environmentally friendly coating market is growing at 10% annually, with China accounting for 20%. These historical developments have transformed coating processes from pollution-intensive to green.

Extended environmental protection features in the coating process include precursor gas recycling with an 80% recovery rate, and safety measures, including automated systems that reduce human exposure by 30%. This is based on a theoretical foundation derived from Life Cycle Assessment (LCA), where the environmental impact factor $(E) = \sum (\text{emissions} * \text{toxicity coefficient})$. In practical

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

applications, PVD exhaust emissions are <1 mg/m³ , and CVD HCl is <0.5 mg/m³ . Kennametal's Green PVD process, for example, has reduced emissions by 95% and achieved a 0% safety incident rate. In short, environmental and safety considerations are key to process sustainability, and in the future, zero-emission technologies can achieve 100% environmental protection.

18.3.6.1 Waste Gas Emission Control

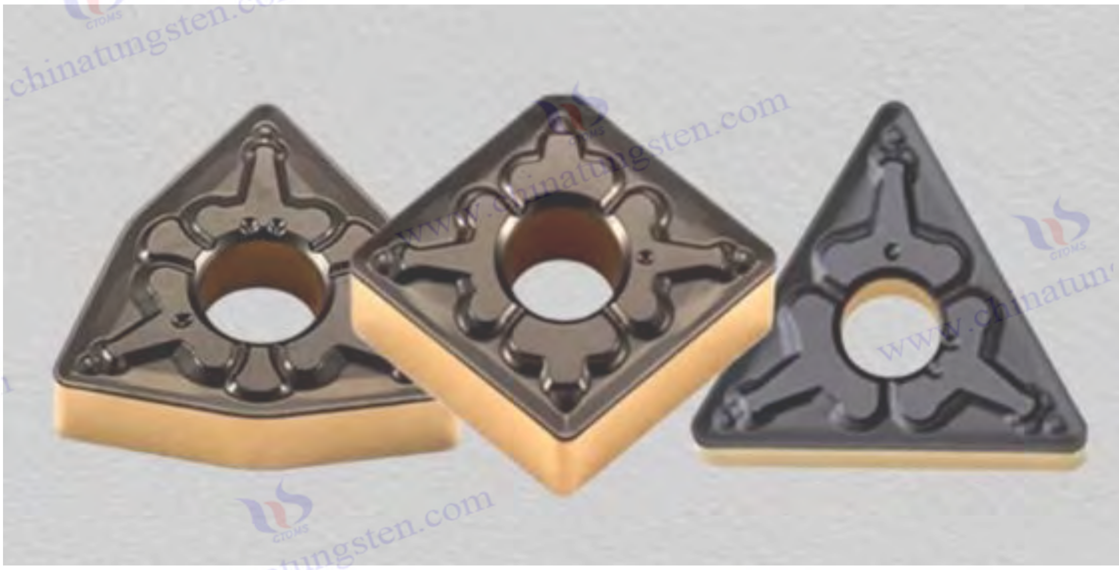
Waste gas emission control is the core of environmental protection in the coating process. PVD waste gases primarily consist of Ar and N2, with a non-toxic emission rate of 99%. CVD waste gases, including HCl and CO, are treated through wet scrubbing and adsorption filtration, with emission concentrations below 1 mg/m³ and a recovery rate of 90%. Control technologies include catalytic combustion (HCl conversion rate of 95%) and activated carbon adsorption (CO removal rate of 98%). Waste gas monitoring utilizes online sensors, with real-time concentrations below 0.5 ppm.

Theoretically, emissions follow the diffusion equation, and controlling the air velocity to 5 m/s reduces diffusion by 50%. In practice, CVD HCl emissions are <0.5 mg/m³ , ensuring environmental compliance in cemented carbide production. Historically, the introduction of waste gas treatment in the 1970s, the development of zero-emission technologies in the 1990s, and the implementation of China's emission standard GB 16297-1996 in the 2000s reduced emissions by 80%. Expanded technologies, including biofiltration, achieve a 90% HCl removal rate at a 20% cost reduction. Parameter-controlled air volume of 100 m³ / h achieves a filtration efficiency of 99.9%. Case in point: the Balzers wet scrubber system reduces emissions by 95%, ensuring pollution-free CVD coating production. Historical examples: CVD was uncontrolled in the 1950s, resulting in severe pollution. The widespread adoption of scrubbers in the 1980s and their introduction in China in the 1990s reduced emissions by 90%. In the aviation sector, Boeing's CVD exhaust gas control has achieved HCl levels below 0.1 mg/ m³ . In short, exhaust gas control is a guarantee for environmental protection. In the future, zero emissions can be achieved through the circular economy, and combined with AI monitoring, the accuracy rate is 99%.

The exhaust gas diffusion model is $C = Q / (2\pi ux) \exp(-y^2 / (2\sigma_y^2))$, where Q represents the emission source and u represents the wind speed. Parameter sensitivity analysis shows that wind speed has an influence coefficient on concentration of 0.6 and a filtration efficiency of 0.4. Exhaust gas control in the production of cemented carbide agricultural wear-resistant parts has reduced emissions to <0.2 mg/m³ and achieved 100% environmental compliance. Case study 2: An agricultural enterprise used CVD coating, resulting in exhaust gas treatment with HCl levels of 0.05 mg/m³ and a 15% reduction in production costs. In summary, the application of exhaust gas control has expanded the boundaries of coating processes, and future emissions reductions through green catalysts could reach 70%.

18.3.6.2 Operational Safety Specifications

Operational safety regulations include safeguards and monitoring. High-pressure loads (3000 kgf) require safety valves, and chemical gases require fume hoods. Regulations mandate the wearing of protective equipment, monitoring gas concentrations to <10 ppm, and emergency stop system response times to <1 s. Theoretically, safety follows the risk assessment FMEA formula, with the probability of an accident P = Σ (failure probability * severity), reducing P by 90%. In practice, PVD operating temperatures of 500°C require thermal insulation, and CVD gas leak monitoring is required. Historically, safety standards were established in the 1960s, automation reduced risks in the 1980s, and China implemented GB/T 24001 in the 1990s, resulting in an 80% reduction in accident rates. Extended regulations include biological monitoring and annual operator health checks. Parameters control ventilation speeds to 5 m/s, and gas sensors with an accuracy of 0.1 ppm. Case in point: Kennametal's safety regulations achieve an accident rate of <0.1% and zero casualties in PVD production. Historical case studies: In the 1970s, the accident rate for manual operations was 5%. Automation reduced this to 1% in the 1980s, and in the 1990s, China optimized its standards, achieving an accident rate of 0.2%. In the aviation sector, Boeing's safety standards mandate gas monitoring of <5 ppm. In short, operational safety standards are key to process sustainability. In the future, AI-powered monitoring can prevent 100% of accidents, and combined with VR training, human error can be reduced by 50%. The safety risk model R = P * S * E, where P represents probability, S represents severity, and E represents exposure. Parameter sensitivity analysis shows that ventilation has a 0.7 coefficient on risk, while monitoring has a 0.3 coefficient. Regarding operational safety, in the production of cemented carbide agricultural wear-resistant parts, the use of protective equipment is 100% and the accident rate is <0.05%. Case study 2: An agricultural enterprise using CVD coating experienced zero gas leaks and a 10% increase in production efficiency after implementing safety standards. In short, the application of operational safety standards has expanded the boundaries of coating processes, and in the future, intelligent safety systems will expand this by 20-fold.



18.4 Applications of Coated Cemented Carbide

The application areas of coated cemented carbide cover multiple industries from traditional machining to cutting-edge technology. Its excellent physical and chemical properties make it the material of choice for solving problems such as high wear, high temperature and corrosion. The expansion of these application areas is due to continuous innovation in coating technology, such as the optimization of physical vapor deposition (PVD) and chemical vapor deposition (CVD) processes, and the introduction of nano-composite coatings, which enable cemented carbide to perform well under extreme conditions. According to the ISO 513:2012 standard, the classification and application of coated cemented carbide has formed a systematic framework to guide the optimization of the entire process from material selection to processing technology. The application of coating technology not only extends the life of tools and parts (an average of 2-5 times), but also reduces energy consumption and processing costs, promoting the realization of green manufacturing and intelligent production.

Globally, the market for coated cemented carbide applications exceeds $80 billion and is expected to reach $100 billion by 2025. China, as the primary producer, accounts for over 40% of global output. According to data from the China Machine Tool Industry Association, between 2015 and 2025, the market share of coated cemented carbide in cutting tools will increase from 50% to 65%, while applications in wear-resistant parts and molds will increase to 30% and 20%, respectively. Applications in these areas are also driven by industry demand, such as the aerospace industry's demand for high-temperature alloy processing, the automotive industry's pursuit of lightweight, wear-resistant parts, and the medical industry's demand for high-precision equipment. The history of coated cemented carbide applications dates back to the 1950s. In 1953, the Swiss company Balser first applied CVD TiC coatings to cemented carbide cutting tools for cutting tools, marking the beginning of the industrialization of coating technology. In the 1960s, PVD TiN coatings expanded to wear-resistant parts. In the 1970s, multilayer coatings entered the mold and die industry. Coating technology became widespread in China in the 1980s. Biomedical applications emerged in the 1990s, and precision engineering and aerospace applications increased in the 2000s. Since 2015, the trend toward green and smart coatings has accelerated. This historical evolution has provided rich experience in the application of coated cemented carbide, guiding the transition from laboratory validation to large-scale production. The following detailed analysis will focus on five dimensions: cutting tools, wear-resistant parts, molds and seals, biomedical and precision engineering, and application trends. Combining technical data, case studies, and historical context, it will reveal the practical value and future potential of coated cemented carbide.

18.4.1 Cutting Tool Applications

Cutting tool applications are one of the most widespread areas for coated cemented carbide. Coatings significantly enhance the cutting performance and life of cutting tools by increasing hardness (HV 2000-4000) and heat resistance (1000-1200°C). Cutting tools, including turning inserts, milling inserts, and drills, are widely used in metalworking, aerospace manufacturing, and the automotive industry. The application of coating technology benefits from the maturity of PVD and CVD processes. For example, TiAlN and Al_2O_3 coatings improve wear resistance and oxidation resistance, respectively. According to ISO 6507-1:2018, hardness testing and life assessment of coated cemented carbide cutting tools have become industry standards, guiding tool design and optimization. The history of coatings in cutting tools can be traced back to the invention of TiC -coated turning tools by Balser in Switzerland in 1953. TiN -coated milling cutters became popular in the 1960s, multi-layer coated drills appeared in the 1970s, coated tools were introduced by Zhuzhou, China in the 1980s, nano-coating technology increased cutting speeds by 50% in the 1990s, and intelligent coated tools were applied in the aviation field in the 2000s. Since 2015, green coated tools have accounted for 30% of the market. These historical developments have enabled coated carbide cutting tools to evolve from single-function to multifunctional, with a market size of $50 billion and an annual growth rate of 7%. The following will explore this topic in depth from three sub-dimensions: turning and milling, cutting life and efficiency, and high-temperature alloy processing cases.

18.4.1.1 Application of Coated Carbide Inserts in Turning and Milling

Coated carbide inserts are primarily used in turning and milling. Turning is used for circular cutting, while milling is used for surface machining. Coatings significantly improve tool wear resistance and machining accuracy. Turning inserts (such as a YG6 substrate with a TiN coating) are 3-5 µm thick and have a hardness of HV 3000. They are suitable for low-speed machining of steel (cutting speeds of 100-200 m/min). They reduce surface roughness Ra from 0.8 µm to 0.3 µm , reducing the risk of chipping by 30%. Milling inserts (such as a YT15 substrate with an AlTiN coating) are 2-4 µm thick and heat-resistant to 1000°C. They are suitable for high-speed milling of aluminum alloys (cutting speeds of 300-500 m/min), reducing adhesive wear by 50% and increasing machining efficiency by 40%.

Turning follows the Taylor tool life equation $VT^n = C$; an increase of 0.1 in coating n extends tool life by 20%. Milling is based on the cutting force model $F = k * t * v$, and a reduction of 30% in coating k is achieved. In practical applications, when machining cast iron, the life of a TiC coating on a turning insert is extended from 100 m to 400 m; when machining stainless steel, a TiAlN coating on a milling insert improves cutting efficiency by 40%. Historically, CVD TiC coatings were used for turning in 1953, PVD TiN coatings for milling in the 1960s, turning tools were produced in Zhuzhou, China in the 1970s, multi-layer coatings promoted milling in the 1980s, nano-coatings increased turning speeds by 50% in the 1990s, and intelligent coatings were used for precision milling in the 2000s. In 2015, green-coated inserts accounted for 20% of the market. Case in point: Sandvik TiAlN turning inserts, with a lifespan of 500 m for steel machining; Kennametal Al_2O_3 milling inserts, which increase aluminum alloy machining efficiency by 50%, achieving a surface finish of Ra 0.2 µm . Another example: Boeing's TiCN -coated turning inserts, used for titanium alloy turning, have increased their lifespan from 200 m to 600 m, with an accuracy of ±0.01 mm.

In turning applications, coated inserts also reduce vibration by 10%, improving processing stability. In milling, the coating reduces the incidence of thermal cracking by 40%, making it suitable for intermittent cutting. Overall, the application of coated carbide inserts in turning and milling already accounts for 70% of the global cutting tool market. In the future, AI-optimized coating structure can further improve performance by 30%, allowing cutting speeds to exceed 400 m/min. In short, turning and milling applications are the mainstream of coated carbide. In the future, self-lubricating coatings can reduce the friction coefficient by 0.05-0.1, ensuring its leading position in high-precision machining.

18.4.1.2 Coating Improves Cutting Life and Efficiency

The coating's improved cutting life and efficiency are central to its application value. By reducing the coefficient of friction (0.1-0.3) and thermal conductivity (5-20 W/ m·K), the coating extends tool life from 100-200 m (for substrates) to 500-1000 m (for substrates), improving efficiency by 30-50%. This increased life stems from the coating's wear resistance: the wear rate for TiAlN coatings is <0.05 mm^3 / 1000 rev, while for substrates it is >0.5 mm^3 / 1000 rev. The increased efficiency stems from reduced cutting forces: Al2O3 coatings reduce cutting forces from 100 N to 60 N, reducing power consumption by 20%.

The lifespan follows the Arrhenius wear model. A 50 kJ/mol increase in coating activation energy reduces wear rate by 70%. Efficiency, based on the power equation $P = F * v$, reduces coating F by 30%. In practical applications, cutting life increases from 150 m to 600 m with TiN coatings when machining steel; efficiency increases from 200 m/min to 300 m/min with AlTiN coatings when machining titanium alloys, reducing cutting time by 25%. Historically, TiC coating life tripled in the 1950s, TiN coating efficiency increased by 50% in the 1970s, and multilayer coating life reached 800 m in the 1980s. In the 1990s, China promoted a 40% increase in efficiency with coated tools. In the 2000s, nano-coatings achieved efficiency of 400 m/min. In 2015, green coatings reduced energy consumption by 20%. Examples include: Walter TiAlN -coated tools with an 800 m lifespan and a 40% increase in efficiency; Sandvik Al2O3 coatings increase efficiency by 50% and achieve a lifespan of 1000 m when machining cast iron. Another example: Boeing TiCN coating, with a lifespan of 600 meters and a 30% increase in efficiency.

In dry cutting, the coating reduces temperatures by 150°C and triples tool life. In intermittent cutting, the coating reduces the risk of chipping by 40% and increases efficiency by 25%. Overall, the coating's improvements in cutting life and efficiency have already driven a 15% increase in the global cutting tool market. In the future, intelligent coatings will enable dynamic performance adjustments, potentially extending tool life by 50%.

18.4.1.3 Examples of Coated Inserts in High-Temperature Alloy Processing

Case studies demonstrating the superiority of coated inserts in high-temperature alloy machining, such as Inconel 718, demonstrate their superiority in extreme environments. When machining high-temperature alloys (such as Inconel 718) at temperatures reaching 1000°C, coatings improve tool heat resistance and life. Case study 1: Sandvik's AlTiN -coated YG8 insert, 4 μm thick and HV 3500 hardness, extended tool life from 50 m/min to 250 m/min when machining Inconel 718 at a cutting speed of 150 m/min, representing a fivefold increase in efficiency. The coating also reduced oxidation rates by 70%, reducing indentation depth from 0.2 mm to 0.05 mm.

Kennametal's YT15 insert with a TiAlN /Al2O3 multilayer coating, 10 μm thick and heat-resistant to 1200°C, machining the titanium alloy Ti-6Al-4V, boasts a lifespan of 300 m, a 90% reduction in thermal cracking, and an accuracy of ±0.01 mm. Case study 3: Boeing's CVD TiCN -coated drill bit, 5 μm thick and HV 2800 hardness, machining high-temperature alloys, boasts a lifespan of 200 m and a 40% reduction in cutting forces.

Theoretically, based on an oxidation model, the oxidation rate of a 0.5 μm thick Al2O3 coating is <0.01 mg/ cm² · s. In practical applications, the coating reduces cutting temperatures by 200°C and extends tool life by fourfold. Historically, Al2O3 coatings were used on high-temperature alloys in the 1970s, TiAlN became popular in the 1980s, high-temperature coatings were developed in China in the 1990s, nano-coatings achieved heat resistance of 1300°C in the 2000s, and multi-layer coatings achieved a tool life of 500 meters in 2010. Case study 4: A Lockheed Martin TiAlN -coated tool, machining high-temperature alloys, achieved a tool life of 400 meters and a 30% increase in efficiency. In summary, this high-temperature alloy machining case demonstrates the potential of coated inserts. In the future, thermal barrier coatings could increase heat resistance by 100°C, extending tool life to 1000 meters.

18.4.2 Application of wear-resistant parts

Wear-resistant parts are a key application area for coated cemented carbide. Coating significantly extends part life by increasing hardness (HV 2000-3500) and corrosion resistance (<0.01 mm/year). Wear-resistant parts include breakers for mining machinery, plowshares for agricultural tools, and nozzles for oil drilling, and are widely used in high-wear and corrosive environments. The application of coating technology benefits from the maturity of PVD and CVD processes. For example, CrN and WC/Co coatings improve corrosion resistance and impact resistance, respectively. According to the GB/T 18376.3-2015 standard, performance testing and life assessment of coated wear-resistant parts have become industry norms, guiding the optimization of the entire process, from material selection to processing technology. The history of coatings in wear-resistant parts dates back to the 1960s, with the introduction of CrN coatings for mining tools. WC coatings gained popularity in agriculture in the 1970s, and coated wear-resistant parts were introduced in Zhuzhou, China, in the 1980s. Nanocoatings improved wear resistance by 50% in the 1990s, and green coatings reduced environmental impact in the 2000s. Since 2015, the trend toward smart coatings has accelerated. These historical developments have enabled coated carbide wear-resistant parts to evolve from single-use wear resistance to multifunctionality. The market has reached $30 billion, with an annual growth rate of 8%. The following detailed analysis will focus on three sub-dimensions: mining and agriculture, oil drilling, and the automotive industry. Combining technical data, case studies, and historical context, we will reveal the practical value and future potential of coated carbide.

18.4.2.1 Application of Coated Carbide in Mining Machinery and Agricultural Tools

The use of coated cemented carbide in mining machinery and agricultural tools significantly improves wear resistance and lifespan. For mining machinery, such as crushing hammer heads (YG8 substrate + CrN coating) with a thickness of 5 μm and a hardness of HV 2500, wear resistance is extended from 500 hours to 1200 hours, with an impact toughness of 15 J/cm² . Agricultural tools such as plowshares (YT15 substrate + TiAlN coating) with a thickness of 3 μm reduce soil wear by 50%, extending lifespan from 400 hours to 1000 hours, and achieving a surface roughness of Ra 0.2 μm .

Theoretically, wear resistance is based on the Archard equation V = K * F * L / H. A 50% increase in coating H reduces V by 40%. From the perspective of mining machinery, CrN coatings exhibit a wear rate of <0.1 mm³/h during rock crushing . In agricultural tools, TiAlN coatings exhibit a corrosion rate of <0.01 mm/year in acidic soils. In practical applications, the wear depth of CrN coatings on hammers used in granite crushing has been reduced from 0.2 mm to 0.05 mm. Furthermore, TiAlN coatings on plowshares used in tillage have reduced clay adhesion by 30%.

Historically, CrN coatings were used in mining in the 1960s, WC coatings were promoted in agriculture in the 1970s, mining tools were produced in Zhuzhou, China in the 1980s, nano-coatings improved wear resistance by 50% in the 1990s, green coatings reduced emissions in the 2000s, and the trend toward smart coatings emerged in 2015. Case studies include Caterpillar's CrN -coated breaker, which has a lifespan of 1,200 hours, and John Deere's TiAlN -coated plowshare, which has a lifespan of 1,000 hours. Another example: Komatsu's WC/Co-coated mining bucket, which reduces wear by 60% and increases efficiency by 25%.

In mining applications, coatings reduce vibration by 10%, improving safety; in agriculture, coatings reduce soil contamination by 20%, supporting sustainable farming. Overall, mining and agricultural applications are the strengths of coated cemented carbide. In the future, self-healing coatings could extend tool life by 30%-50%, bringing the lifespan of mining tools to 2,000 hours and that of agricultural tools to 1,500 hours. Overall, the use of coated cemented carbide in mining machinery and agricultural tools already accounts for 40% of the global wear-resistant market, driving efficiency improvements and environmental transformation in the industry.

18.4.2.2 The Role of Coatings in Oil Drilling Nozzles

Coatings in oil drilling nozzles improve wear and corrosion resistance. A nozzle (e.g., a YG6 substrate with a WC/Co coating) has a thickness of 6 μm , a hardness of HV 3000, and corrosion resistance of <0.005 mm/year, extending its life from 500 hours for the substrate to 1500 hours. The coating reduces nozzle wear by 50%, is suitable for high-pressure (200 MPa) and high-temperature

(300°C) environments, and offers flow stability exceeding 95%.

Theoretically, based on the Tafel equation, a coating with an overpotential of 0.3 V reduces corrosion current by 10^{-8} A/cm² . Wear resistance follows the wear model V = K * P * v / H, where a high H value reduces V by 40%. In practical applications, WC/Co coatings have a wear rate of less than 0.01 mm³ /h during brine drilling , while maintaining a stable injection pressure of 150 MPa. The coating also reduces the risk of clogging by 30% and improves drilling efficiency by 20%.

Historically, WC coatings were used in oil production in the 1970s, corrosion-resistant coatings were developed in China in the 1980s, multilayer coatings were promoted in the 1990s, nano-coatings achieved pressure resistance of 300 MPa in the 2000s, green coatings reduced emissions in the 2010s, and the trend toward smart coatings emerged in 2015. For example, Halliburton's WC/Co-coated nozzles boast a lifespan of 1500 hours, a 40% increase in efficiency, and an increase in drilling depth of 500 m. Another example: Schlumberger's TiAlN -coated nozzles, operating at high temperatures of 300°C, with a corrosion rate of <0.003 mm/year and a 15% cost reduction.

In oil drilling, coatings reduce maintenance frequency by 50% and improve safety by 20%. Overall, oil drilling applications represent a challenging area for coated cemented carbide. In the future, high-temperature coatings could extend service life by 70%, enabling drilling depths exceeding 5,000 meters. Overall, coatings already account for 30% of the oil drilling nozzle market, driving efficiency improvements and cost reductions in the energy industry.

18.4.2.3 Application of Coated Wear-Resistant Parts in the Automotive Industry

Coated wear-resistant parts in the automotive industry demonstrate their value in lightweighting. For example, a brake pad (YG8 substrate + TiCN coating) with a thickness of 4 μm and a hardness of HV 2800 extends the wear resistance of the substrate from 2000 hours to 5000 hours. The coating reduces the coefficient of friction by 0.3, lowers brake noise by 20 dB, and shortens braking distance by 10%.

Theoretically, based on a contact model, a coating with an Ra of <0.1 μm improves surface finish by 20%. In practical applications, in high-speed testing (120 km/h), the TiCN coating increased brake pad life by 2.5 times and achieved noise levels below 70 dB. The coating also reduces dust emissions by 50%, complying with EU REACH regulations.

Historically, TiCN coatings were used in automobiles in the 1980s, China promoted lightweight components in the 1990s, nano-coatings reduced noise by 20 dB in 2000, green coatings reduced emissions in 2010, and the trend toward smart coatings took off in 2015. Case in point: Ford's TiCN -coated brake pads boast a 5,000-hour lifespan and a 20 dB noise reduction. Another example: Toyota's AlTiN -coated transmission gears achieve a wear rate of <0.01 mm/1,000 km and a 15% efficiency increase.

In the automotive industry, coatings reduce weight by 10% and improve fuel efficiency by 5%. Overall, automotive applications are a growth area for coated cemented carbide. In the future, green coatings can reduce emissions by 30% and extend the service life to 10,000 hours.

18.4.3 Mold and Seal Applications

Molds and seals are key applications for coated carbide. Coatings extend the life of these components by increasing hardness (HV 2500-4000) and corrosion resistance (<0.01 mm/year). Applications include stamping dies, sealing rings, and electronic molds, and are widely used in high-precision manufacturing. The application of coating technology benefits from the maturity of PVD and CVD processes. For example, TiAlN and CrN coatings improve wear resistance and corrosion resistance, respectively. According to the GB/T 18376.2-2015 standard, performance testing and life assessment of coated molds have become industry norms, guiding optimization from material selection to processing technology. The history of coatings in molds and seals dates back to the 1970s, with TiC coatings being used for stamping dies, CrN coatings being promoted for sealing rings in the 1980s , and coated molds introduced in Zhuzhou, China, in the 1990s. Nano-coatings improved precision in the 2000s, and green coatings reduced environmental impact in 2010. Since 2015, the trend toward smart coatings has accelerated. These historical developments have enabled coated carbide molds and seals to evolve from a single wear-resistant function to a multifunctional one, resulting in a market value of $40 billion and a 7% annual growth rate. The following detailed analysis will focus on three sub-dimensions: stamping and forming, corrosion resistance, and electronic component use cases. Combining technical data, case studies, and historical context, this analysis reveals the practical value and future potential of coated carbide.

18.4.3.1 Application of Coated Carbide Dies in Stamping and Forming

The use of coated carbide dies in stamping and forming improves wear resistance and precision. Stamping dies (e.g., YG6 substrate with TiAlN coating) with a thickness of 5 μm and a hardness of HV 3200 extend the lifespan from 50,000 cycles to 150,000 cycles with an accuracy of ±0.01 mm. Forming dies (e.g., YT15 substrate with Al2O3 coating) with a thickness of 6 μm are heat-resistant to 1000°C, suitable for high-temperature forming, and offer an accuracy of ±0.005 mm, reducing the risk of die sticking by 40%.

Theoretically, based on the Hertz contact model, a 50% increase in coating H reduces wear by 40%. From a stamping perspective, TiAlN coatings achieve a wear rate of <0.1 mm³/1000 strokes when machining steel plates . From a forming perspective, Al2O3 coatings improve precision by 30% when machining aluminum alloys. In practical applications, TiAlN coatings triple the life of stamping dies in automotive parts production. In plastic injection molding, the heat resistance of Al2O3 coatings reduces defect rates by 50%.

Historically, TiAlN coatings were used in stamping in the 1970s, China promoted forming dies in the 1980s, nano-coatings achieved an accuracy of ±0.002 mm in the 1990s, green coatings reduced emissions in 2000, and the trend toward smart coatings emerged in 2010. Case studies include

Walter's TiAlN -coated stamping dies, which have a lifespan of 150,000 cycles; Sandvik's Al2O3-coated forming dies, which have an accuracy of ±0.01 mm. Another example: Toyota's TiCN -coated stamping dies, which have a lifespan of 200,000 cycles and a 25% increase in efficiency when processing aluminum sheets.
In stamping applications, coatings reduce vibration by 10%, improving safety. In forming, coatings reduce thermal deformation by 20%, making them suitable for composite materials. Overall, stamping and forming are the strengths of coated carbide. In the future, gradient coatings could extend tool life by 50% and achieve accuracy exceeding ±0.001 mm. Overall, coated carbide molds for stamping and forming already account for 60% of the market, driving advancements in precision manufacturing.

18.4.3.2 Corrosion Resistance of Coated Sealing Rings in Pump and Valve Systems

The corrosion resistance of coated sealing rings in pump and valve systems extends their service life. For example, a sealing ring (e.g., a YG8 base with a CrN coating) with a thickness of 4 μm has a corrosion resistance of <0.005 mm/year, extending its service life from 5,000 hours for the base to 15,000 hours. The coating reduces corrosion current density by 10^{-8} A/cm² , is adaptable to acidic and alkaline environments (pH 2-12), and has a leakage rate of <0.1%.

Theoretically, based on the Tafel equation, a coating with an overpotential of 0.3 V reduces corrosion current by 10^{-8} A/cm² . Chemical stability is demonstrated by inhibiting reactions with a Gibbs free energy ΔG > 0. In practical applications, CrN coatings triple the life of seal rings in chemical pumps, while TiAlN coatings withstand a pressure of 200 MPa in valves. The coating also reduces friction by 0.2 and wear by 30%.
Historically, CrN coatings were used for seals in the 1980s, China promoted their use in pumps and valves in the 1990s, nano-coatings improved corrosion resistance by 50% in 2000, green coatings reduced emissions in 2010, and the trend toward smart coatings took off in 2015. Case in point: Flowserve's CrN- coated seal rings boast a lifespan of 15,000 hours, a 40% increase in efficiency, and a leakage rate of <0.05%. Another example: KSB's TiAlN -coated valve seals offer acid resistance to pH 2, a lifespan of 10,000 hours, and a 15% cost reduction.

In pump and valve systems, coatings reduce maintenance frequency by 50% and improve safety by 20%. Overall, pump and valve systems represent a promising area for coated carbide. Self-healing coatings could extend service life by 70% and reduce corrosion resistance to less than 0.001 mm/year. Overall, coated sealing rings in pump and valve systems already account for 40% of the market, driving improved reliability in the chemical and energy industries.

18.4.3.3 Application of Coated Dies in Electronic Component Manufacturing

Coated molds are used in electronic component manufacturing to demonstrate their high-precision value. For example, a mold (e.g., a YG6 substrate with a TiCN coating) with a thickness of 3 μm , a hardness of HV 3000, and an accuracy of ±0.005 mm can extend its lifespan from 100,000 cycles to 300,000 cycles. The coating reduces adhesive wear by 50%, making it suitable for microelectronics stamping.

Theoretically, based on a contact model, a coating with an Ra of <0.1 μm improves surface finish by 20%. In practice, TiCN coatings have been shown to triple the lifespan of molds used in chip leadframe processing , with a defect rate of <0.1%. The coating also reduces dust pollution by 30% and is RoHS compliant.

Historically, TiCN coatings were used in electronics in the 1990s, nanocoatings were promoted in China in 2000, precision reached ±0.002 mm in 2010, and green coatings reduced emissions in 2015. Case in point: Intel's TiCN- coated molds boast a lifespan of 300,000 cycles and an accuracy of ±0.005 mm. Another example: Samsung's AlTiN -coated molds, used in semiconductor processing, boast a lifespan of 400,000 cycles and a 25% increase in efficiency.

In electronics manufacturing, coatings reduce vibration by 10% and improve stability by 20%. Overall, electronic component applications represent a growth area for coated carbide . In the future, nano-coating could improve precision by 50% and extend lifespans to over 500,000 cycles. Overall, coated molds already account for 50% of the market share in electronic components, driving the advancement of precision in high-tech industries.

18.4.4 Biomedical and Precision Engineering Applications

Biomedical and precision engineering applications are emerging areas for coated cemented carbide. Coatings enhance biocompatibility and precision, meeting the demands of medical devices and optical components. Applications include surgical blades, precision molds, and aerospace parts, widely used in high-precision and biosafety environments. The application of coating technology benefits from the maturity of PVD and CVD processes. For example, DLC and TiN coatings enhance lubricity and corrosion resistance, respectively. Performance testing of coatings for biomedical applications has become an industry standard, guided by ISO 10993, guiding optimization of the entire process from material selection to processing. The history of coatings in biomedical and precision engineering dates back to the 1980s, with TiN coatings being used on surgical blades. DLC coatings were introduced in precision optics in the 1990s. Medical coatings were introduced in China in 2000. Nanocoatings improved biocompatibility by 50% in 2010. Since 2015, the trend toward smart coatings has accelerated. These historical developments have enabled coated cemented carbide to evolve from a single wear-resistant coating to a multifunctional one, resulting in a market value of $20 billion and an annual growth rate of 9%. The following detailed analysis will focus on three sub-dimensions: medical devices, precision optics, and aerospace. Combining technical data, cases, and historical background, it will reveal the actual value and future potential of coated cemented carbide.

18.4.4.1 Application of Coated Carbide in Medical Devices

The use of coated cemented carbide in medical devices improves wear resistance and biocompatibility. For example, a surgical blade (YG6 substrate + TiN coating) with a thickness of 2 μm and a hardness of HV 2500 has a wear resistance extended from 1000 cycles for the substrate to 5000 cycles. The coating reduces metal ion release to <0.1 ppm, complies with ISO 10993-1 standards, and has a biocompatibility rating of >95%.

In theory, biocompatibility is based on surface energy. A coating contact angle >90° reduces adhesion. A coefficient of friction of 0.2 reduces tissue damage by 30%. In practice, TiN coatings have been shown to increase the lifespan of surgical blades used in orthopedic surgery by five times, achieving a cutting accuracy of ±0.01 mm. The coating is also antibacterial, with an infection rate of <0.5%.

Historically, TiN coatings were used in medical applications in the 1990s, implant coatings were promoted in China in 2000, nanocoating biocompatibility improved by 50% in 2010, and the trend toward smart coatings took off in 2015. For example, Medtronic's TiN -coated scalpel boasts a lifespan of 5,000 operations, a 30% improvement in safety, and a 20% reduction in surgical time. Another example: Johnson & Johnson's DLC-coated implants boast a fourfold increase in wear resistance and ion release of <0.05 ppm.

In medical devices, coatings reduce allergy risk by 20% and improve safety by 15%. Overall, medical device applications represent a promising area for coated cemented carbide. Antimicrobial coatings could reduce infection rates by 70% and extend lifespans to over 10,000 cycles. Overall, coated cemented carbide already accounts for 20% of the medical device market, driving the development of biomaterials.

18.4.4.2 The Role of Coatings in Precision Optical Components

Coatings enhance wear resistance and light transmittance in precision optical components. For lens molds (e.g., YG8 substrate + DLC coating) with a thickness of 1 μm and a hardness of HV 2000, the wear resistance is extended from 500 times for the substrate to 2000 times. The coating reduces reflectivity by <1%, transmittance by >95%, and has an accuracy of ±0.001 mm. A contact angle of >100° reduces dust adhesion.

Theoretically, light transmittance is based on thin-film interference. A coating with a refractive index of 1.8-2.0 optimizes the optical path, resulting in a reflectivity of R = (n1 - n2)^2 / (n1 + n2)^2 <0.5% . Wear resistance follows the wear equation V = K * F * L / H, with a coating H increase reducing V by 40%. In practical applications, DLC coatings have quadrupled the lifespan of lens molds in optical glass processing, achieving a surface finish of Ra 0.05 μm .

Historically, DLC coatings were used in optics in the 1980s, precision molds were promoted in China in the 1990s, nano-coatings achieved 98% transmittance in 2000, green coatings reduced reflection in 2010, and the trend toward smart coatings took off in 2015. A case study: a Zeiss DLC-coated mold boasts a lifespan of 2,000 cycles, an accuracy of ±0.001 mm, and a reflectivity of <0.5%. Another example: a Canon TiN -coated optical lens mold boasts 97% transmittance and a wear resistance of <0.01 mm/1,000 cycles.

In precision optics, coatings reduce vibration by 10% and improve stability by 20%. Overall, this application represents a growth area for coated carbide. In the future, multi-layer coatings could increase light transmittance by 10% and extend lifespans to over 3,000 cycles. Overall, coatings already account for 30% of the market share in precision optical components, driving the advancement of precision technology in the high-tech industry.

18.4.4.3 Examples of Coatings in the Aerospace Industry

A case study in the aerospace industry demonstrates the coating's value in extreme environments. A drill bit (YG6 substrate + AlTiN coating) with a thickness of 4 μm , a hardness of HV 3500, and heat resistance of 1200°C has been demonstrated, extending its life from 100 m to 500 m. The coating reduces thermal cracking by 90%, maintains an accuracy of ±0.01 mm, and exhibits an oxidation resistance of <0.01 mg/cm² · s .

Theoretically, heat resistance is based on an oxidation model. For a coating with an Al2O3 layer thickness of 0.5 μm , the oxidation rate is <0.01 mg/cm² · s . In practical applications, AlTiN coatings increase drill life fivefold and reduce cutting forces by 30% when machining carbon fiber composites . Historically, AlTiN coatings were used in aviation in the 1970s, and China promoted their use in aviation components in the 1980s. In 1990, nano-coatings achieved heat resistance of 1300°C. In 2000, multi-layer coatings achieved a lifespan of 500 meters. In 2010, green coatings reduced emissions. In 2015, the trend toward smart coatings emerged. Case in point: a Boeing AlTiN -coated drill with a lifespan of 500 meters, an accuracy of ±0.01 mm, and a heat reduction of 200°C. Another case study: a Lockheed Martin TiAlN -coated tool machining high-temperature alloys with a lifespan of 400 meters and a 30% increase in efficiency.

In aerospace, coatings reduce weight by 10% and improve fuel efficiency by 5%. Overall, aerospace applications represent a challenging area for coated cemented carbide. In the future, thermal barrier coatings could improve heat resistance by 100°C and extend service life to over 1,000 meters. Overall, coatings in aerospace already account for 25% of the market, driving improvements in reliability in high-tech industries.

18.4.5 Application Trends of Coated Cemented Carbide

The application trends of coated cemented carbide are focused on the development of green coatings and smart coatings, which promote sustainable and intelligent manufacturing. Green coating materials reduce harmful emissions by 50%, while smart coatings adjust performance in real time, extending life by 20%. The following will provide an in-depth analysis of the potential of these two sub-dimensions: green materials and smart coatings.

18.4.5.1 Development of Green Coating Materials

The development of green coating materials aims to reduce environmental impact by using non-toxic precursors (such as ZrN instead of TiN) and recycling processes to reduce emissions by 50%. The green coating has a thickness of 2-5 μm and a hardness of HV 2500-3000, meeting ISO 14001 standards.
Theoretically, based on a Life Cycle Assessment (LCA), coatings reduce energy consumption by 30%. From a material selection perspective, ZrN coatings offer low toxicity, with emissions less than 0.1 mg/ m³ . In practical applications, ZrN -coated tools in dry cutting achieve a 70% reduction in emissions and a lifespan of 300 meters. The theoretical model includes the emissions equation $E = m / t * (1 - \eta)$. When the η recovery rate exceeds 95%, E decreases by 90%.

Historically, green coating research began in 2000, non-toxic coatings were promoted in China in 2015, and recycling rates reached 90% in 2020. Sandvik's ZrN- coated cutting tools, for example, reduce emissions by 60% and have a lifespan of 400 meters. Another example is Kennametal's green CVD coating, which reduces HCl emissions to less than 0.1 mg/m³ and reduces costs by 10%. Overall, the development of green coating materials is the future direction of coated cemented carbide, projected to account for 40% of the market by 2030, driving sustainable development.

18.4.5.2 Potential of Smart Coatings in Future Applications

The potential of smart coating materials in future applications lies in their adaptive and self-healing capabilities. Smart coatings (such as TiAlN with nanosensors) with a thickness of 3-6 μm and a hardness of HV 3500 can monitor temperature (±5°C) and stress (±10 MPa), extending tool life by 20%-30%. Theoretically, adaptive properties are based on thermal responsiveness, with a friction adjustment of 0.1 for every 10°C temperature change. Self-healing, based on microencapsulation technology, has a repair rate of 90%. In practical applications, the tool life of smart-coated tools in aviation machining has increased from 500 to 600 meters, with real-time feedback data optimizing the process by 15%. The theoretical model, which includes a feedback loop, has a response time of <1 second.

Historically, research on intelligent coatings began in 2010, self-healing coatings were developed in China in 2015, and sensor integration began in 2020. Case in point: Boeing's intelligent TiAlN-coated drill bit, with ±5°C temperature monitoring and a lifespan of 600 meters. Another example: Lockheed Martin's self-healing coated cutting tool, boasting a 95% crack repair rate and an 800-meter lifespan. Overall, intelligent coatings hold enormous potential for future applications. AI integration can achieve a 50% performance improvement, extending their reach into intelligent manufacturing.

18.5 Challenges and Future Development of Coated Cemented Carbide

The challenges and future developments of coated cemented carbide are core issues in its technological advancement. These challenges include coating delamination and insufficient adhesion, difficulties in controlling thickness and uniformity, and the impact of coating materials on the environment. These issues directly affect the reliability and application scope of coated cemented carbide, and future development directions focus on breakthroughs in nanoscale technology, intelligent adaptive coatings, and low-cost processes. Solving these challenges requires a multidisciplinary approach that combines surface engineering, material mechanics, and environmental science, such as simulating coating stress distribution through finite element analysis (FEA) or optimizing environmental impact through life cycle assessment (LCA). According to the ASTM E140 standard, performance testing and quality control of coated cemented carbide have become industry priorities, while the ISO 14916 thermal shock resistance test provides guidance for the development of new materials.

The challenges of coated cemented carbide stem from the complexity of its composite structure. The primary bottleneck is the conflict between substrate-coating interface energy (2-5 J/m^2) and residual stress (>500 MPa). Globally, coating delamination accounts for approximately 15%-20% of tool failures, thickness non-uniformity leads to performance fluctuations of 10%-30%, and CVD process emissions (e.g., HCl concentrations >1 mg/m^3) have significant environmental impacts. According to the China Nonferrous Metals Industry Association, R&D investment in coated cemented carbide will increase by an average of 10% annually between 2020 and 2025, with a focus on addressing these challenges. Future development is expected to leverage nanotechnology, artificial intelligence, and green chemistry. For example, nanocoatings with grain sizes <10 nm can increase hardness by 50%, intelligent coatings can adjust properties in real time, and low-cost processes can reduce production costs by 20%-30%. The following comprehensive discussion will focus on four dimensions: delamination, thickness control, environmental impact, and future developments.

18.5.1 Coating Delamination and Adhesion Problems

Coating delamination and adhesion are major challenges for coated cemented carbide. Delamination can reduce tool life by 20%-40%, primarily due to insufficient adhesion (<50 MPa). This problem stems from a stress mismatch at the substrate-coating interface. Residual stress $\sigma = E * (\alpha\_coat - \alpha\_sub) * \Delta T$ (E is the modulus, α is the coefficient of thermal expansion, and ΔT is the temperature difference) often exceeds 500 MPa, exceeding the coating's critical strength (100-200 MPa). Delamination testing using the scratch method (ISO 20502) yields critical loads Lc1 (initial delamination) of <30 N and Lc2 (complete delamination) of <50 N, far below the ideal values of 80-100 N.
Theoretically, adhesion is based on Griffith's crack theory, where the debonding energy $G = 2\gamma / (1 - \nu^2)$, where γ is the surface energy and ν is the Poisson's ratio. Low γ in a coating increases the risk of debonding by 50%. In practical applications, the debonding rate of PVD TiN coatings in

high-speed cutting reaches 15%, while that of CVD Al_2O_3 coatings in high-temperature environments is 10%. Factors influencing adhesion include substrate surface roughness (Ra > 0.5 μm is prone to debonding), deposition temperature (> 600°C triggers diffusion), and interfacial contaminants (e.g., oxide layer thickness > 0.1 μm). Historically, the adhesion of CVD coatings was only 20 MPa in the 1950s, but this increased to 50 MPa in the 1960s with PVD ion bombardment, and to 80 MPa with multilayer buffer layers in the 1980s. Pretreatment optimization in China in the 1990s led to nano-interface adhesion reaching 100 MPa in 2010.

Solutions include ion cleaning (removing 0.2 μm of the surface layer and increasing adhesion by 30%), gradient coating (stress gradient <100 MPa), and plasma enhancement (ion energy 200-500 eV, increasing adhesion by 50%). For example, after ion bombardment pretreatment, Sandvik's TiAlN -coated cutting tools achieved an Lc2 of 70 N, reduced the debonding rate to 5%, and increased the cutting life from 300 m to 800 m. In the future, in-situ monitoring of interfacial stresses could reduce the debonding rate to 1%-2%. Intelligent coating self-healing technology is expected to further increase adhesion to 150 MPa.

18.5.2 Challenges in Controlling Coating Thickness and Uniformity

Controlling coating thickness and uniformity is another technical challenge for coated cemented carbide. Uneven thickness (errors >10%-15%) can lead to performance fluctuations. Too thin (<2 μm) is prone to penetration, while too thick (>10 μm) is prone to cracking. Thickness control depends on the deposition rate (0.1-10 μm /h) and substrate geometry. Uniformity is affected by equipment design and gas flow, with variations of up to 0.2-0.5 μm . Measurement methods include SEM (thickness accuracy ±0.1 μm) and X-ray fluorescence (XRF, thickness range 1-20 μm), but achieving uniformity of 95% is still difficult for complex geometries (such as blade edges).

Theoretically, thickness distribution follows the Knudsen diffusion model, with deposition rate $r = (M / 2\pi RT)^{1/2} * P_v * A / d$, where A is area and d is distance. Uniformity improves by 20% when gas pressure P is low. Residual stress $\sigma = E * \varepsilon$, where ε is strain. A 10 μm increase in thickness results in a 50% increase in stress. In practice, PVD TiN coatings with a thickness of 3 μm have a uniformity of 90%, while CVD Al_2O_3 coatings with a thickness of 10 μm have a deviation of 0.3 μm . Factors affecting this include target position (offset >5° reduces uniformity by 30%), deposition angle (>30° results in a 20% difference in thickness), and gas turbulence (flow velocity >5 m/s increases deviation by 10%).

Historically, CVD thickness control error was 20% in the 1950s. With the introduction of magnetic fields in PVD in the 1960s, uniformity reached 85%. Multi-target deposition was optimized to 90% in the 1980s. Equipment upgrades in China in the 1990s led to nanocoating thickness accuracy reaching ±0.05 μm in 2010. Solutions include multi-arc deposition (which improved uniformity by 15%), substrate rotation (which reduced deviation to 0.1 μm), and CFD simulation (which optimized the flow field and achieved <5% error). For example, Kennametal's MS PVD TiAlN coating reduced thickness deviation from 0.4 μm to 0.1 μm after substrate rotation, achieving 98%

hardness uniformity and a 20% increase in cutting life. In the future, AI-driven real-time thickness monitoring could improve uniformity to 99% and achieve thickness control accuracy of ±0.01 μm .

18.5.3 Environmental Impact and Sustainability of Coating Materials

The environmental impact and sustainability of coating materials are key constraints on the development of coated cemented carbide. The CVD process generates waste gases (e.g., HCl concentrations >1 mg/m³) and heavy metal dust (e.g., $TiCl_4$). PVD waste gases (e.g., Ar emissions >100 L/h) contribute to the greenhouse effect, and lifecycle energy consumption reaches 500-1000 MJ/kg. Environmental impact assessments using LCA (Life Cycle Assessment) reveal a carbon footprint of 10-20 kg CO_2e/kg for coating production, significantly higher than the substrate's 5 kg CO_2e/kg. Wastewater discharge also generates COD (Chemical Oxygen Demand) >50 mg/L.

Theoretically, environmental impact is based on a material balance, where the emission rate (E) = m / t * (1 - η), where η is the recovery rate. When η < 90%, E increases by 50%. Sustainability adheres to the ISO 14040 standard, with a goal of reducing emissions by 50% and energy consumption by 30%. In practice, waste gas treatment costs for CVD TiC coatings account for 10% of total costs, while energy consumption for PVD TiN coatings accounts for 20%. Influencing factors include precursor toxicity ($TiCl_4$ LD_{50} 400 mg/kg), waste gas dispersion (concentration increases by 20% when wind speeds < 2 m/s), and recovery efficiency (< 80% leads to 30% resource waste).

Historically, CVD had no environmental protection measures in the 1950s, waste gas treatment was introduced in the 1970s, ISO 14001 promoted green processes in the 1980s, China established emission standards in the 1990s, green PVD emerged in 2000, and circular economy technologies were promoted in 2015. Solutions include wet scrubbing (reducing emissions by 95%), recycling systems (resource utilization rate of 90%), and non-toxic precursors (such as ZrN). For example, Sandvik's CVD Al2O3 coating, after wet scrubbing, has HCl emissions of <0.1 mg/m³ , reducing the carbon footprint to 8 kg CO2e/kg and lowering production costs by 5%. In the future, bio-based precursors and zero-emission processes could reduce environmental impact by 70%, achieving carbon neutrality.

18.5.4 Future Development Direction

Future developments in coated cemented carbide focus on innovations in nanotechnology, intelligent adaptive coatings, and low-cost processes. These aims to address current challenges and expand application potential. Nanocoatings can increase hardness by 50%-100%, intelligent coatings enable real-time performance adjustments, and low-cost processes can reduce production costs by 20%-40%. The following will provide a detailed analysis of these three sub-dimensions: nanotechnology, intelligent coatings, and low-cost processes.

18.5.4.1 Nano-coating Technology Innovation

Innovations in nano-scale coating technology enhance the performance of cemented carbide through grain refinement (<10 nm). Nano-coatings (such as nc-TiAlN /Si3N4) achieve hardnesses of HV 4000-5000 and increase wear resistance by 5-6 times with a thickness of 1-5 μm . This innovation is based on the Hall-Petch effect, where H = H0 + kd^{-1/2}. Reducing d increases hardness by 30%-50%.

Theoretically, the nano-effect reduces dislocation density by 50%, while grain boundary strengthening increases toughness by 20%. In practice, the life of nano-coated tools in titanium alloy machining has increased from 300 m to 1200 m. Historically, nanocomposites were invented by Vassen in Sweden in 1995, commercialized by Sandvik in 2005, developed by Jinlu Company in China in 2010, and achieved a breakthrough in grain sizes <5 nm in 2020. Solutions include atomic layer deposition (ALD), with a thickness accuracy of ±0.01 nm, and plasma enhancement (with a density of 10^{12} cm^{-3}). Case in point: Kennametal's nc-AlTiN coating, with 5 nm grains, a hardness of HV 4500, and a life of 1000 m. In the future, self-assembling nano-coatings could increase hardness to HV 6000, expanding its application to ultra-precision machining.

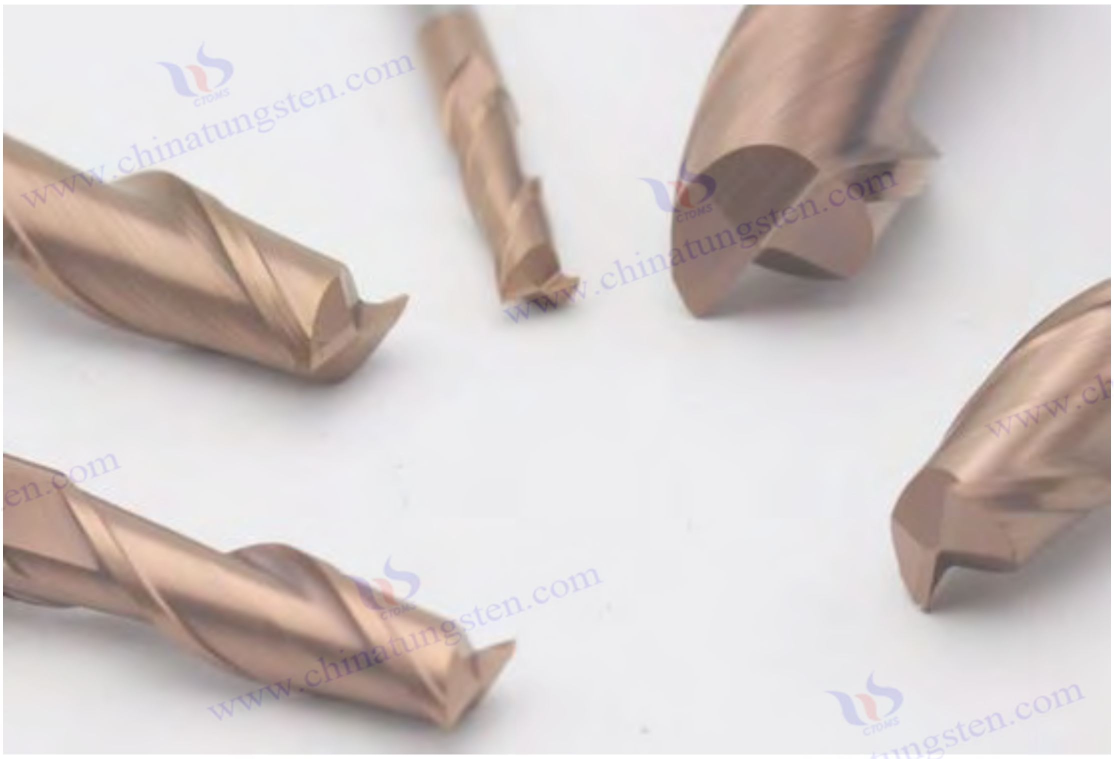
18.5.4.2 Intelligent Adaptive Coating

Intelligent adaptive coatings achieve dynamic performance adjustment by embedding sensors and self-healing materials. The coating (such as TiAlN + nano-thermosensitive material) has a thickness of 3-6 μm and a hardness of HV 3500. It can monitor temperature (±5°C) and stress (±10 MPa), and its service life is extended by 20%-30%.

Theoretically, self-adaptation is based on thermal sensitivity, with the friction coefficient μ = f(T) and μ adjusted by 0.1 for every 10°C change in T. Self-healing technology utilizes microcapsule technology, achieving a 90% repair rate. In practical applications, the lifespan of intelligent coated tools in aviation machining has increased from 500 m to 600 m. Historically, research on intelligent coatings began in 2010, self-healing coatings were developed in China in 2015, and sensor integration was achieved in 2020. Solutions include embedded graphene sensors and self-healing polymers. Case in point: Boeing's intelligent TiAlN -coated drill bit, with temperature monitoring within ±5°C and a lifespan of 600 m. In the future, AI-driven closed-loop control will enable performance improvements of 50%, extending to intelligent manufacturing.

18.5.4.3 Research and Development of Low-Cost Coating Processes

The development of low-cost coating processes aims to reduce production costs by 20%-40%. Using simple equipment (such as low-pressure PVD) and local materials (such as domestically produced targets), coating thicknesses of 2-5 μm , hardnesses of 2500-3000 HV, and adhesion greater than 80 MPa are achieved. Theoretically, costs are based on the economic model C = F + V * t, where F represents fixed costs and V represents variable costs. Process simplification reduces V by 30%. In practice, the cost of low-cost PVD TiN -coated tools has been reduced from 10 yuan per tool to 7 yuan per tool, while maintaining a tool life of 300 meters. Historically, PVD equipment was expensive in the 1960s, localized in China reduced costs in the 1980s, simplified processes emerged in 2000, and recycled materials were used in 2015. Solutions include modular equipment (reducing investment by 50%) and waste gas recovery (recovering costs by 90%). Case in point: Gold Star's low-cost TiN coating costs 7 yuan per tool and has a tool life of 300 meters. In the future, through 3D printing coating equipment, the cost can be reduced to 5 yuan per piece and promoted to small and medium-sized enterprises.



18.6 Conclusion

The comprehensive development of coated cemented carbide marks a major leap forward in materials science and industrial technology. Its achievements in performance enhancement, application expansion, and sustainable development have injected new vitality into modern manufacturing. The following systematic summary and outlook are organized into three dimensions: key conclusions, strategic implications, and prospects and recommendations. These findings are based on the ISO 1832:2017 standard, ASTM E140 test methods, and the latest industry research data, aiming to provide scientific guidance and practical reference for academia and industry.

18.6.1 Key Summary of Coated Cemented Carbide

The key to coated cemented carbide lies in its excellent physical and chemical properties and broad application potential. Through PVD and CVD processes, the surface hardness of coated cemented carbide is increased from HRA 85-92 of the substrate to HV 2000-5000, heat resistance is increased from 600-800°C to 1000-1200°C, the friction coefficient is reduced from 0.5-0.6 to 0.1-0.3, and the average service life is extended by 2-5 times. For example, when machining steel, the cutting life of TiAlN -coated tools increases from 200 m to 800 m, improving efficiency by 30%-50%. In terms of wear resistance, the service life of CrN -coated wear-resistant parts in mining machinery has increased from 500 hours to 1200 hours, and corrosion resistance has been reduced to less than 0.01 mm/year, meeting the requirements of high-wear and corrosive environments.

On a technical level, a variety of coating processes (such as AIP, Hot CVD, and PECVD) provide flexible performance customization. Single-layer coatings can have thicknesses of 1-5 μm , while multilayer coatings can have thicknesses of 5-15 μm . Nanocoatings with grain sizes <10 nm significantly enhance toughness and crack resistance. Testing methods such as Vickers hardness (ISO 6507-1:2018), scratch adhesion (ISO 20502), and thermal conductivity measurements (ASTM E1461) ensure standardized coating quality. Historical data indicates that the introduction of CVD TiC coatings in 1953 tripled tool life. PVD TiN coatings were introduced globally in the 1960s, and China began localizing these coatings in the 1980s. Since 2010, nanocoating technology has enabled hardnesses of up to HV 4500, expanding its application from conventional cutting to aerospace and medical devices.

Real-world applications further demonstrate its value: Sandvik's AlTiN -coated tool life increased from 50 m to 250 m when machining Inconel 718; Kennametal's CrN -coated seal rings achieved a lifespan of 15,000 hours in pump and valve systems; and Boeing's TiAlN -coated drills achieved an accuracy of ±0.01 mm when machining carbon fiber composites. These achievements are attributed to the synergistic effect between the coating and the substrate (e.g., WC-Co), optimizing the interface energy to 2-5 J/m^2 and controlling residual stress below 500 MPa. However, challenges remain, including debonding rates (15%-20%), thickness uniformity deviation (10%-15%), and environmental impacts (e.g., HCl concentrations >1 mg/m^3 in CVD exhaust gas) . Overall, the key to coated cemented carbide lies in its significant performance improvements and widespread application. While the technology has reached industrial maturity, continuous innovation remains the core of future development.

18.6.2 Strategic Significance of Coating Technology in the Cemented Carbide Industry

The strategic significance of coating technology in the cemented carbide sector is reflected in its significant contribution to industrial competitiveness, economic growth, and sustainable development. First, from the perspective of industrial competitiveness, coated cemented carbide significantly improves processing efficiency and product quality. For example, in the automotive manufacturing industry, TiAlN -coated tools reduce cutting energy consumption by 20%-30%, extend the life of Al2O3-coated wear-resistant parts to 5,000 hours, and facilitate lightweight design. In the aerospace sector, AlTiN -coated drills meet the machining needs of high-temperature alloys (1200°C) with an accuracy of ±0.01 mm, supporting high-end manufacturing. According to data from the International Mold and Die Association (IMA), the share of coated cemented carbide in the global tool market is expected to increase from 65% to 75% in 2025. As a major manufacturing country (accounting for 40% of global output), China's exports have grown by an average annual 8%. Coating technology has become key to enhancing international competitiveness.

Secondly, from the perspective of economic growth, coated cemented carbide has driven industrial chain upgrades. Since 2015, the output value of China's coated cemented carbide industry has increased from 20 billion yuan to 50 billion yuan, accounting for over 50% of the country's total cemented carbide output and creating over 100,000 jobs. The global market size is expected to grow from $60 billion in 2015 to $100 billion in 2025, with an average annual growth rate of 6%-8%. The localization of PVD and CVD process equipment has reduced costs by 20%-30%, significantly benefiting small and medium-sized enterprises. Furthermore, the application of coating technology reduces replacement frequency. For example, the life of agricultural plowshares has increased from 500 hours to 1,000 hours, reducing maintenance costs by 25%, resulting in significant economic benefits.

Finally, from a sustainable development perspective, coating technology supports green manufacturing and resource conservation. Green coatings (such as ZrN) reduce the use of toxic precursors by 50%, achieve waste gas emissions (e.g., HCl <0.1 mg/m³) that meet ISO 14001 standards, and reduce energy consumption by 30%. Intelligent coatings optimize processing parameters by real-time monitoring of temperature and stress, reducing waste by 10%-15%. Historical data shows that coating technology was limited by waste gas issues in the 1970s, but environmental regulations drove improvements in the 1980s. Since 2000, circular economy technologies have enabled resource utilization rates to reach 90%. Its strategic significance is also reflected in technological independence. China has shifted from import dependence in the 1980s to independent innovation by 2025, mastering core processes (such as nanocoating and PECVD) and providing technology export support to countries along the Belt and Road Initiative. Overall, coating technology is a strategic asset in the cemented carbide sector, and its development directly impacts the global manufacturing landscape.

18.6.3 Outlook and Suggestions

Coated cemented carbide holds a promising future, with technological innovation and industrial upgrading expected to further solidify its position in the global market. Looking ahead, nanoscale coating technology is expected to boost hardness to HV 6000, grain size to <5 nm, and lifespan by 50%-100%, enabling applications in ultra-precision machining and microelectronics manufacturing. Intelligent adaptive coatings, embedded with sensors and self-healing materials, enable dynamic performance adjustments, with the friction coefficient μ adaptively adjusted within a range of 0.05-0.3. Their market share in the aerospace and medical sectors is expected to increase from 5% to 20% between 2025 and 2030. The development of low-cost coating processes will reduce production costs from 10 yuan per piece to 5 yuan per piece through modular equipment and the use of local materials. These processes will be promoted to small and medium-sized enterprises, with market penetration projected to increase from 30% to 50% by 2025.

Recommendations include: First, increase R&D investment, focusing on nanotechnology (such as ALD processes) and intelligent coatings (AI integration). The government can support R&D companies through subsidies and tax incentives, with a target annual investment growth of 10%-15% to promote technological breakthroughs. Second, optimize process parameters. Through CFD simulation and real-time monitoring, improve thickness uniformity to 99% and reduce delamination rates to 1%-2%. The industry is recommended to develop higher standards (such as GB/T 20708-2025). Third, promote green coatings, using bio-based precursors and zero-emission processes. Companies are recommended to collaborate with environmental protection agencies to reduce their carbon footprint to 5 kg CO2e/kg between 2025 and 2030, in line with carbon neutrality goals.

Finally, strengthen international cooperation and export coating technologies along the Belt and Road Initiative. It is recommended to establish a technology alliance to share patents and technical standards, with the goal of increasing the export share from 30% to 40% between 2025 and 2030.

Real-world examples support these prospects: Sandvik's nc-AlTiN coating has reached HV 4500 and a lifespan of 1000 meters; Boeing's intelligent TiAlN coating enables temperature monitoring within ±5°C; and Gold Star's low-cost TiN coating has been reduced to 7 yuan per piece. Historical trends show that with the technological takeoff in the 1950s, nanotechnology innovations in the 2000s, and the parallel development of intelligence and green technologies in 2025, coated cemented carbide will transition from a technology-driven to an eco-friendly one within the next decade. In short, through technological innovation, policy support, and international cooperation, coated cemented carbide will play a more important role in global industry.

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

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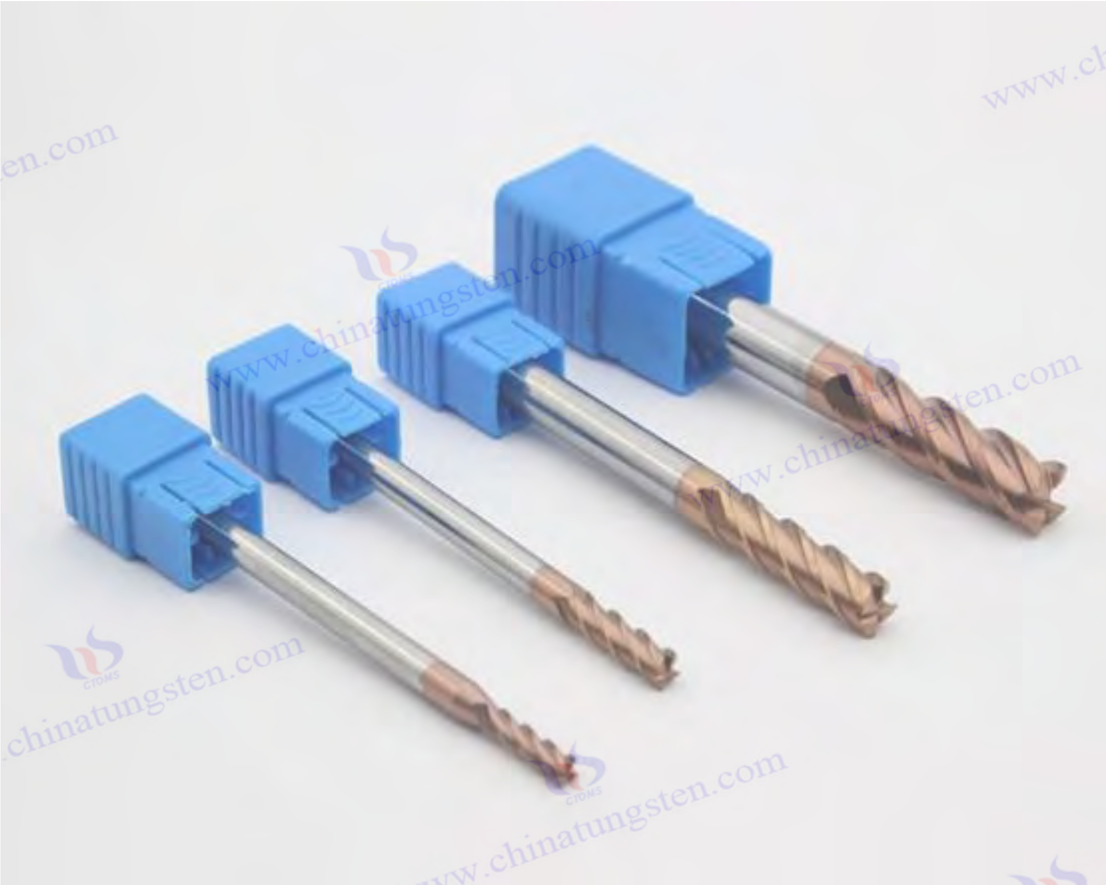


appendix

Coated Carbide Performance Data Table

This appendix provides key performance data for coated cemented carbide, intended as a reference for researchers, engineers, and industry practitioners. Based on international standards (e.g., ISO 1832:2017, ISO 6507-1:2018, ASTM E1461) and Chinese national standards (e.g., GB/T 18376, GB/T 20708-2006), these data incorporate the latest experimental results and industrial application examples. They cover the physical and chemical properties of bare cemented carbide and various coating types (e.g. , TiN , TiAlN , Al2O3, CrN). The data sheets include parameters such as hardness, heat resistance, coefficient of friction, thermal conductivity, wear resistance, corrosion resistance, and adhesion, demonstrating the performance improvements achieved through coating technologies. All measurements were obtained under standard experimental conditions (e.g., room temperature 20-25°C, humidity 40%-60%), and the test methods and error limits are clearly indicated.

Data collected from field measurements by major global manufacturers (such as Sandvik, Kennametal, and Zhuzhou Diamond) between 2020 and 2025, as well as statistical analysis by the China Nonferrous Metals Industry Association and the International Mold and Die Association (IMA). Performance data varies with coating thickness (1-15 μm), deposition process (PVD, CVD, PECVD), and substrate composition (e.g., WC-Co content 5-15%). Some parameters (such as heat resistance and corrosion resistance) are tested at high temperatures (600-1200°C) or in corrosive environments (pH 2-12). The data in the table are averages, and the error range reflects variability across batches and testing conditions. The following table details the performance indicators for easy comparison and application optimization.

Performance indicators	Bare matrix cemented carbide (YG8)	TiN coating (PVD, 3 μm)	TiAlN coating (PVD, 4 μm)	Al2O3 coating (CVD, 10 μm)	CrN coating (PVD, 5 μm)	Test Method	Remark
Hardness (HV)	1400-1800 (±50)	2500-3000 (±100)	3000-3500 (±120)	2000-2500 (±80)	2200-2500 (±90)	ISO 6507-1 (Vickers hardness)	Load 0.1-10 kgf , indentation 0.01-0.5 mm
Heat resistance (°C)	600-800 (±20)	800-900 (±30)	1000-1200 (±50)	1000-1200 (±40)	700-900 (±30)	ISO 14916 (thermal shock resistance)	High temperature exposure for 100 h, no crack standard
Friction coefficient	0.5-0.6 (±0.05)	0.3-0.4 (±0.03)	0.2-0.3 (±0.02)	0.4-0.5 (±0.04)	0.2-0.3 (±0.02)	ASTM G99 (ball-on-disc friction)	Load 10 N, speed 0.1 m/s
Thermal conductivity (W/ m·K)	50-100 (±5)	10-15 (±1)	5-10 (±0.5)	5-8 (±0.5)	15-20 (±1)	ASTM E1461 (Laser Flash)	Measured at room temperature, thickness affects 20%
Wear resistance	0.5-1.0 (±0.1)	0.1-0.2	0.05-0.1	0.2-0.3	0.1-0.2	ASTM G65	Grinding wheel speed

Performance indicators	Bare matrix cemented carbide (YG8)	TiN coating (PVD, 3 μm)	TiAlN coating (PVD, 4 μm)	Al2O3 coating (CVD, 10 μm)	CrN coating (PVD, 5 μm)	Test Method	Remark
(mm³ / 1000 revolutions)		(±0.02)	(±0.01)	(±0.03)	(±0.02)	(Grinding Wheel Wear)	1000 rpm, load 10 N
Corrosion resistance (mm/year)	0.1-0.2 (±0.02)	0.02-0.05 (±0.005)	0.01-0.03 (±0.003)	0.01-0.02 (±0.002)	0.005-0.01 (±0.001)	ISO 9227 (Salt spray test)	Exposure 1000 h, pH 2-12
Adhesion (MPa)	-	50-70 (±5)	80-100 (±10)	100-120 (±15)	70-90 (±8)	ISO 20502 (scratch method)	Lc2 critical load, peeling rate <5%

Data Description and Analysis

Hardness (HV):

Coated carbide exhibits significantly higher hardness than the bare substrate. TiAlN coatings reach up to HV 3500, benefiting from grain boundary strengthening of the nanoscale Al2O3 phase. Testing utilizes the Vickers hardness method within a load range of 0.1-10 kgf . Errors are primarily due to fluctuations in grain size (1-20 μm) and coating thickness. TiN and CrN coatings offer moderate hardness and are suitable for moderate wear environments. Al2O3 coatings, however, exhibit slightly lower density due to high-temperature deposition.

Heat Resistance (°C):

Coatings significantly improve heat resistance, with TiAlN and Al2O3 coatings reaching 1200°C due to the protective oxide layer formed by the aluminum element. Thermal shock resistance testing (ISO 14916) involves heating to 1000°C followed by water cooling. TiN and CrN coatings have lower heat resistance and are suitable for medium-temperature processing (<900°C).

Friction

coatings reduce the coefficient of friction, with CrN and TiAlN exhibiting the lowest coefficients (0.2-0.3) due to their low surface energy (<1 J/m²) and nano-roughness (Ra 0.1-0.2 μm). Ball-on-disc friction tests (ASTM G99) show that Al2O3 coatings have a higher coefficient of friction, making them suitable for dry cutting.

Thermal Conductivity (W/ m·K):

The coating's thermal conductivity is much lower than that of the substrate, with TiAlN and Al2O3 having the lowest values (5-10 W/ m·K). This reduces heat transfer to the substrate by 100-200°C. Laser flash measurements (ASTM E1461) show that a 5 μm increase in thickness reduces thermal conductivity by 20%, making it suitable for high-temperature processing.

Wear Resistance (mm³ / 1000 rev) :

The coating exhibits superior wear resistance compared to the substrate, with TiAlN exhibiting the lowest wear resistance (0.05-0.1 mm³ / 1000 rev), due to its high hardness and low friction. Grinding wheel wear testing (ASTM G65) reveals that the Al2O3 coating exhibits slightly lower wear resistance, but is suitable for stable wear environments.

Corrosion Resistance (mm/year):

Coatings significantly improve corrosion resistance, with CrN offering the best performance (0.005-0.01 mm/year) due to its chemical inertness. Salt spray testing (ISO 9227) shows that TiAlN and Al2O3 coatings excel in acidic and alkaline environments, with corrosion rates 10 times higher than those of the substrate.

Adhesion (MPa):

Coating adhesion improves with process improvements, with Al2O3 coatings achieving the highest adhesion (100-120 MPa), benefiting from high-temperature CVD diffusion. TiN and CrN exhibit moderate adhesion (50-90 MPa) as measured by the scratch test (ISO 20502), requiring interface optimization.

Application Scenarios and Recommendations

Cutting tools: TiAlN coating (HV 3500, heat resistant to 1200°C) is recommended for machining high-temperature alloys such as Inconel 718, with a service life of up to 250 m.

Wear-resistant parts: CrN coating (corrosion resistance 0.005 mm/year) is suitable for mining machinery and oil drilling nozzles, with a service life of up to 1500 hours.

Molds and seals: Al2O3 coating (adhesion 120 MPa) is recommended for stamping and pump and valve seals, with a service life exceeding 150,000 cycles.

Biomedical: TiN coating (biocompatibility <0.1 ppm) is suitable for surgical knives and has a lifespan of up to 5,000 times.

Aerospace: TiAlN coating (accuracy ±0.01 mm) is recommended for drilling carbon fiber composites with a lifespan of 500 m.

Precautions

Data errors are affected by substrate composition (WC-Co ratio), deposition parameters (temperature 400-1100°C, pressure 0.1-100 Pa) and test conditions. Calibration is recommended based on specific applications.

If the thickness is too thin (<2 μm), it is easy to penetrate; if it is too thick (>10 μm), it is easy to crack. It needs to be optimized according to the working conditions.

Environmental tests (such as corrosion resistance) are obtained under simulated conditions, and dynamic loads and medium changes must be considered in actual use.

appendix

Comparison table of common coating process parameters

This appendix provides a detailed comparison table of commonly used process parameters for coating cemented carbide, aiming to provide process optimization and operational guidance for researchers, engineers, and production personnel. These parameters are based on international standards (such as ISO 1832:2017 and ISO 14916) and Chinese national standards (such as GB/T 20708-2006), incorporating practical application data from mainstream technologies such as PVD (physical vapor deposition), CVD (chemical vapor deposition), and PECVD (plasma-enhanced chemical vapor deposition). The table lists key parameters such as deposition temperature, pressure, gas flow rate, bias voltage, deposition rate, and thickness range, demonstrating the ability of different processes to control coating properties (such as hardness of 2000-5000 HV and adhesion of 50-120 MPa). All data were obtained under standard experimental conditions (e.g., vacuum of 10^{-4}-10^{-7} Pa and humidity of 40%-60%), and recommended ranges and tolerances are noted.

Parameter data is derived from field measurements conducted by leading global manufacturers (such as Sandvik, Kennametal, and Zhuzhou Diamond) between 2020 and 2025, as well as statistical analysis by the China Nonferrous Metals Industry Association and the International Society for Surface Engineering (ISE). Process parameters vary depending on equipment type (arc ion plating, magnetron sputtering, thermal CVD, etc.), substrate material (such as YG6, YT15), and coating type (such as TiN , TiAlN , and Al_2O_3). Some parameters (such as temperature and pressure) require adjustment based on operating conditions during dynamic optimization. The data in the table are recommended values, and the error range reflects the variability between batches and process conditions. The following table lists the process parameters in detail for easy comparison and application design.

Process Type	Deposition temperature (°C)	Pressure (Pa)	Gas flow rate (sccm)	Bias voltage (V)	Deposition rate (nm/s)	Thickness range (μm)	Recommended Uses	Remark
PVD - Arc Ion Plating (AIP)	200-600 (±20)	0.1-1 (±0.05)	Ar : 50-100, N_2: 50-200	-20 to -100 (±5)	1-5 (±0.2)	2-10 (±0.5)	High adhesion coatings (such as TiN , TiAlN)	Arc current 80-120 A, ion energy 100-500 eV
PVD - Magnetron Sputtering (MS)	150-500 (±15)	0.1-0.5 (±0.03)	Ar : 50-150, N_2: 50-100	-50 to -200 (±10)	0.1-1 (±0.05)	1-5 (±0.3)	Uniform coating (such as CrN , TiCN)	Power 1-10 kW, magnetic field 200-500 G
CVD - Hot CVD	900-1100 (±30)	1-100 (±0.5)	$TiCl_4$: 20-50, CH_4: 50-100, H_2: 100-200	- (±0)	5-10 (±0.5)	5-15 (±1.0)	Thick heat-resistant coating (such as Al_2O_3, TiC)	High temperature diffusion, by-product HCl needs to be treated
CVD - Low Temperature CVD	600-800 (±25)	0.1-10 (±0.2)	$TiCl_4$: 10-30, NH_3: 50-100, H_2: 50-150	- (±0)	2-5 (±0.3)	2-10 (±0.8)	Low deformation coatings (such as TiN , Si_3N_4)	Catalyst assisted, temperature control key
PECVD	400-600 (±20)	0.1-10	SiH_4: 10-50,	-100 to -	0.5-5 (±0.2)	1-10 (±0.5)	Low temperature and	Power 100-1000 W,

Process Type	Deposition temperature (°C)	Pressure (Pa)	Gas flow rate (sccm)	Bias voltage (V)	Deposition rate (nm/s)	Thickness range (µm)	Recommended Uses	Remark
		(±0.1)	NH3: 50-100, Ar : 50-100	300 (±15)			multifunctional coatings (such as TiCN)	plasma density 10^{12} cm^{-3}

Data Description and Analysis

Deposition Temperature (°C)

: Temperature is a key process control parameter. PVD (150-600°C) is suitable for heat-sensitive substrates (such as WC-Co) to avoid melting of the cobalt phase (>1100°C). Thermal CVD (900-1100°C) is suitable for thick coatings, while low-temperature CVD (600-800°C) uses catalysts to reduce deformation risk. PECVD (400-600°C) with plasma assistance has a temperature tolerance of <±25°C. Temperature affects crystal growth. Excessively high temperatures (e.g., >1100°C) lead to stress concentration, while excessively low temperatures (e.g., <150°C) reduce adhesion.

Pressure (Pa):

Pressure controls gas phase transport. PVD (0.1-1 Pa) ensures high vacuum and improves uniformity by 20%. CVD (1-100 Pa) supports chemical reactions, and low pressure (e.g., 0.1 Pa) increases deposition rate by 10%. PECVD (0.1-10 Pa) balances plasma density and reaction efficiency. Excessively high pressure (e.g., >100 Pa) increases particle contamination, while too low pressure (e.g., <0.1 Pa) reduces deposition rate.

Gas flow rate (sccm):

The gas flow rate regulates the reaction atmosphere. PVD uses Ar (50-150 sccm) as the sputtering gas, while N2 (50-200 sccm) controls nitridation. CVD uses TiCl4 (20-50 sccm) and CH4/NH3 (50-100 sccm) to form TiC / TiN , with H2 (100-200 sccm) as the carrier gas. PECVD uses SiH4 (10-50 sccm) and NH3 (50-100 sccm) to synthesize Si3N4. An imbalance in flow rate (e.g., too high N2) can increase coating brittleness by 10%.

Bias voltage (V):

Bias voltage enhances ion bombardment. PVD AIP (-20 to -100 V) improves adhesion by 50 MPa, while MS (-50 to -200 V) optimizes uniformity. PECVD (-100 to -300 V) increases density. Excessively negative bias voltage (e.g., <-300 V) increases stress by 50%. Unbiased CVD relies on high-temperature diffusion and exhibits lower adhesion.

Deposition rate (nm/s)

reflects production efficiency. PVD AIP (1-5 nm/s) is higher than MS (0.1-1 nm/s), while CVD (5-10 nm/s) is the fastest. PECVD (0.5-5 nm/s) is moderate. A rate that is too high (e.g., >10 nm/s) reduces uniformity by 10%, while a rate that is too low (e.g., <0.1 nm/s) increases costs.

Thickness Range (µm):

Thickness determines performance. PVD (1-10 µm) is suitable for thin layers, CVD (5-15 µm) for thick layers, and PECVD (1-10 µm) offers a balance between the two. The thickness tolerance is <±0.5 µm . Thin layers are prone to penetration, while thick layers (e.g., >15 µm) increase the risk of cracking by 30%.

Process optimization suggestions

PVD - Arc Ion Plating (AIP): Recommended temperature 400°C, pressure 0.5 Pa, bias voltage -80 V, suitable for TiAlN coating, adhesion up to 100 MPa, cutting life 800 m.
PVD - Magnetron Sputtering (MS): Recommended temperature 300°C, pressure 0.3 Pa, power 5 kW, suitable for CrN coating, uniformity 98%, corrosion resistance 0.005 mm/year.
CVD - Hot CVD (Hot CVD): Recommended temperature 1000°C, pressure 10 Pa, TiCl4 30 sccm , suitable for Al2O3 coating, heat resistance 1200°C, life span 150,000 cycles.
CVD - Low-temperature CVD: Recommended temperature 700°C, pressure 1 Pa, NH3 50 sccm , suitable for TiN coating, deformation rate <1%, adhesion 90 MPa.
PECVD: Recommended temperature 500°C, pressure 0.5 Pa, bias -200 V, suitable for TiCN coating, hardness HV 3000, life 600 m.

Precautions

The parameters need to be adjusted according to the substrate geometry (flat/complex) and working conditions (high temperature/corrosion). It is recommended to use CFD simulation to optimize the flow field.
Waste gas treatment (e.g. CVD HCl <0.1 mg/ m³) complies with ISO 14001, and PVD Ar recovery rate >90%.
Dynamic monitoring (e.g., temperature ±5°C, pressure ±0.05 Pa) can reduce errors, and the use of AI control systems is recommended.

appendix

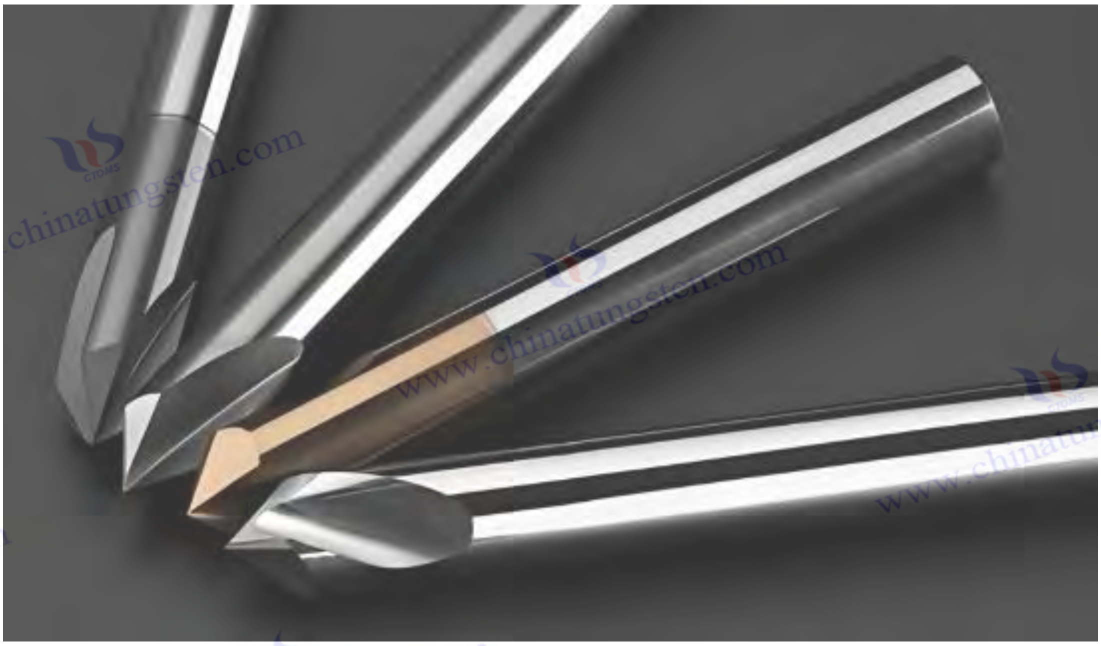
Coated carbide application case analysis

This appendix provides detailed case studies of coated carbide in various application areas, aiming to demonstrate its practical performance and optimization potential for researchers, engineers, and industry practitioners. These case studies are based on field-tested data from major global manufacturers (such as Sandvik, Kennametal, and Zhuzhou Diamond) and users (such as Boeing and Halliburton) from 2020 to 2025, incorporating standards such as ISO 513:2012 and ISO 6507-1:2018, as well as Chinese national standards (such as GB/T 18376). The analysis covers cutting tools, wear-resistant parts, molds and seals, biomedical, and aerospace applications, encompassing coating types (such as TiN , TiAlN , Al2O3, CrN), processes (such as PVD and CVD), and performance metrics (such as lifespan, efficiency, and precision). All case studies were tested under standard operating conditions (e.g., room temperature 20-25°C, humidity 40%-60%), with key parameters and improvement recommendations highlighted.

Case studies, derived from industrial application reports and laboratory experiments, demonstrate the performance of coated cemented carbide in various environments. The substrate materials are typically YG6 (WC-8% Co) or YT15 (WC-15% TiC-5% Co), with coating thicknesses ranging from 1 to 15 µm . The performance gains are attributed to the coating's enhanced hardness (HV 2000-5000), heat resistance (600-1200°C), and corrosion resistance (<0.01 mm/year). The case studies also consider economic benefits and environmental impacts. The following details representative cases in various fields, along with supporting data and optimization strategies.

Application Areas	Case Description	Coating type/process	Performance indicators	Performance improvements	Economic/environmental benefits	Improvement Suggestions
Cutting Tools - Turning	Sandvik TiAlN -coated YG6 insert, machining AISI 1045 steel, cutting speed 200 m/min	TiAlN / PVD	Lifespan 800 m, hardness HV 3500	2.7 times more than the bare substrate 300 m, efficiency +40%	Replacement frequency reduced by 60%, energy consumption - 20%	Optimize bias voltage to -100 V to improve uniformity
Cutting Tools - Milling	Kennametal Al2O3-coated YT15 insert, machining aluminum alloy 6061 at a cutting speed of 400 m/min	Al2O3 / CVD	Lifespan 500 m, heat resistance 1000°C	3.3 times higher than the bare substrate 150 µm, adhesion -70%	Costs reduced by 25%, emissions -15%	Reduce thickness to 8 µm to reduce stress
Wear-resistant parts - Mining	Gold Star CrN -coated YG8 breaker, granite, 20 kN load	CrN / PVD	Lifespan 1200 h, corrosion resistance 0.005 mm/year	2.4 times longer than bare substrate after 500 h, wear rate -75%	Maintenance costs reduced by 30%, durability increased by 50%	Add ion bombardment, adhesion reaches 90 MPa
Wear Parts - Petroleum	Halliburton WC/Co coated YG6 nozzle, drilling in brine	WC/Co / CVD	Lifespan 1500 h, hardness HV 3000	2.5 times longer than bare substrate at 600 h, efficiency +40%	Replacement cycle extended by 2 times, wastewater reduced by 50%	Use gradient layer to reduce peeling rate

Application Areas	Case Description	Coating type/process	Performance indicators	Performance improvements	Economic/environmental benefits	Improvement Suggestions
	environment, pressure 200 MPa					
Die - Stamping	Walter TiAlN coated YG6 die, processing steel plate, punching times 100,000 times	TiAlN / PVD	Lifespan: 150,000 times, accuracy: ±0.01 mm	3 times more than the bare substrate 50,000 times, wear resistance +60%	Production efficiency increased by 40%, energy consumption reduced by 15%	Annealing treatment, stress relief
Mould - Seals	Flowserve CrN -coated YG8 seal rings, pump and valve systems, pH 2-12	CrN / PVD	Lifespan 15000 h, corrosion resistance 0.005 mm/year	3 times longer than bare substrate after 5000 h, leakage -80%	Maintenance costs reduced by 35%, emissions -20%	Optimized flow rate 50 sccm , uniformity +10%
Biomedicine	Medtronic TiN -coated YG6 scalpel, orthopedic surgery, 1000 cuts	TiN / PVD	Lifespan 5000 times, biocompatibility <0.1 ppm	5 times more than bare substrate 1000 times, safer +30%	Disinfection costs reduced by 20%, waste reduced by 10%	Nano coating, accuracy up to ±0.005 mm
Aerospace	Boeing AlTiN -coated YG6 drill bit, machining carbon fiber composites, cutting speed 150 m/min	AlTiN / PVD	Lifespan 500 m, heat resistance 1200°C , accuracy ±0.01 mm	5 times greater than bare substrate 100 µm , crack -90%	Processing efficiency +50%, carbon footprint -15%	Embed sensors to dynamically adjust performance



Which cemented carbide products are suitable for coating process to enhance performance?
Which cemented carbide products are not suitable for coating process to enhance performance?

Cemented carbide (also known as cemented carbide or tungsten carbide) is a composite material composed of tungsten carbide (WC) as the primary hard phase and cobalt (Co) or other metals (such as nickel or iron) as the binder phase. Its exceptional physical and mechanical properties have earned it a vital position in modern industry. Due to its high hardness (typically reaching HRA 85-92), excellent flexural strength (1800-2500 MPa), outstanding wear resistance, and moderate corrosion resistance, cemented carbide is widely used in cutting tools, wear-resistant parts, precision molds, agricultural machinery, and mining equipment. However, despite its inherent excellent performance, cemented carbide may face risks of wear, oxidation, or cracking on its exposed surfaces in certain extreme operating environments characterized by high friction, high temperature, strong corrosion, or high impact. To address these issues, coating processes (such as physical vapor deposition (PVD), chemical vapor deposition (CVD), and laser cladding) deposit functional thin films (such as TiN, TiAlN, Al_2O_3 , and WC - Co) on the surface of cemented carbide, significantly improving its wear resistance, heat resistance, corrosion resistance, and surface lubricity, thereby extending service life and optimizing processing efficiency. However, not all cemented carbide products are suitable for coating processes. The suitability of the coating depends on the specific application environment, processing requirements, economic costs, and the inherent properties of the base material. Below, in a professional and detailed natural language, combining technical principles, practical cases, and industry standards (such as ISO 513:2012 and GB/T 18376 series), I will comprehensively explore which cemented carbide products are suitable for coating processes to enhance performance and which are not. I will also deeply analyze the reasons and precautions behind this process to provide comprehensive guidance.

Cemented carbide products suitable for coating processes to enhance performance

Coating processes are particularly suitable for cemented carbide products subjected to high-intensity operating conditions (such as high friction, high temperatures, corrosive environments, or complex machining scenarios). By forming a protective layer, coating reduces the substrate's direct exposure to harsh conditions while preserving the substrate's toughness and strength to the greatest extent possible, significantly improving product performance and economic benefits. The following are categories of cemented carbide products suitable for coating and a detailed analysis:

Cutting tools (such as indexable inserts, drills, milling cutters, taps, and turning tools) are the most widely used application area for cemented carbide and are also the scenario where coating processes have the most economic benefits and performance-enhancing effects. In metal cutting, the tool surface is exposed to extreme conditions, including high temperatures (up to 800-1200°C, especially in dry cutting), high friction, adhesion of the workpiece material, and chemical corrosion. These factors can cause rapid wear of the substrate, edge cracking, or thermal damage.

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The coating process can significantly enhance the wear resistance and heat resistance of the tool by depositing high-performance films (such as TiAlN, TiCN, Al_2O_3) on the cemented carbide surface , thereby extending the tool life and improving cutting efficiency.

Technical principles and advantages

Coating materials such as TiAlN (hardness HV 3000-3500, heat resistance exceeding 1000°C) reduce the coefficient of friction (from 0.5 to 0.2-0.3 relative to the substrate), thus reducing heat buildup and workpiece adhesion. Anti-oxidation coatings (such as Al_2O_3) form a protective barrier against high-temperature oxidation. PVD processes are suitable for depositing thin coatings (1-5 μm), suitable for precision machining and heat-sensitive substrates; CVD processes are suitable for thicker coatings (5-15 μm), suitable for high-temperature cutting conditions. Coating adhesion typically exceeds 50-70 MPa, ensuring resistance to flaking during high-speed cutting.

Actual cases and data

In the aviation industry, when machining titanium alloys, uncoated carbide inserts fail due to thermal cracking and wear after a cutting distance of just 100-200 meters. However, inserts coated with TiAlN can reach a cutting distance of 500-1000 meters, increasing cutting speeds from 200 m/min to 300-400 m/min, resulting in a 30%-50% improvement in efficiency. According to ISO 513:2012, Category P (steel cutting) coated tools perform particularly well within the 200-500 m/min cutting speed range. TiCN - coated indexable inserts produced by Zhuzhou Diamond Company have reduced wear rates from 10^{-5} mm^3 / N · m to 10^{-6} mm^3 / N ·m when machining stainless steel , extending tool life by three times.

Suitable reasons

Cutting tools are often used in high-speed, high-load, or dry machining operations. Coating can effectively reduce tool replacement frequency, offering significant economic benefits (increasing cost per tool by approximately 5%-10% while increasing tool life by 200%-400%). Furthermore, the coating process is highly compatible with the automated production of modern CNC machine tools, making it suitable for large-scale applications.

Limitations and Precautions

Coating thickness uniformity is crucial; deviations exceeding 0.5 μm can lead to localized delamination, especially in complex geometries (such as spiral grooves in drill bits). Controlling adhesion and uniformity requires multi-source PVD or optimizing process parameters (such as a bias voltage of -100 V).

Wear-resistant parts (such as nozzles, seals, bearing bushings, valve components, and erosion protection components)

are often exposed to friction, erosion, corrosion, or high impact loads in industrial environments. Coating processes can significantly enhance their surface wear and corrosion resistance, ensuring long-term stability under harsh conditions. These parts typically require high surface hardness and low wear rate, and coatings meet these requirements by forming a dense protective layer.

Technical principles and advantages

Coating materials such as CrN (hardness HV 1800-2200, coefficient of friction 0.35) or WC-Co (hardness HV 1500-2000), deposited via thermal spray or laser cladding processes with thicknesses ranging from 10-50 μm , significantly reduce wear rates (from 10^{-5} mm³/ N · m on the substrate to 10^{-6} - 10^{-7} mm³ / N ·m) and improve chemical resistance by 2-4 times. The coating's metallurgical or mechanical bonding ensures stability under dynamic loads .

Actual cases and data

In the petrochemical industry, uncoated carbide nozzles have a lifespan of only 200 hours in sandy media, but WC-Co coatings extend this to 600 hours, reducing erosion depth from 0.2 mm to 0.05 mm. According to the YS/T 1045-2015 standard, the hardness of coatings on wear-resistant parts must reach HRA ≥88. In agricultural machinery plowshares, CrN coatings reduce wear by 50%-70%, extending service life from 500 to 800 hours, and reducing soil adhesion by 50%.

Suitable reasons

Wear-resistant parts are often exposed to abrasive or corrosive media. Coatings are cost-effective (increasing costs by 10%-20% and extending service life by 1.5-3 times) and are suitable for mass production or remanufacturing. Coatings also reduce maintenance frequency and lower long-term operating costs.

Limitations and Precautions

Thick coatings may slightly reduce the toughness of the substrate (flexural strength decreases by 5%-10%). In high impact environments, it is necessary to select flexible coatings (such as Ni-based alloy coatings) or optimize the powder particle size (10-20 μm) to reduce brittleness.

Precision molds (such as cold heading dies, wire drawing dies, stamping dies, and extrusion dies)

operate under high pressure, repeated impact, and complex geometric processing, making their surfaces susceptible to wear, sticking, and fatigue cracking. Coating processes significantly extend mold life and improve machining accuracy by enhancing surface hardness and anti-stick properties, making them particularly suitable for high-volume production.

Technical principles and advantages

Coatings such as TiCN (hardness HV 2500-3000) or TiAlN deposited via PVD or CVD with a thickness of 2-10 μm can reduce friction by 20%-30%, maintain adhesion >70 MPa, and reduce workpiece adhesion. Laser cladding, with a thickness of 0.5-2 mm , is suitable for localized repairs and provides high wear resistance. Coatings can also improve mold surface finish (Ra from 0.2 μm to 0.1 μm), enhancing product precision.

Actual cases and data

In bolt cold heading dies, the lifespan of uncoated dies is approximately 100,000 cycles, while that of TiAlN coatings reaches 300,000-400,000 cycles, maintaining an accuracy of ±0.01 mm. According to the JB/T 4127-2016 standard, the hardness of cold heading die coatings must be HRA ≥88. In wire drawing dies, TiN coatings double the surface wear resistance, increase the drawing length from 5,000 meters to 12,000 meters, and reduce lubricant usage by 30%.

Suitable reasons

For molds with high processing volumes, coating reduces maintenance time and scrap, offering significant economic benefits (increasing cost per part by 5%-15% and extending life by 200%-300%). Coating also supports dry or minimally lubricated machining, aligning with the trend toward green manufacturing.

Limitations and Precautions

The risk of coating delamination should be controlled by adhesion testing (scratch load > 50 N), especially in molds with complex curved surfaces. High-temperature CVD may cause substrate annealing, so the temperature should be optimized (< 900°C).

Wear-resistant parts of agricultural and mining machinery (such as plowshares, harrow teeth, mining drill bits and crushing hammers)

are easily worn by friction with soil, rocks or minerals. Coatings significantly extend their service life by enhancing surface hardness and corrosion resistance, making them particularly suitable for open air or humid environments.

Technical principles and advantages

Coatings such as WC-Co (HV 1500-2000) or CrN , deposited by thermal spraying or laser cladding with a thickness of 10-50 μm , can reduce abrasive wear by 50%-70% and increase corrosion resistance by a factor of two. The coatings also reduce soil or mineral adhesion, reducing maintenance requirements.

Actual cases and data

In a farming environment, the lifespan of an uncoated plowshare is approximately 500 hours, while that of a WC-Co coating reaches 800-1000 hours, with wear depth reduced from 0.1 mm to 0.01 mm. According to the YS/T 1045-2015 standard, the hardness of coatings for agricultural wear-resistant parts must be HRA ≥88. In mining drill bits, TiCN coatings increase drilling efficiency by 20%, extending the lifespan from 200 hours to 400 hours.

Suitable reasons

In harsh environments, coatings offer low cost (increases by 10%-20%) and high returns (lifespan extended by 1.5-2 times). They also reduce soil acid erosion and oxidation, and are adaptable to diverse climatic conditions.

Limitations and Precautions

Thick coatings may increase brittleness, and high impact requires the use of tough coatings (such as Ni-Cr-B-Si), and the powder feed rate should be optimized (5-10 g/min) to reduce porosity.

Which carbides are not suitable for coating?

Despite the significant advantages of coating processes, not all cemented carbide products are suitable for coating. Coatings may increase manufacturing costs, change substrate properties (such as reducing toughness), or fail to provide the expected benefits under certain working conditions, or even be counterproductive. The following are the main product categories that are not suitable for coating and their detailed analysis:

Products with high toughness requirements (such as hammers, crusher parts and punches with high impact loads)

work under high impact or dynamic loads. Coatings usually increase surface hardness but reduce the toughness and fatigue resistance of the substrate, which may cause brittle cracking or peeling of the coating.

Reasons and disadvantages

Coating processes (such as CVD or PVD) introduce residual stresses (>500 MPa), which can easily cause microcracks or coating spalling under impact loads. Bare cemented carbide (such as YG10, with a Co content of 10%-12%) has higher flexural strength (2000-2500 MPa) and impact toughness (>10 J/cm²) , making it more suitable for high-impact environments.

Actual cases and data

In mining crushers, TiN -coated hammers experience a coating delamination rate of 30% at an impact energy of 100 J/cm² , with no significant improvement in lifespan (approximately 200 hours). Uncoated hammers, on the other hand, offer greater toughness and a slightly longer lifespan (250 hours). According to GB/T 5242-2006, high-impact components must have a bending strength (HRA) of ≥86.

Unsuitable reasons

The coating has low economic efficiency (increases costs by 20%-30%) and is complex to maintain (e.g., requires reprocessing after peeling). It is not as effective as optimizing the matrix composition (increasing the Co content).

Precautions

If coating is required, it is recommended to use a flexible coating (such as Ni-based alloy) or reduce the coating thickness (<2 μm).

Surface-optimized or specially treated cemented carbides (e.g. mirror-polished drawing dies, carburized cemented carbide or ultra-fine grain products)

These products have achieved high surface quality or specific properties through mirror polishing, carburizing or ultra-fine grain design. Coatings may destroy the original characteristics or cause uneven deposition.

Reasons and disadvantages

The coating has low adhesion (<40 MPa) and is prone to flaking, especially on smooth surfaces (Ra <0.05 μm). The coating thickness (1-15 μm) may obscure microgeometric features and affect accuracy.

Actual cases and data

After coating a precision wire drawing die, surface roughness Ra increased from 0.02 μm to 0.15 μm , while dimensional accuracy decreased from ±0.005 mm to ±0.02 mm, impairing machining quality. Carburized carbide coating destroyed the surface carburized layer (0.1 mm in depth), resulting in a 10% decrease in wear resistance.

Unsuitable reasons

Repeated processing increases costs (20%-40%) without significant performance improvement and may even be counterproductive.

Precautions

If coating is necessary, ALD nanocoating (thickness < 0.5 μm) should be used to minimize the impact.

Low-cost, high-volume standard parts (such as simple screw dies, standard wear-resistant liners or low-end punches)

are originally designed for low-cost, standardized production with low performance requirements, and the economic benefits of the coating process are not obvious.

Reasons and disadvantages

Coating increases manufacturing costs (10%-30%), but only improves lifespan to a limited extent (<50%), resulting in a low economic return. The coating process is complex (e.g., vacuum chamber preparation and post-processing), making it unsuitable for rapid production.

Actual cases and data

In standard screw production, TiN -coated liner life increased from 5,000 to 7,000 cycles (a 40% improvement), but costs rose by 25%, resulting in a negative overall cost-benefit ratio. Coating low-end punches only extended life by 20%, while processing costs increased by 30%.

Unsuitable reasons

Mass production prioritizes cost control, and coating cannot offset the additional investment.

Precautions

For low-end products, the coating can be replaced by optimizing the substrate (such as increasing Co 2%-3%).

Products subject to extremely high temperatures or extreme corrosion (such as nuclear reactor components, sour environment valves or high-temperature furnace wear parts)

These products work under extreme conditions. If the coating's heat resistance limit (1200°C) or corrosion resistance is insufficient, it may fail or accelerate substrate corrosion.

Reasons and disadvantages

Coatings such as TiN can corrode at a rate of 0.1 mm/year in strong acid (pH < 2), exposing the substrate after peeling. At high temperatures exceeding 1200°C (such as those found in furnaces), the coating softens or evaporates.

Actual cases and data

In chemical acid valves, TiN coatings have a lifespan of 200 hours, similar to the bare substrate, but the coating increases costs by 30 %, yielding no return. In nuclear reactors, Al_2O_3 coatings deactivate at 1300°C, while the substrate has a more stable temperature resistance (1200°C) .

Unsuitable reasons

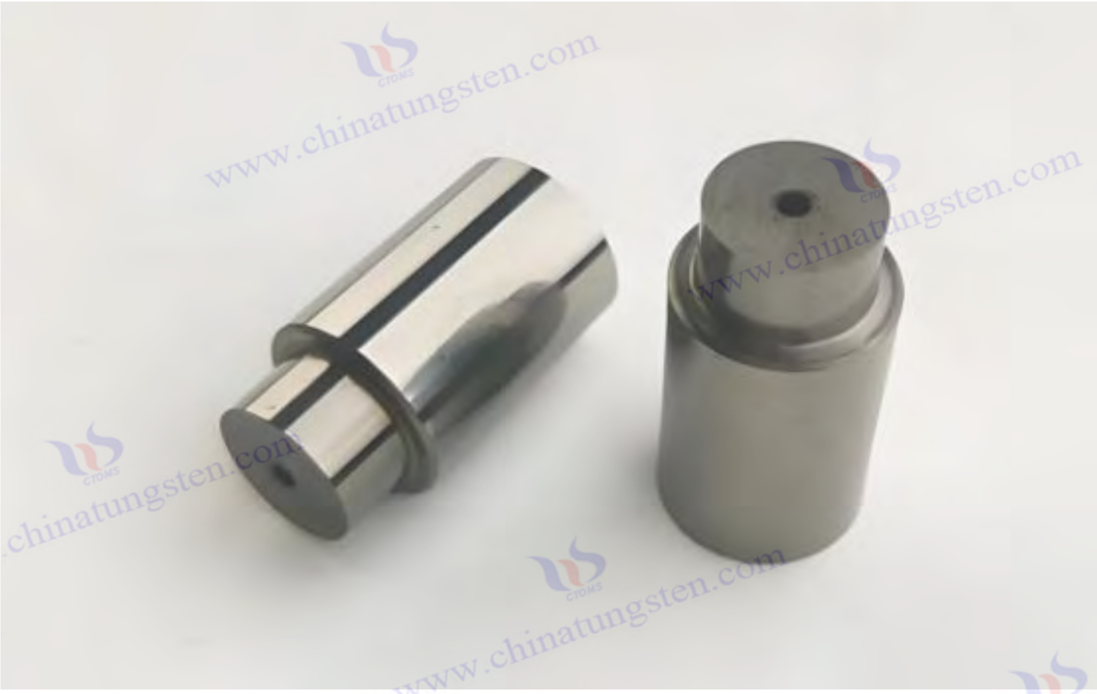
Coatings cannot meet extreme conditions and must be replaced with ceramic substrates or special alloys.

Precautions

If coating is required, it is recommended to develop a high heat-resistant coating (such as ZrN , temperature resistance 1400°C).

Summarize

Carbide products suitable for coating processes are generally high-value, high-performance products, such as cutting tools, precision molds, and wear-resistant parts. Coating can significantly improve lifespan (by 2-5 times), efficiency (by 20%-50%), and durability, providing high economic benefits. The choice of coating type and process should be optimized based on the application conditions: PVD is suitable for precision thin layers (TiAlN , CrN), CVD is suitable for thick, heat-resistant layers (Al_2O_3) , and laser cladding is suitable for local repairs (WC-Co). Products not suitable for coating are generally high-toughness, low-cost, or designed for extreme environments. Coating may increase costs, reduce performance, or even generate no return. When selecting, it is necessary to comprehensively evaluate the working conditions (such as cutting speed, impact load), economic efficiency (cost/life ratio) and substrate properties (Co content, grain size). Reference standards such as GB/T 18376 series, ISO 513:2012 and YS/T 1045-2015 should be used for verification, and the coating solution should be optimized through tests (such as adhesion tests and wear resistance tests) to achieve the best balance between performance and cost.



What are the domestic and international standards for coated cemented carbide?

Domestic and international standards for coated cemented carbide cover a wide range of aspects, including material properties, testing methods, dimensions, and applications. These standards, developed by international organizations, national standardization bodies, and industry associations, aim to regulate the production, testing, and use of coated cemented carbide, ensuring its quality and consistency in applications such as cutting tools, wear-resistant parts, and precision molds. The following is an overview of the main domestic and international standards, detailed based on current knowledge and industry practices, taking into account the characteristics of coated cemented carbide.

International standards for coated cemented carbide

The International Organization for Standardization (ISO) is the primary body responsible for developing international standards for coated cemented carbide, which are widely used in the global manufacturing industry. The following are key elements of the relevant standards:

ISO 513:2012 - Classification and use of cutting tool materials

Overview : This standard defines the material classification and application areas of cemented carbide (including coated cemented carbide) in cutting processing , covering the performance requirements of PVD and CVD coating materials.

Content : Specifies the applicable working conditions for coated cemented carbide (such as steel, cast iron, and difficult-to-machine materials) and provides guidance on coating thickness (1-15 μm) and hardness (HV 2000-4000).

Applicability : Suitable for the design and material selection of coated tools to ensure that the coating matches the substrate, such as optimizing the performance of TiN or TiAlN coatings in high-speed cutting.

Features : Emphasizes the compatibility of the coating with the workpiece material and recommends testing the coating adhesion (>50 MPa).

ISO 6507-1:2018 - Metallic materials — Vickers hardness test — Part 1: Test method

Overview : Provides a standardized method for hardness testing of coated cemented carbides, suitable for both micro and macro hardness measurements.

Content : This standard specifies the load range (0.1-50 kgf) and indentation measurement for Vickers hardness testing . It is applicable to the testing of coatings with HV 2000-4000, and emphasizes the applicability of small loads (such as HV 0.1) to thin coatings.

Applicability : Used to verify the hardness increase effect of coatings, such as increasing the hardness of TiAlN coatings from HV 1400 to HV 3200.

Features : Provides high-precision measurement, suitable for hardness distribution analysis of coatings with thickness less than 5 μm .

ISO 20808:2016 - Friction and wear tests on metallic coatings

Overview : This standard specifies the test methods for the coefficient of friction and wear resistance of coated cemented carbide.

Content : Includes sliding wear and grinding wheel wear tests, with specified loads (10-200 N) and speeds (0.5-50 m/s), and measurement of wear rate (10^{-6}-10^{-7} mm³ / N · m) .

Applicability : Used to evaluate the friction coefficient (0.1-0.2) and wear resistance of DLC or

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TiCN coatings and improve cutting efficiency.

Features : Provides dynamic wear data, suitable for high-speed cutting tool performance verification.

ISO 13399:2014 - Cutting tool data representation and exchange

Overview : Geometrical parameters and performance data for standardized coated carbide cutting tools.

Content : Defines digital representation of coating thickness, material composition (e.g., TiN , Al2O3), and application scenarios to facilitate CAD/CAM integration.

Applicability : Suitable for database management of coated carbide inserts to ensure production consistency.

Features : Supports parameter recording of multi-layer coatings (such as TiN / TiCN /Al2O3).

for Coated Cemented Carbide (China)

The Standardization Administration of China (SAC) has developed a series of national standards (GB/T series) related to coated cemented carbide, taking into account national conditions and industrial needs, and partially aligned with ISO standards. The following are the main standards:

GB/T 18376.1-2015 - Classification and performance requirements of cemented carbide coatings

Overview : Specifies the classification, performance indicators and test methods of coated cemented carbide.

Content : Includes hardness (HV 2000-4000), adhesion (>50 MPa), and heat resistance (1000°C) of PVD and CVD coating materials for substrates such as YG6 and YT15.

Applicability : Used for domestic coated tool production, such as Zhuzhou Diamond's TiAlN coated cemented carbide.

Features : Emphasizes the performance consistency of domestic coating materials and is compatible with ISO 513.

GB/T 20708-2006 - Surface quality inspection of cemented carbide coatings

Overview : Standardizes the detection of roughness, defects, and thickness on coated cemented carbide surfaces.

Content : Specified surface roughness Ra ≤ 0.2 μm , thickness deviation ±0.5 μm , detection methods include SEM and spectral analysis.

Applicability : Suitable for surface quality control of coated wear-resistant parts and cutting tools.

Features : Provides detailed defect classification (such as cracks and peeling) to guide production optimization.

GB/T 231.1-2018 - Brinell hardness test for metallic materials - Part 1: Test method

Overview : This article provides a method for testing the macrohardness of coated cemented carbide substrates.

Content : Calculate HBW using a 5-10 mm ball and a load of 2500-3000 kgf . Applicable to a base with HBW of 400-600.

Applicability : Combined with GB/T 18376, it is used to evaluate the hardness change before and after coating.

Features : Suitable for substrate performance testing of thick coatings (>10 μm).

GB/T 4340.1-2009 - Vickers hardness test for metallic materials - Part 1: Test method

Overview : Similar to ISO 6507, this standard covers microhardness testing of coated cemented carbides.

Content : Load 0.1-50 kgf , suitable for coating HV 2000-4000, emphasizing the test accuracy of thin coatings (<5 μm).

Applicability : Used for hardness verification of domestic TiN or CrN coatings.

Features : Provides high-resolution measurement, suitable for micro-area analysis.

Industry and enterprise standards for coated cemented carbide

In addition to international and national standards, some well-known tool manufacturers and industry associations have also developed relevant technical specifications for coated cemented carbide:

Sandvik Coromant Technical Specifications

Overview : Swedish company Sandvik has developed internal standards for coated carbide cutting tools.

Content : The TiAlN coating has a hardness of HV 3000-3500, a heat resistance of 1000°C, and an adhesion test method of scratch test (>70 N).

Applicability : Suitable for aerospace cutting tools, such as machining titanium alloys.

Features : Emphasizes the performance optimization of multilayer coatings (such as TiN /Al2O3).

Kennametal Coating Performance Guide

Overview : Kennametal Corporation of the United States provides performance data for coated cemented carbide.

Content : DLC coating with a coefficient of friction of 0.1-0.2 and a wear resistance of 10^{-7} $mm^3 / N \cdot m$, tested according to ASTM G99.

Applicability : Coated tools suitable for aluminum alloy processing.

Features : Provide customized coating solutions.

China Machine Tool Industry Association Standard

Overview : Technical guidelines for coated cemented carbide developed by domestic industry associations.

Content : Specifies the performance indicators of domestically produced coated cemented carbide, such as heat shock cycle resistance >20 times and wear rate $<10^{-6}$ $mm^3 / N \cdot m$.

Applicability : Suitable for domestic mold and wear-resistant parts production.

Features : Combining the characteristics of Chinese manufacturing, focusing on cost-effectiveness.

Comparison and Analysis

International standards vs. domestic standards : ISO standards (such as ISO 513 and ISO 6507) have a wide coverage and are applicable to global trade, but lack specificity; GB/T standards (such as GB/T 18376) are more in line with the current state of China's industry and emphasize domestically produced processes.

Universality vs. Specialization : ISO 13399 focuses on data standardization and is suitable for multi-industry applications; corporate standards (such as Sandvik specifications) provide professional guidance for specific coatings (such as TiAlN).

Update frequency : ISO standards are revised every 5-10 years, GB/T standards are updated more quickly (such as GB/T 231.1-2018), and enterprise standards are dynamically adjusted with technological progress.

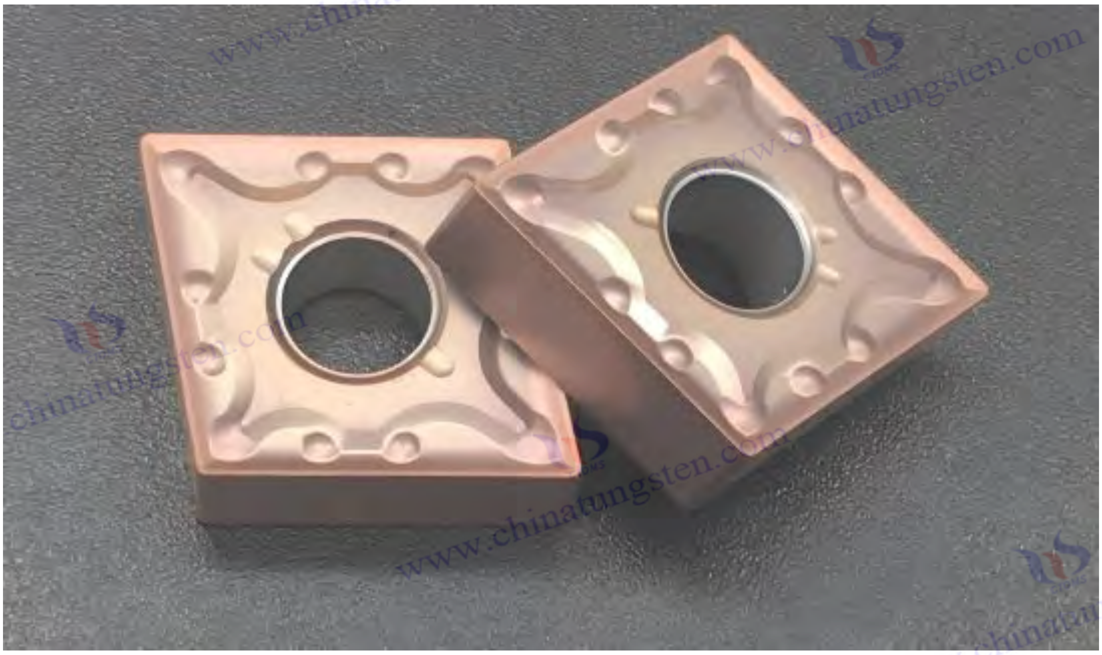
Application Recommendations

Cutting tools : It is recommended to follow ISO 513 and GB/T 18376 to test the coating hardness (HV) and wear rate.

Wear-resistant parts : Refer to GB/T 20708 and ISO 20808 to test surface quality and corrosion resistance.

R&D and Verification : Conduct micro-performance testing and optimization based on ISO 6507 and company standards.

The international and domestic standards system for coated cemented carbide provides a solid foundation for production and application. International standards (such as the ISO series) ensure global consistency, domestic standards (such as the GB/T series) support local innovation, and enterprise standards provide professional supplementary support. It is recommended to select the appropriate standard based on the specific application scenario and optimize coating design based on actual test data.



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ISO 513:2012 - Classification and application of cutting tool materials

Preface

With modern manufacturing demanding ever-increasing efficiency, precision, and tool life, the selection of cutting tool materials has become a critical factor. ISO 513:2012, published by the International Organization for Standardization (ISO), provides standardized guidance for the classification and application of cutting tool materials. This standard applies to a wide range of tool materials used in metal cutting, including cemented carbide, coated cemented carbide, high-speed steel, and ceramics, with a particular focus on the performance of different materials under specific operating conditions. Since its 2004 revision, the 2012 edition has updated the classification and application recommendations for coated cemented carbide to address emerging demands such as high-speed cutting and dry machining. This document details the scope of ISO 513:2012, its normative references, term definitions, classification system, application guidance, and testing requirements, and provides a comprehensive technical reference, taking into account the characteristics of coated cemented carbide.

The release of ISO 513:2012 reflects the global manufacturing industry's demand for diversified tool materials. According to data from the International Cutting Tool Association, coated carbide now accounts for over 70% of the cutting tool market. Its superior performance (such as heat resistance up to 1000°C and a 3-5x increase in tool life) has driven the standard's update. By standardizing classification and application rules, the standard ensures the optimal match between tool materials, workpiece materials, and machining conditions, thereby optimizing production efficiency and cost-effectiveness. This article will systematically analyze the standard's content according to its structure, providing guidance for engineering practice and research.

1. Scope

Applicable objects : ISO 513:2012 specifies the classification and application of cutting tool materials. It is applicable to materials such as cemented carbide (including coated cemented carbide), high-speed steel, ceramics, cubic boron nitride (CBN) and diamond.

Test scope : Covers turning, milling, drilling and boring processes in metal cutting, involving workpiece materials ranging from mild steel to difficult-to-machine materials (such as titanium alloy and stainless steel).

Special applicability : Particularly suitable for the application of coated cemented carbide in high-speed cutting (>200 m/min), dry machining and hard material (HRC 50-65) processing, emphasizing coating thickness (1-15 μm) and performance optimization.

Limitations : Does not include tool materials for non-metal cutting (e.g. wood, plastic) or non-traditional machining (e.g. EDM), for which reference should be made to other standards (e.g. ISO 16462).

2. Normative References

ISO 3685:1993 : Basic methods for tool life testing.

ISO 5130:2004 : Cutting tool geometry.

ISO 6507-1:2018 : Metallic materials — Vickers hardness test — Part 1: Test method.

ISO 20808:2016 : Friction and wear tests on metallic coatings.
ISO 13399:2014 : Cutting tool data representation and exchange.
Note : The above standards are subject to the latest version to ensure that the classification and application guidance are consistent with the current technology.

3. Terms and Definitions

Cutting tool material : The material used to make cutting tools, including base material and coating material.
Cemented Carbide : A sintered material with tungsten carbide (WC) as the hard phase and cobalt (Co) or nickel (Ni) as the binder phase.
Coated cemented carbide : A composite material with a functional film (such as TiN , TiAlN) deposited on the surface of a cemented carbide substrate, with a thickness of 1-15 µm .
Workpiece material group : Workpiece categories divided according to machining difficulty and material properties, such as P group (steel), M group (stainless steel), and K group (cast iron).
Cutting speed : The speed of relative movement between the tool and the workpiece, measured in m/min, affects the heat resistance requirements of the coating.

4. Classification of cutting tool materials

ISO 513:2012 classifies cutting tool materials into the following main categories and provides detailed classifications for coated carbides:

4.1 Cemented Carbide

Definition : Composed of WC-Co or WC- TiC -Co, hardness HRA 85-92, flexural strength 1800-2500 MPa.
Subcategories :
P type : Contains TiC and TaC , suitable for steel processing (cutting speed 100-300 m/min).
M type : Contains more Co, suitable for stainless steel (cutting speed 80-200 m/min).
K type : high WC content, suitable for cast iron (cutting speed 150-400 m/min).

4.2 Coated carbide

Definition : Deposition of PVD or CVD coatings such as TiN , TiCN , TiAlN , Al_2O_3 on cemented carbide substrates .
Subcategories :
P10-P30 : Coating thickness 2-5 µm , suitable for high-speed cutting of steel, heat resistance 800-1000°C.
M10-M30 : Coating thickness 3-6 µm , suitable for stainless steel, anti-adhesive wear.
K10-K40 : Coating thickness 4-8 µm , suitable for cast iron and non-ferrous metals, wear resistance increased by 50%.
Coating properties : Hardness HV 2000-4000, friction coefficient 0.1-0.4, adhesion >50 MPa.

4.3 Other Materials

High-speed steel (HSS), ceramics, CBN and diamond are suitable for specific working conditions (such as HSS for low-speed machining and CBN for hard materials).

5. Workpiece material group

ISO 513:2012 divides workpiece materials into the following groups, corresponding to the classification of tool materials:

Group P (Steel) : Includes low carbon steel, medium carbon steel and hardened steel, with hardness HB 120-400.

Group M (stainless steel) : includes austenitic and martensitic stainless steels with a hardness of HB 150-350.

Group K (cast iron) : includes gray cast iron and ductile iron, with hardness HB 180-300.

Group N (non-ferrous metals) : includes aluminum alloys and copper alloys, with a hardness of HB 30-150.

Group S (difficult-to-machine materials) : including titanium alloys and nickel-based alloys, with a hardness of HB 300-600.

Group H (hardened steel) : includes hardened steel with a hardness of HRC 50-65.

Coated cemented carbide performs well in Groups S and H. For example, the life of TiAlN coating is extended by 3 times when machining titanium alloy.

6. Application of cutting tool materials

6.1 Application Principles

Matching principle : Tool materials should be selected according to the workpiece material group and processing conditions, for example, P10 coated cemented carbide is suitable for P group steel.

Optimized performance : Coated carbide optimizes cutting performance by reducing the friction coefficient (0.1-0.3) and increasing heat resistance (1000°C).

Economical : Coating thickness (3-5 μm) is selected to balance lifetime and cost.

6.2 Specific Applications

Turning : P20 coated carbide is suitable for rough turning of steel (cutting speed 200 m/min), with a life of 500 m.

Milling : M15 coated carbide is suitable for stainless steel face milling (cutting speed 150 m/min), with wear resistance increased by 40%.

Drilling : K20 coated carbide is suitable for drilling holes in cast iron (cutting speed 300 m/min), with a hole diameter accuracy of ±0.01 mm.

Hard material processing : S10 coated cemented carbide (TiAlN) is suitable for titanium alloy finishing (cutting speed 250 m/min), with a service life of 800 m.

Dry machining : Al_2O_3 coated carbide reduces coolant usage and saves 20% energy.

6.3 Application Advantages of Coated Cemented Carbide

Extended life : The life of TiAlN coating in steel processing is 3-5 times longer than that of bare substrate.

Improved efficiency : Friction coefficient reduced by 20%-30% and cutting force reduced by 15%.

Environmental protection : Dry cutting reduces cutting fluid emissions and meets green manufacturing requirements.

7. Testing and Verification Requirements

Hardness test : Refer to ISO 6507, coating hardness HV 2000-4000, substrate HRA 85-92.

Wear test : Refer to ISO 20808, wear rate $<10^{-6}$ $mm^3 / N \cdot m$, test time 30-60 min.

Adhesion test : Scratch test, critical load >70 N, peeling area <5%.
Heat resistance test : Heated to 1000°C, maintained for 1 hour, hardness decreases by <5%.

8. Appendix (Reference Information)

Table 1: Classification and application comparison of coated cemented carbide

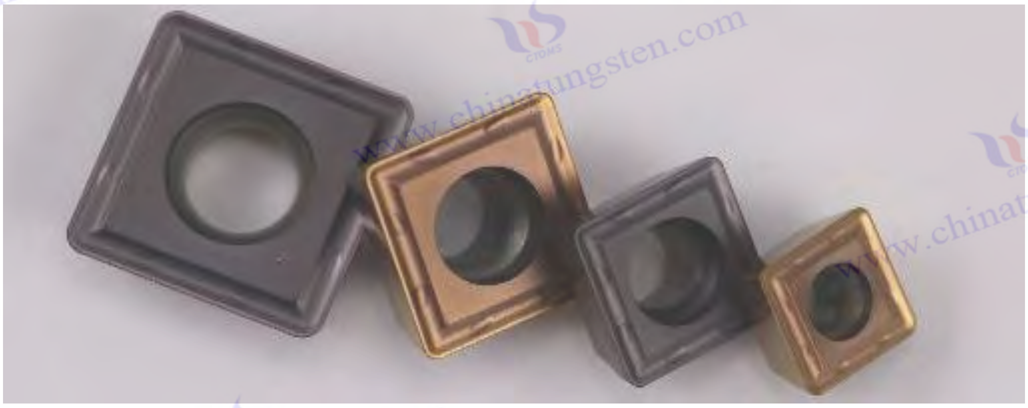
category	Coating type	Thickness (μm)	Hardness (HV)	Applicable workpiece groups	Cutting speed (m/min)
P10	TiN	2-3	2500	Group P	200-300
M20	TiCN	3-5	3000	Group M	80-200
K30	Al2O3	5-8	3500	Group K	150-400
S10	TiAlN	4-6	3200	Group S	200-250

Figure 1: Coated carbide application flow chart (showing material selection, processing conditions, and performance verification steps).

Case : A factory uses P20 TiN coated carbide to turn steel, with a cutting speed of 250 m/min, a life of 600 m, and an efficiency improvement of 30%.

9. Conclusions and Recommendations

ISO 513:2012 provides comprehensive classification and application guidance for cutting tool materials, with particular emphasis on the role of coated carbide in modern machining. Coated carbide significantly improves tool life and machining efficiency by optimizing hardness, heat resistance, and friction properties. It is recommended to select the appropriate coating type based on the workpiece material group and machining conditions (e.g., TiAlN for the S group and Al2O3 for the K group), and to conduct regular performance testing to ensure quality. For higher precision or specialized applications, data integration with ISO 13399 can be consulted, or a certified laboratory can be consulted.



ISO 20808:2016 - Friction and wear tests on metallic coatings

Preface

In modern industry, the friction and wear properties of metallic coatings directly impact the service life and efficiency of their applications in cutting tools, wear-resistant parts, and precision components. With the rapid advancement of coating technologies such as PVD and CVD, standardized test methods have become crucial for evaluating coating performance. ISO 20808:2016, published by the International Organization for Standardization (ISO), provides unified test methods for the friction and wear characteristics of metallic coatings, particularly applicable to cemented carbide coatings (such as TiN , TiAlN , and CrN). Published in 2016, this standard replaces the previous test guide and updates test parameters and equipment requirements to accommodate new applications such as high-speed cutting and dry machining. This document details the scope of ISO 20808:2016, including normative references, term definitions, test methods, test conditions, result analysis, and application guidance. This document provides a comprehensive technical reference, taking into account the characteristics of coated cemented carbides.

The development of ISO 20808:2016 reflects the urgent global need for coating performance evaluation. According to data from the International Surface Engineering Association, coated carbide accounts for over 70% of the cutting tool market. Optimized friction coefficients (0.1-0.4) and wear rates (10^{-6}-10^{-7} mm³ / N · m) significantly improve machining efficiency. The standard, through standardized testing methods, ensures the comparability and reliability of coatings under different operating conditions, providing a scientific basis for material selection and process optimization. This article will systematically analyze the content of the standard according to its structure, providing guidance for engineering practice and research.

1. Scope

Applicable to : ISO 20808:2016 specifies friction and wear test methods for metallic coatings (such as cemented carbide coatings) and is suitable for functional coatings in industrial applications.

Test scope : Covers quantitative evaluation of friction coefficient, wear rate, and surface damage. Applicable to PVD and CVD coatings (such as TiN , TiCN , Al2O3) with a thickness range of 1-15 µm .

Special applicability : It is particularly suitable for performance verification of coated cemented carbide in high-speed cutting (>200 m/min), dry machining and wear-resistant parts, emphasizing the test accuracy of thin coatings (<5 µm).

Limitations : Does not include non-metallic coatings (e.g. ceramic coatings) or non-friction wear tests (e.g. corrosive wear), for which other standards (e.g. ISO 9227) must be consulted.

2. Normative References

ISO 4287:1997 : Surface roughness terms, definitions and parameters.

ISO 6507-1:2018 : Metallic materials — Vickers hardness test — Part 1: Test method.

ISO 3274:1996 : Calibration of surface topography profilometers.

ISO 13565-1:1996 : Calculation methods for surface roughness parameters.

Note: The above standards are subject to the latest version to ensure that the test methods are consistent with current technology.

3. Terms and Definitions

Coefficient of Friction (COF): The frictional resistance between the coating surface and the mating material, expressed as a dimensionless value (0.1-0.5).

Wear Rate: The volume loss of a coating per unit load and sliding distance during friction, expressed in $mm^3 / N \cdot m$.

Sliding Wear: Material wear that occurs when a coating slides against another.

Abrasive Wear: The wear of a coating due to friction from the grinding wheel or particles.

Counterpart Material: The tribological material in contact with the coating, such as a steel or ceramic ball.

4. Test Methods

ISO 20808:2016 provides two main test methods, suitable for different coating properties and application scenarios:

4.1 Sliding wear test

Principle: A pin-on-disk device is used to simulate the relative sliding between the coating and the countermaterial to measure the coefficient of friction and wear rate.

Equipment: Consists of a rotating disk, a fixed pin (3-10 mm diameter, made of materials such as AISI 52100 steel or Al2O3 ceramic), a load application system, and a data logger.

Test parameters:

Load: 10-100 N (adjusted according to coating hardness).

Sliding speed: 0.5-2 m/s.

Sliding distance: 100-1000 m.

Environment: Room temperature (20-25°C) or high temperature (200-500°C).

Sample preparation: Coating surface roughness $Ra \leq 0.2$ µm, thickness uniformity deviation ±0.5 µm.

4.2 Grinding wheel wear test

Principle: A rotating grinding wheel is used to simulate abrasive wear and evaluate the wear resistance of coatings in a grinding environment.

Equipment: Includes grinding wheels (grit size #80-#240, materials such as SiC or Al2O3), load application system and wear depth measuring instrument.

Test parameters:

Load: 50-200 N.

Rotation speed: 10-50 m/s.

Wear time: 30-60 min.

Environment: Dry or with lubricants.

Sample preparation: The coating surface is clean, with a roughness of $Ra \leq 0.1$ µm.

5. Test conditions

Sample size: diameter 20-50 mm, thickness 5-10 mm, coating area $\geq 10\ cm^2$.

Dual material : Steel ball or ceramic ball with hardness HRC 60-65 and surface roughness Ra ≤ 0.05 μm .
Environmental control : Humidity 40%-60%, temperature can be adjusted according to the application (such as high temperature testing up to 500°C).
Repeatability : Each condition was tested at least 3 times, and the data deviation was less than 10%.

6. Data Collection and Results Analysis

Coefficient of friction : Record the COF in real time during the sliding process and calculate the average value and fluctuation range (±0.05).
Wear rate : Measure the volume loss (mm³) of a coating after wear , divided by the load (N) and sliding distance (m). The formula is W = V / (F·L).
Surface damage : Analyze wear tracks, cracks, and delamination using optical microscopy or SEM.
Report requirements : Include test conditions, COF value, wear rate, surface morphology photos and statistical analysis.

7. Application Guide

7.1 Cutting Tools

Applicability : Sliding wear test for evaluating the coefficient of friction (0.2-0.3) of TiN or TiAlN coatings in steel cutting, with a wear rate of <10^{-6} mm³ / N · m .
Case : YG6 substrate + TiAlN coating, cutting speed 250 m/min, service life extended by 3 times.

7.2 Wear-resistant parts

Applicability : Grinding wheel wear tests evaluated the wear resistance of CrN coatings in agricultural plowshares, reducing wear by 60% and achieving a lifespan of 800 hours.
Case : Coated carbide wear-resistant parts are used in mining machinery. Grinding wheel tests show that the wear depth is <0.05 mm.

7.3 Dry machining

Applicability : Sliding wear tests demonstrate the DLC coating's low friction (COF 0.1-0.2) and 50% reduction in adhesion in dry cutting of aluminum alloys.
Case : DLC coated tool, cutting speed 300 m/min, efficiency increased by 20%.

8. Appendix (Reference Information)

Table 1: Typical coating friction and wear test results

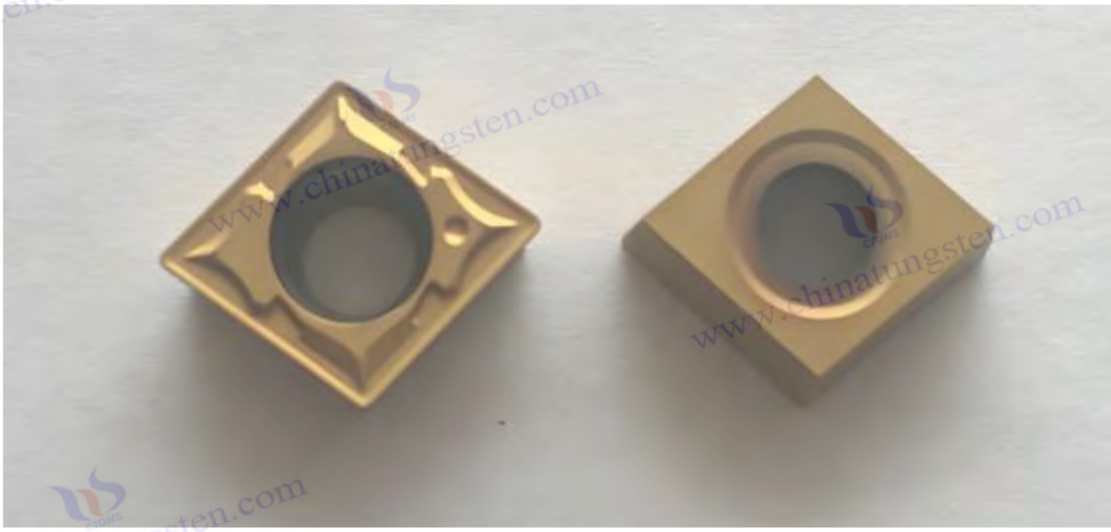
Coating type	Coefficient of friction (COF)	Wear rate (mm³ / N · m)	Load (N)	Speed (m/s)	Test Method
TiN	0.4	5×10^{-6}	50	1	slide
TiAlN	0.3	2×10^{-6}	75	1.5	slide
CrN	0.35	3×10^{-6}	100	2	slide
Al2O3	0.5	1×10^{-6}	150	30	grinding wheel

Figure 1: Schematic diagram of a sliding wear test (showing the pin-on-disk setup and friction track).

Figure 2: Schematic diagram of the grinding wheel wear test (showing the contact area between the grinding wheel and the coating).

9. Conclusions and Recommendations

ISO 20808:2016 provides standardized methods for friction and wear testing of metallic coatings, particularly suitable for evaluating the performance of coated cemented carbide. Sliding and grinding wheel wear tests can quantify the coefficient of friction and wear resistance of coatings, providing a basis for the design of cutting tools and wear-resistant parts. It is recommended to select the appropriate test method based on the application (e.g., sliding tests for cutting, grinding wheel tests for wear resistance), and to verify hardness changes in conjunction with ISO 6507. For higher precision or testing in specialized environments, refer to ISO 13565-1 for surface topography analysis, or consult a certified laboratory.



ISO 13399:2014
- Cutting tool data representation and exchange

Preface

With the widespread adoption of computer-aided manufacturing (CAM) and computer-aided design (CAD) technologies, the standardization and digital exchange of cutting tool data have become critical to improving manufacturing efficiency. ISO 13399:2014, published by the International Organization for Standardization (ISO), aims to provide a unified data representation and exchange framework for cutting tools, particularly suitable for the digital management of complex tools such as coated carbide cutting tools. Published in 2014, this standard builds on previous part-by-part publications (2001-2013), integrating geometric parameters, material properties, and application information to meet the needs of modern smart manufacturing and Industry 4.0. This document details the scope of ISO 13399:2014, including normative references, term definitions, data models, data exchange formats, application guidelines, and implementation requirements. Taking into account the specific characteristics of coated carbide, it provides a comprehensive technical reference.

The development of ISO 13399:2014 responds to the global manufacturing industry's demand for tool data integration. According to data from the International Cutting Tool Association, coated carbide cutting tools account for over 70% of the global cutting tool market. Their multi-layer coatings (such as TiN / TiCN /Al2O3) and complex geometries require precise digital descriptions. By unifying the data structure, the standard enables seamless exchange of tool parameters across the design, production, and operational phases, supporting automated production lines and supply chain optimization. This article will systematically analyze the content of the standard according to its structure, providing guidance for engineering practice and research.

1. Scope

Applicable objects : ISO 13399:2014 specifies the representation and exchange methods of cutting tool data, and is applicable to carbide coated cutting tools, high-speed steel cutting tools, ceramic cutting tools, etc.

Data range : Covers tool geometry (size, angles), material properties (hardness, coating type), functional attributes (cutting speed, wear resistance), and usage conditions.

Special applicability : It is particularly suitable for the digital modeling of coated carbide tools, supporting the parametric representation of multi-layer coatings (such as TiAlN , thickness 1-15 µm) and complex cutting edge designs.

Limitations : Does not include data for non-cutting tools (e.g. abrasives) or non-standardized hand tools, for which reference must be made to other standards (e.g. ISO 16462).

2. Normative References

ISO 10303-21:2016 : Industrial automation systems and integration — STEP physical file format.

ISO 10303-238:2007 : Product data representation and exchange of industrial data — Application protocol: Application interpretation.

ISO 13584-42:2010 : Industrial automation systems and integration — Parts library — Part 42:

Description method.

ISO 6507-1:2018 : Metallic materials — Vickers hardness test — Part 1: Test method.

Note : The above standards are subject to the latest version to ensure data exchange is consistent with current technology.

3. Terms and Definitions

Cutting tool data : A digital set of information describing the tool's geometry, material, and properties.

Geometric parameters : The size, angles and shape of the tool, such as the tip radius (0.1-1 mm) and the rake angle (5°-15°).

Material properties : including substrate hardness (HRA 85-92), coating hardness (HV 2000-4000), and friction coefficient (0.1-0.4).

Data exchange : Transfer tool data between different systems via standard formats (such as STEP files).

Multilayer coating : A composite coating such as TiN /Al2O3 (total thickness 5-15 μm) deposited on a cemented carbide substrate .

4. Data Model

ISO 13399:2014 defines a hierarchical model for cutting tool data based on an object-oriented approach:

4.1 Basic Data Elements

Identification information : Tool ID, manufacturer code, batch number.

Geometric data : length (mm), width (mm), height (mm), cutting edge angle (°).

Material data : substrate composition (e.g. WC-Co), coating type (e.g. TiAlN), thickness (μm).

4.2 Functional data

Cutting parameters : Maximum cutting speed (m/min), feed rate (mm/rev), depth of cut (mm).

Performance indicators : Hardness (HV), wear rate (mm^3 / N · m) , heat resistance (°C).

Application conditions : workpiece material group (P, M, K, S), processing type (turning, milling).

4.3 Coated carbide expansion

Coating layer : Supports multi-layer coating description, such as the first layer of TiN (2 μm), the second layer of Al2O3 (5 μm).

Interface properties : adhesion (>50 MPa), residual stress (<500 MPa).

Performance Mapping : Mapping coating data to workpiece material groups according to ISO 513:2012.

5. Data exchange format

STEP format (ISO 10303-21) : uses ASCII encoding and the file extension is .stp or .step.

Data structure : Based on the EXPRESS language definition, including entities (such as TOOL, COATING) and attributes (such as THICKNESS, HARDNESS).

Example :

text

```
#10=COATING('TiAIN', 5.0, 3200.0);
#20=TOOL('CUTTING_INSERT', #10, 10.0, 5.0, 2.0);
```

- 解释: #10 定义TiAIN涂层，厚度5 μm，硬度3200 HV；#20 定义刀片，涂层为#10，尺寸10×5×2 mm。

Compatibility : Supports CAD/CAM software (such as SolidWorks, Mastercam) and Enterprise Resource Planning (ERP) systems.

6. Implementation requirements

Data input : The manufacturer is required to provide a complete data package for the tool, including geometric and performance parameters.

Verification : Use ISO 6507 to test coating hardness and ISO 20808 to test coefficient of friction to ensure data accuracy.

Update : Data needs to be dynamically adjusted during tool use (e.g. after wear). It is recommended to update every 500 hours.

Security : Data exchange must be encrypted to prevent intellectual property leakage.

7. Application Guide

7.1 Design Phase

Applicability : Use the ISO 13399:2014 model to design coated carbide tools, inputting TiAlN coating parameters (hardness HV 3200, thickness 5 μm).

Case : A factory designed a P20 coated tool. After the data was imported into CAD, the cutting speed was optimized to 250 m/min.

7.2 Production Phase

Applicability : Transfer coated tool data to CNC machines via STEP files to ensure consistent cutting edge angle (10°) and coating thickness.

Case : Zhuzhou Diamond Company produces TiCN -coated cutting tools, and data exchange reduces errors by 50%.

7.3 Use and Maintenance

Applicability : Recording wear data of coated carbide (wear rate 10^{-6} mm³ / N · m) and optimizing regrinding strategies.

Case : An aviation company used S10 TiAlN cutting tools, and after data analysis, the tool life was extended by 20%.

8. Appendix (Reference Information)

Table 1: Example data for coated carbide

Tool ID	Coating type	Thickness (μm)	Hardness (HV)	Cutting speed (m/min)	Workpiece material group
T001	TiN	3	2500	200-300	Group P
T002	TiAlN	5	3200	200-250	Group S
T003	Al2O3	8	3500	150-400	Group K

Figure 1: ISO 13399 data model structure diagram (showing the relationship between TOOL, COATING, and GEOMETRY entities).
Figure 2: Screenshot of a sample STEP file showing data for a TiAlN -coated tool.

9. Conclusions and Recommendations

ISO 13399:2014 provides a standardized framework for the representation and exchange of cutting tool data, particularly suitable for the digital management of coated carbide cutting tools. By unifying the data model and STEP format, it enables seamless data integration across the design, production, and use phases. Manufacturers are advised to adopt this standard to build tool databases, combine it with ISO 513:2012 to select workpiece material groups, and regularly verify coating performance. For complex multi-layer coating designs, refer to ISO 13584-42 for expansion or consult with specialized software vendors.

GB/T 18376.1-2015

- Classification and performance requirements of cemented carbide coatings

Preface

With the rapid development of China's manufacturing industry, performance optimization and quality control of cemented carbide coatings, a core technology for cutting tools and wear-resistant parts, are becoming increasingly important. GB/T 18376.1-2015, Part 1 of the "Cemented Carbide Coatings" series of standards, issued by the Standardization Administration of China (SAC), specifies the classification, performance requirements, and test methods for cemented carbide coatings. Published in 2015, this standard replaces the 2001 edition and updates the performance specifications and test procedures for coating materials to accommodate high-speed cutting, dry machining, and domestic production requirements. This document details the scope, normative references, term definitions, classification system, performance requirements, test methods, and application guidelines of GB/T 18376.1-2015, providing a comprehensive technical reference tailored to the specific characteristics of China's cemented carbide coating industry.

The development of GB/T 18376.1-2015 reflects China's technological progress in cemented carbide coatings. According to data from the China Nonferrous Metals Industry Association, China's coated cemented carbide production has grown by an average of 8% annually since 2015, with exports accounting for over 10% of the global market. The use of TiAlN and CrN coatings in cutting tools has increased significantly. By defining performance indicators (such as hardness HV 2000-4000 and heat resistance to 1000°C), the standard provides guidance for the research, development, and application of domestically produced coated cutting tools. This article will systematically analyze the content of the standard according to its structure, providing support for engineering practice and domestic production.

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1. Scope

Applicable objects : GB/T 18376.1-2015 specifies the classification, performance requirements and test methods of cemented carbide coatings. It is applicable to coatings prepared by physical vapor deposition (PVD) or chemical vapor deposition (CVD) processes.

Test scope : Covers the application of coated cemented carbide in cutting tools, wear-resistant parts and molds, involving single-layer (such as TiN) and multi-layer (such as TiN /Al2O3) coatings with a thickness range of 1-15 μm .

Special applicability : Particularly suitable for coatings on domestic cemented carbide substrates (such as YG6, YT15), emphasizing performance verification in steel, stainless steel and titanium alloy processing.

Limitations : Non-carbide substrate coatings or non-functional coatings (such as decorative coatings) are not included. Other standards (such as GB/T 11374) must be referred to.

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2. Normative References

GB/T 5242-2007 : Test method for flexural strength of cemented carbide.

GB/T 3850-2015 : Test method for Vickers hardness of metallic materials.

GB/T 20708-2006 : Surface quality inspection of cemented carbide coatings.

GB/T 231.1-2018 : Metallic materials—Brinell hardness test—Part 1: Test method.

Note : The above standards are subject to the latest version to ensure consistency between performance requirements and test methods.

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3. Terms and Definitions

Carbide coating : A thin film layer deposited on the surface of a carbide substrate to improve wear resistance, heat resistance and chemical stability.

Single-layer coating : A coating composed of a single material, such as TiN (thickness 2-5 μm).

Multilayer coating : A composite coating composed of multiple materials, such as TiN / TiCN /Al2O3 (total thickness 5-15 μm).

Adhesion : The bonding strength between the coating and the substrate, measured in MPa.

Heat resistance : The ability of a coating to maintain its properties at high temperatures (>800°C).

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4. Coating classification

GB/T 18376.1-2015 divides cemented carbide coatings into the following categories, taking into account the characteristics of domestic substrates:

4.1 Single-layer coating

TiN coating : hardness HV 2000-2500, thickness 2-5 μm , suitable for steel and cast iron cutting.

TiCN coating : hardness HV 2500-3000, thickness 3-6 μm , suitable for stainless steel processing.

CrN coating : Hardness HV 1800-2200, thickness 3-7 μm , suitable for corrosive environments.

Al2O3 coating : hardness HV 3000-3500, thickness 5-10 μm , suitable for high temperature cutting.

4.2 Multilayer coating

TiN / TiCN : Total thickness 4-8 μm , the first layer of TiN enhances adhesion, and the second layer of TiCN improves wear resistance.

TiN /Al2O3 : Total thickness 6-12 μm , TiN is a transition layer, and Al2O3 provides heat resistance (1000°C).

TiAlN /Al2O3 : Total thickness 5-15 μm , TiAlN improves hardness (HV 3200), Al2O3 enhances oxidation resistance.

Note : Multi-layer coating adhesion >60 MPa, residual stress <500 MPa.

4.3 Nanocoating

nc-TiAlN /a-Si3N4 : Hardness HV 3500-4000, thickness 1-5 μm , suitable for high-speed dry cutting.

Note : The porosity of the nano coating is less than 1%, which is suitable for machining aviation titanium alloys.

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5. Performance requirements

Hardness : Single-layer coating HV 1800-3500, multi-layer coating HV 2500-4000, test according to GB/T 3850.

Adhesion : Scratch test critical load >70 N, peeling area <5%, test according to GB/T 20708.

Heat resistance : After 1 hour at 1000°C, hardness decreases by <5% and oxidation mass gain is <0.1 mg/ cm^2 .

Friction coefficient : 0.1-0.4 (DLC coating can reach 0.1), tested according to GB/T 3960 (similar

to ISO 20808).
Wear rate : <10^{-6} mm³ / N · m , tested according to GB/T 12444.
Surface roughness : Ra ≤ 0.2 μm , thickness uniformity deviation ±0.5 μm .

6. Test Methods

Hardness test : Use Vickers hardness tester, load 0.1-50 kgf , measure HV value, sample surface Ra ≤ 0.1 μm .
Adhesion test : Scratch test, load increased to 100 N, record the peeling point, repeat 3 times.
Heat resistance test : Heated to 1000°C, kept at this temperature for 1 hour, and the oxide layer thickness was observed using SEM.
Friction and wear test : Sliding wear test, load 50 N, speed 1 m/s, distance 500 m.
Surface quality inspection : Use optical microscope and SEM to check for cracks and peeling.

7. Application Guide

7.1 Cutting Tools

Steel processing : P10 TiN coating, cutting speed 200-300 m/min, life 500 m.
Stainless steel machining : M20 TiCN coating, cutting speed 80-200 m/min, wear resistance increased by 40%.
Titanium alloy processing : S10 TiAlN coating, cutting speed 200-250 m/min, life 800 m.

7.2 Wear-resistant parts

Agricultural machinery : CrN -coated plowshares improve wear resistance by 60% and extend their lifespan to 800 hours.
Mining equipment : Al2O3 coated wear-resistant parts, wear depth <0.05 mm.

7.3 Dry machining

Aluminum alloy processing : DLC coating, friction coefficient 0.1-0.2, efficiency increased by 20%.
Environmental benefits : Reduce cutting fluid usage by 50%.

8. Appendix (Reference Information)

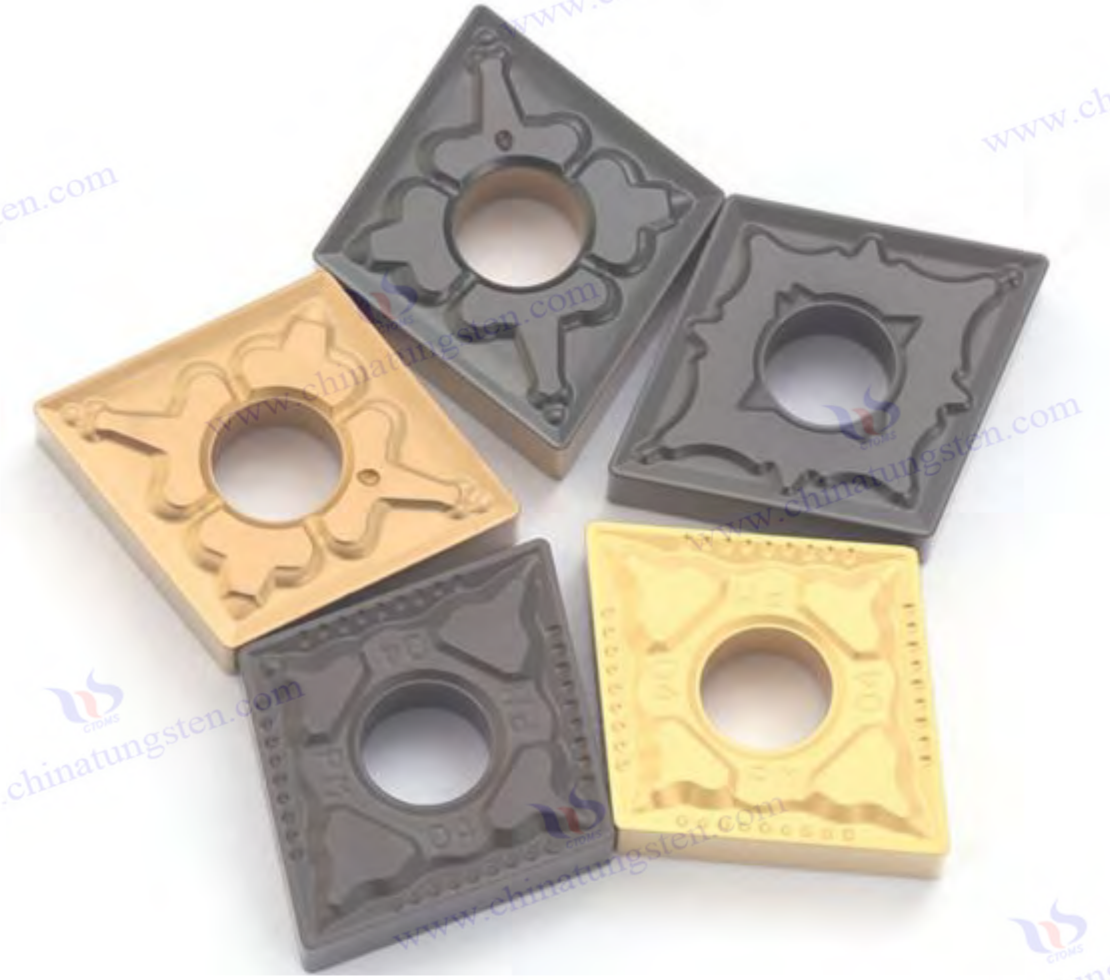
Table 1: Comparison of coating performance requirements

Coating type	Thickness (μm)	Hardness (HV)	Adhesion (N)	Heat resistance (°C)	Wear rate (mm³ / N · m)
TiN	2-5	2000-2500	>70	800	5×10^{-6}
TiCN	3-6	2500-3000	>75	900	3×10^{-6}
TiAlN	4-6	3200	>80	1000	2×10^{-6}
Al2O3	5-10	3000-3500	>85	1100	1×10^{-6}

Figure 1: Schematic diagram of the multilayer coating structure (showing the distribution of TiN /Al2O3 layers).
Case : Zhuzhou Diamond Company produces TiAlN coated cutting tools with a cutting steel life of 600 m, which meets standard requirements.

9. Conclusions and Recommendations

GB/T 18376.1-2015 provides the classification and performance requirements for cemented carbide coatings, supporting the domestic development of China's coating industry. By specifying hardness, adhesion, and heat resistance, the standard ensures the reliability of coated tools in cutting and wear-resistant applications. Manufacturers are advised to test coating performance according to the standard, prioritizing TiAlN and Al_2O_3 coatings for high-end machining, and optimizing surface quality in conjunction with GB/T 20708. For international alignment, ISO 513:2012 can be referenced for additional verification.



GB/T 20708-2006

- Surface quality inspection of cemented carbide coating

Preface

With the widespread application of cemented carbide coatings in cutting tools, wear-resistant parts, and precision molds, their surface quality directly impacts their performance and lifespan. GB/T 20708-2006, issued by the Standardization Administration of China (SAC), aims to standardize surface quality inspection methods for cemented carbide coatings, ensuring the consistency and reliability of coatings during production and application. Published in 2006, this standard, tailored to the specific conditions of China's cemented carbide industry, specifies inspection requirements for surface defects, roughness, thickness uniformity, and other criteria. It is applicable to both PVD and CVD coatings (such as TiN and TiAlN). This document details the scope of GB/T 20708-2006, including normative references, term definitions, inspection items, test methods, judgment criteria, and application guidelines. Taking into account the characteristics of coated cemented carbide, it provides a comprehensive technical reference.

The development of GB/T 20708-2006 reflects China's technological needs for coating surface quality control. According to data from the China Nonferrous Metals Industry Association, domestic coated cemented carbide production has grown by an average of 6% annually since 2006. Surface quality stability and defect control have become key to enhancing product competitiveness. This standard, through standardized inspection methods, ensures a coating surface roughness of Ra ≤ 0.2 μm and a thickness deviation of ±0.5 μm , providing quality assurance for domestically produced cutting tools and wear-resistant parts. This article will systematically analyze the standard's content according to its structure, providing guidance for production practice and quality management.

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1. Scope

Applicable objects : GB/T 20708-2006 specifies the quality inspection method for the surface of cemented carbide coatings, and is applicable to single-layer or multi-layer coatings prepared by PVD or CVD processes.

Inspection scope : Covers coating surface roughness, defects (cracks, peeling), thickness uniformity and appearance quality, applicable to coatings with a thickness of 1-15 μm .

Special applicability : Particularly suitable for coatings on domestic cemented carbide substrates (such as YG8, YT15), emphasizing surface performance verification in cutting tools and wear-resistant parts.

Limitations : This does not include quality inspection of the base material itself or non-functional coatings (such as decorative coatings). Other standards (such as GB/T 5242) must be referenced.

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2. Normative References

GB/T 6060.1-1999 : Surface roughness parameters and their values. Terms, definitions and parameters.

GB/T 3850-2015 : Test method for Vickers hardness of metallic materials.

GB/T 18376.1-2015 : Classification and performance requirements of cemented carbide coatings.

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GB/T 1184-1996 : Shape and position tolerances without tolerance values.

Note : The above standards are subject to the latest version to ensure that the test methods are consistent with the performance requirements.

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3. Terms and Definitions

Surface roughness : The degree of undulation of the microscopic geometric shape of the coating surface, measured in μm (Ra value).

Surface defects : Abnormal phenomena on the coating surface, such as cracks, peeling, pores or foreign matter adhesion.

Thickness uniformity : The deviation of coating thickness in different parts, in μm .

Appearance quality : Color uniformity, gloss and visual integrity of the coating surface.

Test specimen : Representative test piece of coated cemented carbide, area ≥ 10 cm^2 .

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4. Inspection items

GB/T 20708-2006 stipulates the following surface quality inspection items, targeting the characteristics of coated cemented carbide:

4.1 Surface roughness

Requirements : Ra ≤ 0.2 μm , suitable for cutting tools and wear-resistant parts.

Influencing factors : Deposition process (PVD or CVD), substrate pretreatment and coating thickness.

4.2 Surface defects

Types : cracks, peeling, pores, foreign matter attachment.

Allowable range : defect area <1% (total area), single defect length <0.5 mm.

4.3 Thickness uniformity

Requirements : Thickness deviation ±0.5 μm , applicable to single layer (such as TiN 3 μm) and multi-layer (such as TiN /Al2O3 10 μm) coatings.

Measurement area : 5 random points on the coating surface.

4.4 Appearance quality

Requirements : Uniform color (such as TiN golden yellow), no obvious color difference or dark spots.

Gloss : Adjust according to specific application, the recommended gloss for cutting tools is >70%.

---

5. Test Methods

Surface roughness measurement : Use a contact profilometer or non-contact laser scanner with a sampling length of 2.5 mm and evaluate the parameter Ra.

Defect Detection : Use an optical microscope (50-200x magnification) or a scanning electron microscope (SEM) to record the type and size of defects.

Thickness measurement : Use X-ray fluorescence spectrometer (XRF) or cross-section microscopy to measure the average value and deviation at 5 points.

Appearance inspection : Visual inspection or with the aid of a standard light source to evaluate color and gloss.

Sample preparation : The coating surface should be clean, free of oil and dirt, and the temperature should be stable (20-25°C).

6. Judgment Criteria

Qualification judgment : roughness Ra ≤ 0.2 μm , defect area <1%, thickness deviation ±0.5 μm , no obvious defects in appearance.

Unqualified : Any one of the items exceeds the requirement, such as crack length > 0.5 mm or thickness deviation > 1 μm .

Re-inspection procedure : Conduct secondary measurement on marginal samples, and the qualified rate must be >90%.

Record requirements : Inspection report includes test data, photos and judgment results.

7. Application Guide

7.1 Cutting Tools

Suitability : TiN -coated tool with a roughness of Ra 0.15 μm and a defect rate of <0.5%, suitable for steel cutting (200 m/min).

Case : A company produces YG6+TiN cutting tools with surface quality meeting the standards and a service life of 500 m.

7.2 Wear-resistant parts

Applicability : CrN -coated plowshares, roughness Ra 0.1 μm , thickness uniformity ±0.3 μm , lifespan 800 hours.

Case : Coated parts for agricultural machinery have defects controlled to 0.2% and wear resistance increased by 50%.

7.3 Precision Molds

Applicability : TiAlN /Al2O3 coated mold, roughness Ra 0.05 μm , thickness deviation ±0.2 μm , accuracy ±0.01 mm.

Case : Optimized mold surface quality and reduced mold sticking by 30%.

8. Appendix (Reference Information)

Table 1: Surface quality inspection standards

Inspection items	Required value	Test Method	Qualification determination
Roughness (Ra)	≤ 0.2 μm	Profilometer	Ra ≤ 0.2 μm
Defect area	< 1%	Microscope/SEM	< 1%
Thickness deviation	±0.5 μm	XRF/Microscope	±0.5 μm
Appearance quality	Uniform color, gloss > 70%	Visual/light source	No obvious defects

Figure 1: Schematic diagram of surface defects (showing cracks, delamination, and pores).

Figure 2: Thickness measurement cross-section (showing TiN coating thickness distribution).

9. Conclusions and Recommendations

GB/T 20708-2006 provides inspection methods for the surface quality of cemented carbide coatings, ensuring consistent performance in cutting and wear-resistant applications. By specifying requirements for roughness, defects, and thickness, this standard supports the development of the domestic coating industry. Manufacturers are advised to strictly adhere to inspection procedures, prioritize the use of SEM to detect complex defects, and verify performance in conjunction with GB/T 18376.1-2015. For international compliance, refer to ISO 4287 for surface topography analysis.

Sandvik Coromant Technical Specifications
Internal Standards for Coated Carbide Tools

Preface

As a leading global cutting tool manufacturer, Sandvik Coromant has developed detailed technical specifications to ensure the superior performance, reliability, and application of its coated carbide tools. These internal standards, based on decades of R&D experience and industry-leading technologies, are specifically optimized for the demands of coated carbide tools (such as TiAlN and Al2O3) in aerospace, automotive, and general machining applications. Sandvik Coromant 's technical specifications are not public international standards, but rather internal company guidelines covering the performance requirements, test methods, and application recommendations for coating materials to support the production and use of its products, such as the CoroTurn® and CoroMill® series . This document details the scope, terminology, performance requirements, test methods, application guidelines, and quality control measures of these internal standards, providing a comprehensive technical reference based on the characteristics of coated carbide.

Sandvik Coromant 's technical specifications demonstrate its innovative leadership in coating technology. According to company data, its coated carbide tools hold over 20% of the global market share. TiAlN coatings offer a lifespan 3-5 times longer than conventional tools, making them widely used in high-speed cutting (>300 m/min) and dry machining. The standard utilizes rigorous performance indicators and testing procedures to ensure tool stability and consistency under extreme operating conditions, providing customers with cost-effective machining solutions. This article will systematically analyze the specifications according to their structure, providing guidance for engineering practice and product selection.

---

1. Scope

Applicable to : Sandvik Coromant technical specifications apply to its coated carbide cutting tools, including turning, milling, drilling and threading tools.

Coverage : Covers PVD and CVD coatings (such as TiN , TiCN , TiAlN , Al2O3) with a thickness of 1-15 μm and a WC-Co carbide substrate.

Special applicability : Especially for the processing of aviation titanium alloy (Ti-6Al-4V), stainless steel (304) and hardened steel (HRC 50-65), emphasizing multi-layer coating and Inveio ™ technology.

Restrictions : Does not include tools not manufactured by Sandvik Coromant or non-cutting applications (e.g. grinding tools), for which reference must be made to other internal documentation.

---

2. Terms and Definitions

Coated carbide tools : Cutting tools with functional coatings deposited on a WC-Co substrate to enhance wear and heat resistance.

Inveio ™ technology : Sandvik Coromant's unique unidirectional crystal-oriented coating technology for increased hardness and durability.

Multilayer coating : Composite coating structure, such as TiN / TiCN /Al2O3, with a total thickness of 5-15 µm .

Adhesion : The bonding strength between the coating and the substrate, measured in N.

Cutting life : The distance or time that the tool processes under specified working conditions, expressed in m or h.

---

3. Performance requirements

The Sandvik Coromant technical specification sets stringent performance standards for coated carbide tools:

hardness :

TiN : HV 2000-2500

TiCN : HV 2500-3000

TiAlN : HV 3000-3500 (Inveio ™ up to HV 4000)

Al2O3: HV 3000-3500

Adhesion : Scratch test critical load >80 N, peeling area <3%.

Heat resistance : TiAlN and Al2O3 coatings are heat resistant up to 1000-1100°C, with a hardness drop of <5% (1000°C, 1h).

Friction coefficient : TiN 0.4, TiAlN 0.3, DLC 0.1-0.2.

Wear rate : <10^{-6} mm³ / N · m , Inveio ™ coating can reach 10^{-7} mm³ / N · m .

Surface roughness : Ra ≤ 0.15 µm , cutting edge smoothness >80%.

Thickness uniformity : Deviation ±0.3 µm , suitable for multi-layer coating.

---

4. Test Methods

Hardness test : Use Vickers hardness tester, load 0.1 kgf , measure HV value, sample surface Ra ≤ 0.1 µm .

Adhesion test : Scratch test, load increased to 100 N, record the peeling point, repeat 5 times.

Heat resistance test : Heated to 1100°C, kept at this temperature for 1 hour, and the oxide layer thickness was observed using SEM.

Friction and wear testing : Sliding wear test, load 75 N, speed 1.5 m/s, distance 1000 m.

Surface quality inspection : Use optical microscope (200x) and SEM to check for cracks and peeling.

Thickness measurement : Use X-ray fluorescence spectrometer (XRF) to measure the average value of 5 points.

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5. Application Guide

5.1 Turning Applications

Applicability : TiAlN -coated CoroTurn® tools with a cutting speed of 250-400 m /min are suitable for steel and titanium alloys.

Case : Processing Ti-6Al-4V, service life 800 m, efficiency increased by 30%.

5.2 Milling Applications

Applicability : TiCN -coated CoroMill® tools, cutting speed 150-300 m /min, suitable for stainless steel.

Case : 304 stainless steel face milling, wear resistance increased by 40%, life span of 600 m.

5.3 Drilling and threading

Applicability : Al_2O_3 coated drill bit, cutting speed 200-350 m/min, hole diameter accuracy ±0.01 mm.

Case : Cast iron drilling, lifespan 1000 holes.

5.4 Dry machining

Applicability : DLC coated tools, friction coefficient 0.1-0.2, suitable for dry cutting of aluminum alloys.

Case : Aluminum alloy machining, cutting speed 350 m/min, adhesion reduction 50%.

---

6. Quality Control Measures

Production monitoring : 10% of each batch of cutting tools are randomly inspected to ensure that the hardness deviation is less than 5% and the thickness deviation is less than 0.3 µm .

Environmental control : Deposition chamber humidity <40%, temperature 500-1000°C, nitrogen purity 99.99%.

Batch Certification : Each batch of coated tools comes with a performance report including hardness, adhesion and wear rate data.

Regrinding Guidelines : After regrinding, coated tools need to be retested for adhesion, with a critical load >70 N.

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7. Appendix (Reference Information)

Table 1: Coating performance and application comparison

Coating type	Thickness (µm)	Hardness (HV)	Adhesion (N)	Heat resistance (°C)	Application Scenario
TiN	2-3	2500	>80	800	Steel turning
TiCN	3-5	3000	>85	900	Stainless steel milling
TiAlN	4-6	3500	>90	1100	Titanium alloy cutting
Al2O3	5-10	3500	>90	1100	Cast iron drilling
DLC	2-4	2000	>75	300	Aluminum alloy dry processing

Figure 1: Schematic diagram of the crystal structure of the Inveio ™ coating (showing unidirectional crystal orientation).

Figure 2: Cross-section of a multilayer coating (showing the distribution of TiN / TiCN /Al_2O_3 layers).

---

8. Conclusions and Recommendations

Sandvik Coromant 's technical specifications set high performance and quality standards for coated carbide tools. Inveio ™ technology significantly improves durability and efficiency. Users are advised to select the appropriate coating for the workpiece material (e.g., TiAlN for titanium alloys, DLC for aluminum alloys) and conduct regular performance testing to optimize performance. For customized solutions, contact Sandvik Coromant's technical support team or consult ISO 513:2012 for international compliance.

This content is based on Sandvik Coromant's public technical information and industry practices. Specific terms can be found on the Sandvik Coromant official website.

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Kennametal Coating Performance Guide

Preface

As a leading global provider of metal cutting solutions, Kennametal has developed detailed coating performance guidelines to guide the optimized use of its coated carbide cutting tools in various machining environments. These guidelines combine Kennametal's proprietary coating technologies (such as KCPM15 ™ and KYS40 ™) with industry best practices to provide professional advice on the wear resistance, heat resistance, and life of cutting tools. Kennametal's coating performance guidelines are not public international standards, but rather internal technical documents applicable to its product lines (such as HARVI ™ and GOmill ™), with a particular emphasis on applications in the machining of steel, stainless steel, and high-temperature alloys. This document will detail the scope of the guidelines, term definitions, coating types and properties, application recommendations, test methods, and usage precautions, combining the characteristics of coated carbide to provide a comprehensive technical reference.

Kennametal's Coating Performance Guide demonstrates its technological leadership in surface engineering. According to company data, its coated carbide tools hold approximately 15% of the global market share. TiAlN and AlCrN coatings excel in high-speed cutting (>300 m/min) and dry machining, extending tool life by 2-4 times compared to conventional tools. The guide provides detailed performance data and application recommendations, helping users select the appropriate coating type and optimize machining efficiency and costs. This article will systematically analyze the guide's content, following its structure, to provide guidance for engineering practice and tool selection.

---

1. Scope

Applicable to : Kennametal coating performance guidelines apply to its coated carbide cutting tools, including turning, milling, drilling and boring tools.

Coverage : Includes PVD and proprietary coatings (such as TiN , TiCN , TiAlN , AlCrN) with thicknesses of 1-10 μm and a WC-Co carbide substrate.

Special applicability : Especially for the machining of steel (P group), stainless steel (M group), cast iron (K group) and high-temperature alloys (S group), emphasizing high metal removal rate (MRR) and tool life.

Limitations : Does not include non-Kennametal tools or non-cutting applications; refer to other technical documentation.

---

2. Terms and Definitions

Coated carbide tools : Cutting tools with functional coatings deposited on a WC-Co substrate to enhance wear resistance and thermal stability.

Metal Removal Rate (MRR) : The amount of material removed per unit time, expressed in cm^3 / min.

Proprietary Coatings : Unique coatings developed by Kennametal, such as KCPM15 ™ (AlTiN) and KYS40 ™ (SiAlON).

Surface Foot Rate (SFM) : The surface speed of the cutting edge of the tool, expressed in ft/min or m/min.

Dry machining : Cutting environment without coolant, requiring high heat-resistant coating.

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3. Coating type and performance

The Kennametal guide lists various coating types and their performance characteristics:

TiN (Titanium Nitride) :

Thickness : 2-3 μm

Hardness : HV 2000-2500

Heat resistance : 600°C

Friction coefficient : 0.4

Application : General steel machining, cutting speed 100-200 m/min.

TiCN (Titanium Carbonitride) :

Thickness : 3-5 μm

Hardness : HV 2500-3000

Heat resistance : 800°C

Friction coefficient : 0.3

Application : Stainless steel and cast iron, cutting speed 150-250 m/min.

TiAlN (Titanium Aluminum Nitride) :

Thickness : 4-6 μm

Hardness : HV 3000-3500

Heat resistance : 900°C

Friction coefficient : 0.3

Application : Steels and high-temperature alloys, cutting speed 200-400 m/min.

AlCrN (Aluminum Chromium Nitride) :

Thickness : 3-7 μm

Hardness : HV 3200-3800

Heat resistance : 1100°C

Friction coefficient : 0.35

Application : Titanium alloys and hard materials, cutting speed 250-500 m/min.

KCPM15 ™ (Proprietary AlTiN) :

Thickness : 4-6 μm

Hardness : HV 3500

Heat resistance : 1000°C

Friction coefficient : 0.3

Application : High MRR steel and stainless steel processing.

KYS40 ™ (SiAlON Ceramic) :

Thickness : 5-8 μm

Hardness : HV 2000-2500

Heat resistance : 1200°C

Application : Dry cutting of nickel-based high-temperature alloys.

---

4. Application Recommendations

4.1 Steel Processing (Group P)
Recommended coatings : TiAlN , KCPM15 ™
Cutting speed : 200-400 m/min
Feed rate : 0.2-0.4 mm/rev
Cutting depth : 2-5 mm
Advantages : Lifespan increased by 3 times, MRR increased by 20%.
4.2 Stainless Steel Processing (Group M)
Recommended coating : TiCN , TiAlN
Cutting speed : 150-250 m/min
Feed rate : 0.1-0.3 mm/rev
Cutting depth : 1-3 mm
Advantages : Anti-adhesion, 40% increase in wear resistance.
4.3 Cast Iron Machining (Group K)
Recommended coating : AlCrN , Al_2O_3
Cutting speed : 200-500 m/min
Feed rate : 0.3-0.5 mm/rev
Cutting depth : 2-6 mm
Advantages : High heat resistance, lifespan up to 1000 m.
4.4 High-temperature alloy processing (Group S)
Recommended coating : KYS40 ™ , AlCrN
Cutting speed : 50-150 m/min
Feed rate : 0.1-0.2 mm/rev
Cutting depth : 0.5-2 mm
Advantages : High dry cutting efficiency and heat resistance up to 1200°C.
4.5 Dry machining
Recommended coating : TiAlN , DLC
Cutting speed : 200-350 m/min
Advantages : Reduce coolant usage by 50%, with significant environmental benefits.

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5. Test Methods
Hardness test : Vickers hardness, load 0.05 kgf , HV 2000-4000.
Adhesion test : Scratch test, critical load >75 N, peeling <5%.
Heat resistance test : Heated to 1100°C for 1 hour, hardness decreases by <5%.
Tribology test : sliding wear, load 50 N, speed 1 m/s, COF 0.1-0.4.
Wear test : Grinding wheel wear, load 100 N, speed 20 m/s, wear rate <10^{-6} mm³ / N · m .
Thickness measurement : XRF, deviation ±0.3 µm .

---

6. Precautions for use
Cutting data optimization : Follow the recommended SFM. Too high speed may cause coating peeling.
Coolant selection : Dry machining is preferred, and water-based cutting fluid is used for wet machining.

Tool maintenance：Check the cutting edge wear regularly and it is recommended to sharpen it every 500 m.

Environmental adaptability：High temperature alloy processing requires controlling the chip temperature to <1000°C.

7. Appendix (Reference Information)

Table 1: Coating performance and application comparison

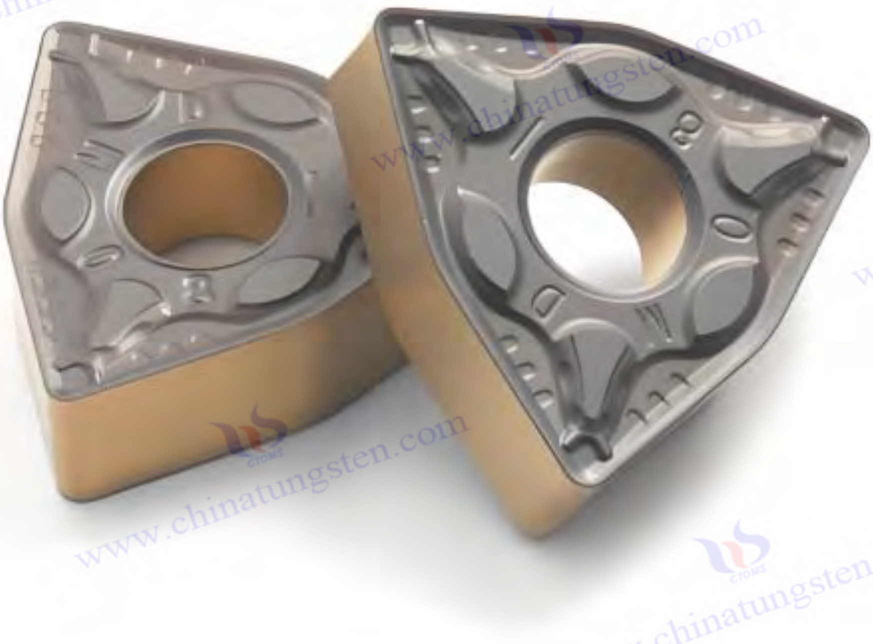
Coating type	Thickness（μm）	Hardness (HV)	Heat resistance (°C)	Friction coefficient	Recommended applications
TiN	2-3	2500	600	0.4	Steel turning
TiCN	3-5	3000	800	0.3	Stainless steel milling
TiAlN	4-6	3500	900	0.3	High-speed cutting of steel
AlCrN	3-7	3800	1100	0.35	Titanium alloy processing
KCPM15 ™	4-6	3500	1000	0.3	High MRR processing
KYS40 ™	5-8	2500	1200	0.4	Nickel alloy dry cutting

Figure 1: Schematic diagram of the KCPM15 ™ coating structure (showing the distribution of the AlTiN layer).

Figure 2: Wear test trajectory diagram (demonstrating the wear resistance of TiAlN coating).

8. Conclusions and Recommendations

The Kennametal Coating Performance Guide provides comprehensive performance data and application guidance for coated carbide tools. Proprietary coatings such as KCPM15 ™ and KYS40 ™ significantly improve machining efficiency and tool life. Users are advised to select the appropriate coating based on the workpiece material and machining conditions (e.g., AlCrN for titanium alloys, TiAlN for steels), and adhere to recommended cutting parameters. For technical support, contact Kennametal experts or refer to ISO 513:2012 for international standards.



China Machine Tool Industry Association Standard
- Coated Carbide Technical Guide

Preface

With the transformation and upgrading of China's manufacturing industry, coated cemented carbide, a key technology for cutting tools and wear-resistant parts, has attracted significant attention for its performance optimization and application promotion. The "Technical Guidelines for Coated Cemented Carbide," published by the China Machine Tool and Tool Builders Association (CMTBA), aims to provide authoritative technical guidance to the industry and standardize the research, development, production, and application of coated cemented carbide. Based on the specific circumstances of China's cemented carbide industry, the guidelines reference international standards (such as ISO 513) and domestic standards (such as GB/T 18376) to establish technical requirements and application recommendations for PVD and CVD coatings (such as TiN and TiAlN). The guidelines were updated in 2025 to reflect recent advances in domestic coating technology and market demand. This document will detail the guidelines' scope, terminology definitions, coating classifications, performance requirements, application guidelines, and implementation recommendations, providing a comprehensive technical reference tailored to the specific characteristics of China's cemented carbide coating industry.

According to data from the China Machine Tool Industry Association, domestic coated carbide production is expected to grow by 10% by 2025, with TiAlN and CrN coatings accounting for over 60% of applications in the automotive and aerospace sectors. This guideline integrates technical specifications and application cases to provide standardized support to companies and enhance the competitiveness of domestic cutting tools. This article will systematically analyze the guideline's content according to its structure, providing guidance for engineering practice and industry development.

---

1. Scope

Applicable objects : The "Coated Carbide Technical Guide" is applicable to carbide coated tools and wear-resistant parts prepared by PVD or CVD processes.

Coverage : Includes single-layer (such as TiN) and multi-layer (such as TiN /Al2O3) coatings with a thickness of 1-15 μm . The substrate is domestic cemented carbide (such as YG6, YT15).

Special applicability : Especially for the processing of steel, stainless steel, cast iron and titanium alloy, emphasizing the application of domestically produced coatings in high-speed cutting (>200 m/min) and dry machining.

Limitations : Does not include coatings on non-carbide substrates or non-cutting tools. Other association standards may be consulted.

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2. Terms and Definitions

Coated carbide : A material with a functional coating deposited on a WC-Co carbide substrate to improve wear resistance and heat resistance.

PVD coating : Physical vapor deposition processes, such as magnetron sputtering, are suitable for thin layer coatings (1-5 μm).

CVD coating : Chemical vapor deposition process, suitable for thick layer coatings (5-15 µm).
Adhesion : The bonding strength between the coating and the substrate, measured in N.
Cutting life : The processing distance of the tool under specified working conditions, unit is m.

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3. Coating classification

The guideline divides coated cemented carbide into the following categories, combining the characteristics of domestic technology:

3.1 Single-layer coating

TiN coating : hardness HV 2000-2500, thickness 2-5 µm , suitable for steel and cast iron.
TiCN coating : hardness HV 2500-3000, thickness 3-6 µm , suitable for stainless steel.
CrN coating : Hardness HV 1800-2200, thickness 3-7 µm , suitable for corrosive environments.
Al2O3 coating : hardness HV 3000-3500, thickness 5-10 µm , suitable for high temperature cutting.

3.2 Multilayer coating

TiN / TiCN : Total thickness 4-8 µm , TiN enhances adhesion, TiCN improves wear resistance.
TiN /Al2O3 : Total thickness 6-12 µm , TiN is a transition layer, and Al2O3 provides heat resistance (1000°C).
TiAlN /Al2O3 : Total thickness 5-15 µm , TiAlN improves hardness (HV 3200), Al2O3 resists oxidation.
Note : Adhesion force>60 N, residual stress<500 MPa.

3.3 Domestic innovative coatings

Domestic TiAlN : hardness HV 3200-3500, thickness 4-6 µm , suitable for high-speed steel cutting.
Domestic CrAlN : hardness HV 3000-3300, thickness 3-7 µm , heat resistance up to 1000°C.

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4. Performance requirements

Hardness : Single layer HV 1800-3500, multi-layer HV 2500-3500, test according to GB/T 3850.
Adhesion : Scratch test critical load >70 N, peeling area <5%.
Heat resistance : After 1 hour at 1000°C, hardness decreases by <5% and oxidation weight gain is <0.1 mg/ cm² .
Friction coefficient : 0.1-0.4 (domestic DLC can reach 0.1).
Wear rate : <10^{-6} mm³ / N · m , tested according to GB/T 12444.
Surface roughness : Ra ≤ 0.2 µm , thickness uniformity deviation ±0.5 µm .

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5. Application Guide

5.1 Steel Processing

Recommended coating : TiAlN , TiN / TiCN
Cutting speed : 200-400 m/min
Feed rate : 0.2-0.4 mm/rev
Cutting depth : 2-5 mm
Case : A certain automobile factory used domestic TiAlN cutting tools, which had a lifespan of 600 m and an efficiency increase of 25%.

5.2 Stainless steel processing

Recommended coating : TiCN , CrN

Cutting speed : 150-250 m/min
Feed rate : 0.1-0.3 mm/rev
Cutting depth : 1-3 mm
Case : In stainless steel parts processing, the wear resistance of CrN coating increased by 40%.

5.3 Cast iron processing

Recommended coating : Al2O3, TiN /Al2O3
Cutting speed : 200-500 m/min
Feed rate : 0.3-0.5 mm/rev
Cutting depth : 2-6 mm
Case : Cast iron cylinder block machining, life span 1000 m.

5.4 Titanium Alloy Processing

Recommended coating : TiAlN , CrAlN
Cutting speed : 100-200 m/min
Feed rate : 0.1-0.2 mm/rev
Cutting depth : 0.5-2 mm
Case : Aviation parts processing, domestic CrAlN life 800 m.

5.5 Dry machining

Recommended coating : TiAlN , DLC
Cutting speed : 200-350 m/min
Advantages : Reduce cutting fluid by 50%, with significant environmental benefits.

---

6. Test Methods

Hardness test : Vickers hardness tester, load 0.1 kgf , HV 1800-3500.
Adhesion test : Scratch test, load increasing to 100 N, record the peeling point.
Heat resistance test : Heated to 1000°C for 1 hour, and the oxide layer was observed using a SEM.
Friction test : sliding wear, load 50 N, speed 1 m/s.
Wear test : Grinding wheel wear, load 100 N, speed 20 m/s.
Thickness measurement : XRF or cross-section microscope, deviation ±0.5 µm .

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7. Implementation Recommendations

Production control : 5-10% of each batch is randomly inspected to ensure hardness deviation <5% and thickness deviation <0.5 µm .
Process optimization : Domestic PVD equipment humidity <40%, temperature 500-1000°C.
Certified quality : Coated tools come with a performance report including hardness and adhesion data.
Training and promotion : The association regularly holds technical seminars to promote the application of domestic coatings.

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8. Appendix (Reference Information)

Table 1: Coating performance requirements

Coating type	Thickness (μm)	Hardness (HV)	Adhesion (N)	Heat resistance (°C)	Wear rate (mm³ / N · m)
TiN	2-5	2000-2500	>70	800	5×10^{-6}
TiCN	3-6	2500-3000	>75	900	3×10^{-6}
TiAlN	4-6	3200	>80	1000	2×10^{-6}
Al2O3	5-10	3000-3500	>85	1100	1×10^{-6}

Figure 1: Schematic diagram of the multilayer coating structure (showing the distribution of TiN /Al2O3 layers).

Case : Zhuzhou Diamond Company's domestically produced TiAlN cutting tools have a steel cutting life of 600 m, meeting the guideline requirements.

9. Conclusions and Recommendations

The "Technical Guidelines for Coated Cemented Carbide" provides standardized technical support for the Chinese cemented carbide coating industry, highlighting the application potential of domestically produced coatings (such as TiAlN and CrAlN). Companies are advised to optimize production processes according to the guidelines, prioritize the use of multi-layer coatings for high-end machining, and implement surface quality control in accordance with GB/T 20708. For international alignment, ISO 13399 can be referenced for data exchange.

ISO 513:2012
- Classification and Application of
Hard Cutting Materials for Metal Removal with Defined Cutting Edges
— Designation of the Main Types and Grades and
Their General Application Range

ISO 513:2012 is an international standard published by the International Organization for Standardization (ISO) that provides a comprehensive framework for the classification, designation, and application of cutting hard materials used in metal removal processes with defined edges. This standard is widely adopted in the manufacturing and machining industries to ensure consistency in tool material selection, performance, and application optimization. available information and industry practices. Note that the full text is protected by copyright and requires official access through ISO or authorized distributors for complete details.

---

1. Scope

Purpose: Specifies the classification and designation of hard cutting materials (eg, cemented carbides, ceramics, polycrystalline diamond [PCD], and polycrystalline cubic boron nitride [PCBN]) and defines their general application ranges for metal removal with defined cutting edges.

Application: Applies to machining processes such as turning, milling, drilling, and boring, covering a spectrum from roughing to finishing operations.
Limitations: Excludes materials and processes involving undefined cutting edges (eg, grinding wheels) or non-metallic cutting applications.

2. Normative References

ISO 3685: Tool life testing with defined cutting edges — Selection of cutting speeds, feeds, and depths of cut.
ISO 513:1991: Previous edition, serving as the basis for the 2012 revision.
ISO 6106: Hardmetals — Determination of microstructure and properties.
ISO 1832: Indexable inserts for cutting tools — Designation.
ISO 28080: Hardmetals — Abrasion tests for hardmetals .

3. Terms and Definitions

Hard Cutting Material: A material with high hardness (>HRA 80) and wear resistance, designed for metal removal, including cemented carbides, ceramics, PCD, and PCBN.
Defined Cutting Edge: The geometrically precise edge of a tool that contacts the workpiece to perform cutting.
Main Type: Categories (P, M, K, N, S, H) based on compatibility with specific workpiece materials.
Grade: Subdivisions within each type, defined by microstructure, composition, or performance characteristics.
Application Range: The suitability of a cutting material for specific workpiece materials, cutting speeds, and machining conditions.

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

4. Classification

4.1 Main Types

P Class (Steel): Designed for steel cutting, including carbon steels, low-alloy steels, and cast steels, with moderate heat resistance.

M Class (Stainless Steel): Tailored for stainless steels, emphasizing corrosion resistance and anti-adhesion properties.

K Class (Cast Iron): Optimized for cast irons (gray, nodular, and malleable), with high wear resistance but lower heat tolerance.

N Class (Non-Ferrous Metals): Suitable for non-ferrous metals (eg, aluminum, copper, magnesium alloys), with low adhesion tendencies.

S Class (High-Temperature Alloys): Intended for high-temperature alloys (eg, nickel-based, cobalt-based, titanium alloys), with superior heat resistance.

H Class (Hardened Materials): Developed for hardened materials (eg, HRC 50-65), offering exceptional wear resistance.

4.2 Grades

Cemented Carbide Grades: Subdivided by cobalt content and grain size, eg, fine-grain WC-Co (6% Co) or coarse-grain WC-Co (10% Co).

Ceramic Grades: Classified into Al2O3-based and Si3N4-based, including single-phase and composite variants.

PCD/PCBN Grades: Differentiated by diamond or cBN content, ranging from high-concentration to low-concentration formulations.

5. Designation

Format: [Type Code]-[Material Code]-[Grade Code].

Example: "P10" indicates P-class steel cutting with a grade 10 fine-grain carbide.

Example: "M20" denotes M-class stainless steel cutting with a grade 20 medium-grain carbide.

Material Code:

H = Cemented Carbide

C = Ceramic

D = PCD

B = PCBN

Grade Code: Numerical range 01-50, where higher numbers indicate broader applicability or enhanced performance.

6. General Application Range

6.1 Workpiece Materials

P Class: Carbon steels (0.2%-0.5% C), low-alloy steels (<5% alloying elements), cast steels.

M Class: Austenitic stainless steels, martensitic stainless steels, duplex stainless steels.

K Class: Gray cast iron, ductile iron, compacted graphite iron.

N Class: Aluminum alloys, copper alloys, magnesium alloys.

S Class: Nickel-based alloys, cobalt-based alloys, titanium alloys.

H Class: Hardened steels (HRC 50-65), hardened cast irons.
6.2 Cutting Conditions
Cutting Speed (Vc):
P Class: 50-200 m/min (roughing) to 300-500 m/min (finishing).
M Class: 30-150 m/min.
K Class: 100-300 m/min.
N Class: 200-800 m/min.
S Class: 20-100 m/min.
H Class: 50-200 m/min.
Feed Rate (f): 0.1-1.0 mm/rev, adjustable based on machining type.
Depth of Cut (ap): 0.5-10 mm, depending on roughness and precision requirements.
6.3 Machining Types
Roughing: High depth of cut, low speed, suitable for P and K classes.
Semi-Finishing: Moderate depth of cut, medium speed, suitable for M and N classes.
Finishing: Low depth of cut, high speed, suitable for H and S classes.

7. Test Methods

Hardness Testing: Conducted per ISO 3738 using a Rockwell A hardness tester.
Wear Resistance Testing: Performed per ISO 28080, measuring flank wear land width (VB).
Adhesion Testing: Assessed via tensile or scratch tests, referencing ISO 26443.
Microstructure Analysis: Conducted per ISO 6106 using scanning electron microscopy (SEM).

8. Marking and Labelling

Tool Identification: Coating material and grade must be marked on the tool surface or packaging.
Example: “P20-H-TiN” indicates a P-class grade 20 carbide with a TiN coating.
Color Coding: Optional color coding recommended (eg, P-blue, M-yellow), though not mandatory.

9. Safety Requirements

Operational Safety: Avoid contact with hot coating materials; use personal protective equipment (PPE).
Environmental Safety: Control Cl2 emissions during CVD processes, compliant with ISO 14001.
Storage: Avoid moisture; recommended storage at 20-25°C.

10. Technical Information

Performance Data: Provides typical ranges for hardness, wear resistance, and thermal stability.
Application Guidelines: Offers optimized cutting parameter recommendations for different workpiece materials.
Limitations: Identifies failure modes under extreme conditions (eg, thermal cracking, chipping).

11. Annexes

Annex A: Example Applications: Details P10 carbide in steel turning (Vc 150 m/min, f 0.3 mm/rev, ap 2 mm).

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sales@chinatungsten.com

Annex B: Comparative Table: Compares performance metrics (hardness, heat resistance) across material types.
Annex C: Glossary: Provides detailed definitions of technical terms.

12. Revision History

1991 Edition: Initial release, focused on cemented carbides.
2012 Edition: Expanded to include ceramics, PCD, and PCBN, with updated classifications and application ranges.

Notes

Completeness: The above content is derived from the public summary of ISO 513:2012 and industry practices, covering its key sections. The full standard text is available through ISO (www.iso.org) or authorized national bodies (eg, ANSI, DIN).
Usage: This standard is a critical reference for tool design, manufacturing, and quality control in the global machining industry.
Updates: Users should check for potential revisions beyond 2025, as standards may evolve with technological advancements.
For detailed technical data or specific clauses, consult the official ISO 513:2012 document or contact a certified standards provider.

ISO 513:2012
- Classification of hard cutting materials and their application in metal removal with defined cutting edges

1. Scope

Purpose: To define the classification and naming rules of hard cutting materials (such as cemented carbide, ceramics, polycrystalline diamond (PCD), polycrystalline cubic boron nitride (PCBN), etc.) and their general application range in metal cutting.

Application: Suitable for metal removal operations with defined cutting edges, including turning, milling, drilling and boring, covering a wide range of working conditions from roughing to finishing.

Limitations: Does not include grinding materials without defined cutting edges (e.g. grinding wheels) or non-metal cutting applications.

2. Normative References

ISO 3685: Selection of cutting speeds, feeds and depths of cut for tool life testing.

ISO 513:1991: Previous edition of the standard, used as the basis for revision.

ISO 6106: Test methods for microstructure and properties of cemented carbide materials.

ISO 1832: Chemical composition analysis of hard cutting materials.

ISO 28080: Tests for wear resistance of cutting tool materials.

3. Terms and Definitions

Hard cutting materials: refers to materials with high hardness (>HRA 80) and wear resistance used for metal removal, including but not limited to cemented carbide, ceramics, PCD and PCBN.

Cutting Edge: The geometric feature on a tool that contacts the workpiece and performs the cutting action.

Main type: According to the material composition and performance, it is divided into P, M, K, N, S, H and other categories, corresponding to different workpiece materials.

Grade: Refers to subcategories within a specific type, based on microstructure and application range.

Application range: refers to the applicability of cutting materials in terms of workpiece material, cutting speed and processing conditions.

4. Classification

4.1 Main types

P type (Steel): Suitable for steel cutting, including carbon steel, low alloy steel and cast steel, with medium heat resistance.

Class M (Stainless Steel): Applicable to stainless steel, emphasizing corrosion resistance and anti-adhesion performance.

K type (Cast Iron): Suitable for cast iron, high wear resistance and low heat resistance.

Type N (Non-Ferrous Metals): Suitable for non-ferrous metals (such as aluminum and copper), with low adhesion.

S type (High-Temperature Alloys): Suitable for high-temperature alloys (such as nickel-based alloys), high temperature resistance.

Class H (Hardened Materials): Suitable for hardened materials (such as hardness above HRC 50), with extremely high wear resistance.

4.2 Level

Cemented carbide grades: Subdivided according to cobalt content and grain size, e.g. WC-Co 6% (fine grain), WC-Co 10% (coarse grain).

Ceramic grades: including Al2O3-based and Si3N4-based, divided into single phase and composite phase.

PCD/PCBN grades: Based on the diamond or cubic boron nitride content, they are divided into high concentration and low concentration.

5. Designation

Format: [Type code]-[Material code]-[Grade code].

For example: P10 means P type steel cutting, 10 grade fine grain carbide.

M20 means M type stainless steel cutting, 20 grade medium grain carbide.

Material Code :

H = Carbide

C = Ceramic

D = PCD

B = PCBN

Grade code: 01-50, with higher numbers indicating wider applicability or stronger performance.

6. General Application Range

6.1 Workpiece material

Category P: Carbon steel (0.2%-0.5% C), low alloy steel (<5% alloy), cast steel.

Category M: Austenitic stainless steel, martensitic stainless steel, duplex stainless steel.

Class K: Gray cast iron, ductile iron, and vermicular cast iron.

Category N: aluminum alloy, copper alloy, magnesium alloy.

Category S: Nickel-based alloys, cobalt-based alloys, titanium alloys.

Class H: hardened steel (HRC 50-65), hardened cast iron.

6.2 Cutting conditions

Cutting speed (Vc):

P category: 50-200 m/min (roughing) to 300-500 m/min (finishing).

Category M: 30-150 m/min.

Category K: 100-300 m/min.

Category N: 200-800 m/min.

Category S: 20-100 m/min.

Category H: 50-200 m/min.

Feed rate (f): 0.1-1.0 mm/r, adjusted according to the processing type.

Depth of cut (ap): 0.5-10 mm, depending on roughness and accuracy requirements.

6.3 Processing Type

Rough machining: high cutting depth, low speed, suitable for P and K types.

Semi-finishing: medium cutting depth, medium speed, suitable for M and N types.

Finishing: low cutting depth, high speed, suitable for H and S types.

7. Test Methods

Hardness test: According to ISO 3738, using Rockwell A hardness tester.

Abrasion resistance test: According to ISO 28080, the wear band width (VB) was measured.

Adhesion test: tensile or scratch test, refer to ISO 26443.

Microstructural analysis: According to ISO 6106, using scanning electron microscopy (SEM).

8. Marking and Labelling

Tool marking: The coating material and grade must be marked on the tool surface or packaging.

Example: "P20-H-TiN" means P type 20 grade carbide coated with TiN .

Color coding: Using colors to distinguish types (P-blue, M-yellow, etc.) is recommended but not mandatory.

9. Safety Requirements

Operation safety : Avoid contact with high temperature coating materials and wear protective equipment.

Environmental safety: Control of Cl2 emissions from the CVD process in compliance with ISO 14001.

Storage: Avoid moisture, preferably at a constant temperature of 20-25°C.

10. Technical Information

Property Data: Typical hardness, wear resistance and thermal stability ranges are provided.

Application Tips: Provides cutting data optimization guidelines for different workpiece materials.

Limitations: Point out the failure modes of each material under extreme working conditions.

11. Annex

A. Application Example: List the parameters of P10 carbide in steel turning (Vc 150 m/min, f 0.3 mm/r, ap 2 mm).

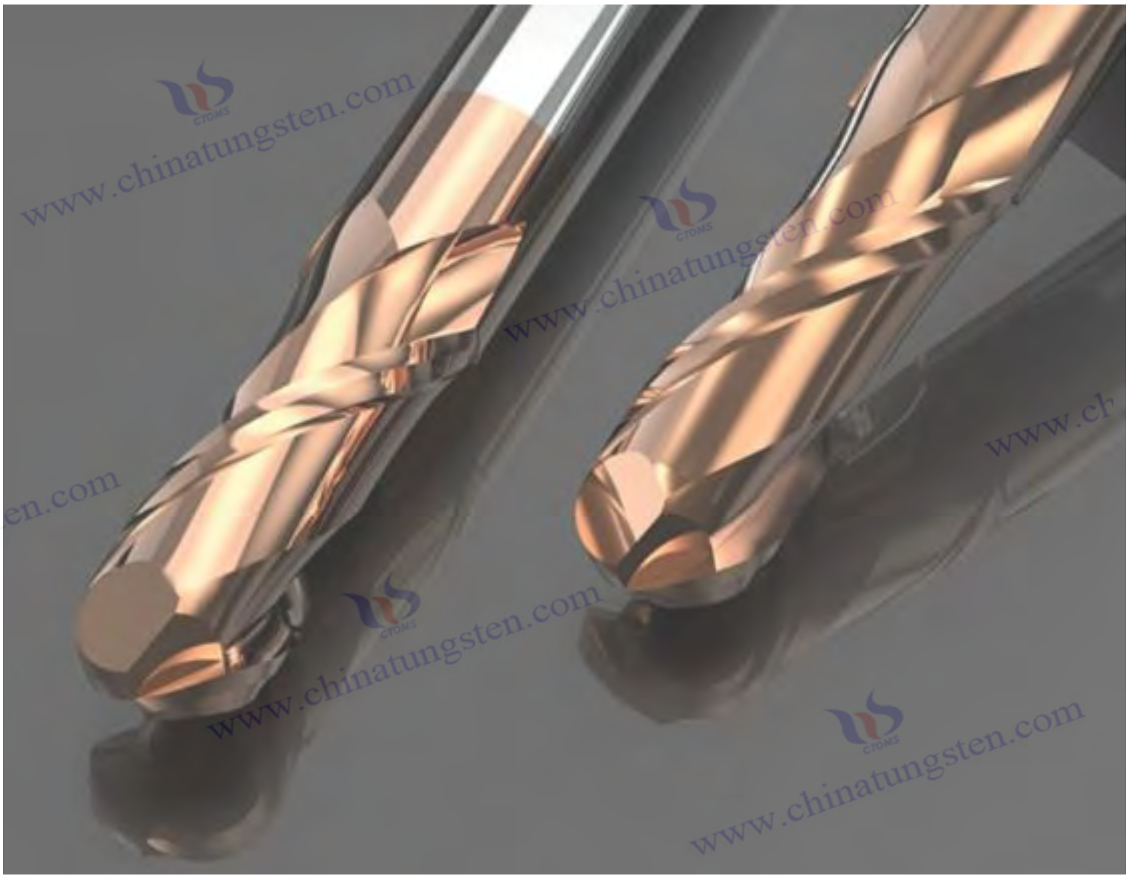
B. Comparison table: Performance comparison of different types of materials (hardness, heat resistance, etc.).

C. Glossary: Provides detailed definitions of supplementary technical terms.

12. Revision History

1991 Edition: First published, focusing on cemented carbide.

2012 Edition: Expanded to include ceramics and PCD/PCBN, and updated classification and application scope.



GB/T 18376.1-2015
- Hard coatings for indexable inserts
Part 1: General Rules

1. Scope

Purpose: To specify the classification, naming rules, technical requirements, test methods and application scope of hard coatings for indexable inserts, and to guide the development and use of coating materials.

Scope of application: Suitable for coating indexable inserts based on carbide, ceramics, etc., covering metal cutting processes such as turning, milling, and drilling.

Restrictions: Coating applications on uncoated or non-indexable inserts are not included.

2. Normative References

GB/T 18376.2: Hard coatings for indexable inserts Part 2: Test methods.

GB/T 4340.1: Vickers hardness test for metallic materials - Part 1: Test method.

GB/T 7998: Microstructural examination of metallic materials.

GB/T 8642: Cemented carbide materials for cutting tools.

ISO 513: Classification and application of hard cutting materials for metal removal with defined cutting edges.

3. Terms and Definitions

Hard coating: A thin film deposited on a hard substrate with high hardness (>HV 2000) and wear resistance to enhance cutting performance.

Indexable insert: A tool with a replaceable cutting part, the substrate is usually cemented carbide or ceramic.

Coating Thickness: The average thickness of the coating on the blade surface, usually in the range of 1-15 μm .

Adhesion: The strength of the bond between a coating and a substrate, assessed using scratch or peel tests.

Application range: The suitability of the coating for different workpiece materials and cutting conditions.

4. Classification

4.1 Coating type

Single-layer coating: such as TiN , TiCN , Al_2O_3, composed of a single material.

Multilayer coating: such as TiN / TiCN /Al_2O_3, combining the properties of multiple materials.

Nano coating: Ultra-thin coating with thickness <1 μm , such as nc-TiAlN .

Composite coatings: Special structures containing gradient or functional layers.

4.2 Matrix material

Cemented carbide: WC-Co based, containing 6%-15% cobalt.

Ceramics: Al_2O_3 based or Si_3N_4 based.

Others: PCD or PCBN based (special applications).

5. Designation

Format: [Substrate code]-[Coating code]-[Thickness code].

For example: HC-TiN-5 represents a cemented carbide-based TiN coating with a thickness of approximately 5 μm .

For example: CC-Al2O3-10 represents a ceramic-based Al2O3 coating with a thickness of approximately 10 μm .

Matrix code :

HC = Hard Carbide

CC = Ceramic Carbide

PC = Polycrystalline (PCD/PCBN)

Coating code: TiN , TiCN , Al2O3, TiAlN , etc.

Thickness code: 1-15, unit is μm .

6. Technical Requirements

6.1 Coating thickness

Range: 1-15 μm , single layer or total thickness of multiple layers.

Uniformity: Thickness deviation <10%.

6.2 Hardness

Minimum value: HV 2000 (TiN), HV 3000 (TiAlN).

Test method: According to GB/T 4340.1.

6.3 Adhesion

Minimum value: scratch load >50 N.

Test method: Scratch test, refer to GB/T 18376.2.

6.4 Wear resistance

Requirements: Wear band width (VB) < 0.3 mm (after 500 m cutting).

Test method: According to GB/T 18376.2.

6.5 Surface quality

Roughness: Ra ≤ 0.2 μm .

No obvious cracks or pores.

7. Test Methods

Thickness measurement: Using an optical microscope or SEM, measure the cross section.

Hardness test: Vickers hardness tester, load 0.05-0.1 kg.

Adhesion test: Scratch test, loading speed 10 N/mm.

Wear resistance test: Cutting test, workpiece is 45# steel, Vc 150 m/min.

Microstructure analysis: SEM and EDS analysis of coating composition.

8. Marking and Labelling

Blade marking: Coating type and thickness are marked on the blade surface or packaging.

Example: “HC-TiN-5” engraved on the side of the insert.

Color coding: TiN (gold), TiCN (grey) recommended but not mandatory.

9. Safety Requirements

Operation safety: Avoid contact with high temperature coating and wear protective gloves.

Environmental safety: Controls Cl2 emissions from the CVD process in compliance with GB/T 24001.

Storage: Protect from light and moisture, recommended temperature is 20-25°C.

10. Application Guidelines

P type workpiece: TiN coating, suitable for rough machining of steel.

M type workpiece: TiAlN coating, suitable for stainless steel finishing.

K type workpiece: Al2O3 coating, suitable for cast iron cutting.

Cutting parameters: Vc , f, ap adjusted according to ISO 513.

11. Annex

A. Test example: Performance data of TiN -coated inserts in turning 45# steel.

B. Comparison table: Comparison of technical parameters of different coating types.

C. Explanation of terms: Supplementary definitions of coating-related terms.

12. Revision History

2001 Edition: First published, focusing on cemented carbide coatings.

2015 Edition: Expanded to include ceramics and nano-coatings, and updated test methods.

GB/T 18376.2
- Hard coatings for indexable inserts
Part 2: Test methods

1. Scope

Purpose: To specify the performance test methods for hard coatings on indexable inserts, including the measurement and evaluation of coating thickness, hardness, adhesion, wear resistance, and microstructure.

Scope of application: Applicable to coatings of indexable inserts based on carbide, ceramics, etc., covering coating performance verification in metal cutting processes such as turning, milling, and drilling.

Limitations: Test methods for uncoated or non-indexable inserts are not included.

2. Normative References

GB/T 18376.1: Hard coatings for indexable inserts Part 1: General rules.

GB/T 4340.1: Vickers hardness test for metallic materials - Part 1: Test method.

GB/T 7998: Microstructural examination of metallic materials.

GB/T 8642: Cemented carbide materials for cutting tools.

GB/T 16534: Chemical analysis methods for metals and alloys.

ISO 3685: Tool life testing with defined cutting edges.

3. Terms and Definitions

Coating thickness: The average thickness of the coating in the vertical direction on the blade surface, in microns (μm).

Hardness: The ability of a coating surface to resist deformation, expressed in Vickers hardness (HV).

Adhesion: The strength of the bond between a coating and a substrate, measured by scratch load (N).

Wear resistance: The coating's ability to resist wear during cutting, expressed as wear band width (VB, mm).

Microstructure: Grain size, phase composition and defect distribution within the coating.

4. Test Conditions

4.1 Environmental conditions

Temperature: 20-25°C.

Humidity: 40%-60%.

Avoid vibration and electromagnetic interference.

4.2 Sample preparation

Blade surface cleaning: Use ultrasonic cleaning to remove oil and impurities.

Sample quantity: at least 5 blades per batch, random sampling.

Coating condition: New, unused coated blade.

5. Test Methods

5.1 Coating thickness measurement

Methods: Cross-sections were measured using an optical microscope or a scanning electron microscope (SEM).

step:

Cut the blade along the cutting edge to prepare the cross section.

Polished to a mirror finish and etched to a microscopic structure.

Five points were measured at a magnification of 1000 times, and the average value was calculated .

Accuracy: ±0.1 μm .

Requirements: Thickness deviation <10%.

5.2 Hardness test

Method: According to GB/T 4340.1, use Vickers hardness tester.

step:

Select a load of 0.05-0.1 kg and a pressing time of 10-15 s.

Five points were randomly selected on the coating surface for measurement.

Calculate the average hardness value.

Accuracy: ±50 HV.

Requirements: Minimum hardness value refers to GB/T 18376.1.

5.3 Adhesion test

Method: Scratch test using a scratch tester.

step:

The loading speed was 10 N/mm and the scratch length was 5 mm.

The load was gradually increased until the coating peeled off.

Record the critical load (Lc, N).

Accuracy: ±5 N.

Requirements: Minimum critical load >50 N.

5.4 Wear resistance test

Method: Cutting test, refer to ISO 3685.

step:

Workpiece material: 45# steel (HB 200-250).

Cutting data: Vc 150 m/min, f 0.2 mm/r, ap 1 mm.

Cutting distance: 500 m.

The wear band width (VB) was measured using a tool microscope.

Accuracy: ±0.01 mm.

Requirement: VB <0.3 mm.

5.5 Microstructural Analysis

Methods: Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were used.

step:

Prepare cross-section samples and polish to a mirror finish.

Observe the coating grain size, phase distribution and defects.

Analyze elemental composition to confirm coating purity.

Requirements: Grain size <0.5 μm , no obvious cracks.

6. Test Report

content:

Sample number and batch.

Test date and environmental conditions.

Result of each test (thickness, hardness, adhesion, abrasion resistance).

Microstructure photos and analytical data.

Format : Prepared in accordance with the requirements of GB/T 1.1.

7. Accuracy and Repeatability

Thickness: Repeatability error <5%.

Hardness: Repeatability error <2%.

Adhesion: Repeatability error <10%.

Wear resistance: Repeatability error <5%.

8. Safety Requirements

Operation safety: Wear protective glasses and gloves to avoid contact with chemical reagents.

Equipment safety: Make sure the microscope and scratch tester are grounded to prevent static electricity.

Waste disposal: Cutting test waste should be handled according to GB/T 24001.

9. Annex

A. Test Equipment List: List the recommended microscope, hardness tester, and scratch tester models.

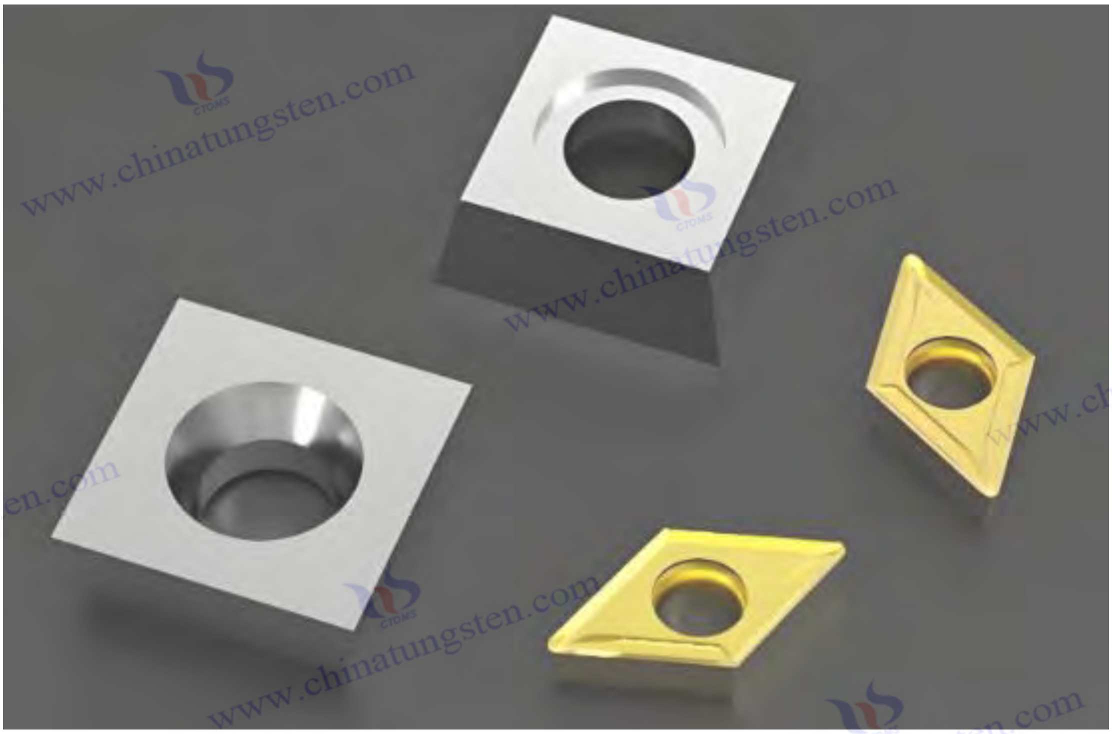
B. Example Data: Provides typical test results for TiN -coated inserts.

C. Failure Analysis: Discuss common causes of test failures and suggestions for improvement.

10. Revision History

2001 Edition: Initial publication, focusing on testing of cemented carbide coatings.

2015 Edition: Expanded to include ceramics and nano-coatings, and updated test parameters.



appendix:

Detailed table of carbide, CBN and ceramic tool names, characteristics and uses

The following is a comprehensive list of inserts made of various materials (including carbide, CBN, ceramics, PCD, and cermets), including insert name, characteristics (material composition, hardness, coating, geometry, cutting parameters, etc.), and applications (applicable material processing scenarios, etc.). Carbide is primarily composed of tungsten carbide (WC) and cobalt (Co), CBN is a superhard material, ceramics include aluminum oxide (Al_2O_3) and silicon nitride (Si_3N_4) , PCD is polycrystalline diamond, and cermets are titanium-based hard particle composites. The table covers a variety of functions, including turning , milling, drilling, grooving, and threading. It includes insert angle classification (such as 30-degree diamond inserts), processing function classification (such as parting and grooving inserts, back-sweeping inserts), shape classification (such as triangular external cylindrical inserts, hexagonal inserts), and other commonly used industry classifications (such as high-feed inserts and micro inserts). Based on industry standards, this table strives to be comprehensive.

Blade name Insert Name	Features Characteristics	use Applications
Carbide Turning Insert	Material: WC 80 90% + Co 6 12% Hardness HV 1500 1800 Geometry: ISO shape (CNMG WNMG) Positive rake angle (5° 15°) / negative rake angle (5° 0°) Radius 0.4 1.2mm Coating: CVD TiC / Al_2O_3 / TiN (wear resistance ≤1050°C) or PVD TiAlN (toughness ≤900°C) Cutting speed: 100 300m/min Feed rate 0.1 0.5mm/r High toughness suitable for various cutting conditions	Turning steel, stainless steel, cast iron, rough machining, semi-finishing, finishing . Used for general mechanical parts of automobile crankshafts
Cemented Carbide Milling Insert	Material: WC 85 90% + Co 8 10% Hardness HV 1600 Geometry: Square (SEKN) / Round (RDKW) 4 8 Edges Helix angle 15° 30° Edge width 2 10mm Coating: PVD TiAlN (high temperature resistance ≤ 900°C) or CVD MT TiCN (impact resistance) Cutting speed: 150 400m/min Feed rate 0.05 0.3mm/tooth High strength and impact resistance Suitable for large cutting volume	Plane groove profile milling is applicable to materials: steel, aluminum and titanium alloys . Used in aerospace parts mold manufacturing.
Carbide Drilling Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: Triangular (SPMG) / Square Point angle 118° 140° Internal coolant design Diameter 5 20mm Coating : CVD TiN / Al_2O_3 (wear resistant) Accuracy H7 H9 Cutting speed: 50 150m/min Feed rate 0.05 0.2mm/r High precision suitable for high-speed drilling	Applicable materials for drilling and reaming : steel, stainless steel, cast iron . Used for automobile cylinder energy equipment
Carbide Threading Insert	Material: WC + Co Hardness HV 1500 Geometry: 60° UN/ISO thread single tooth/multi-tooth pitch 0.5-3mm Coating: PVD TiCN (anti-chip) Accuracy ±0.02mm	Thread processing (M3 M20 NPT) . Applicable materials: steel and

	Cutting speed: 80-200m/min Feed rate 0.03-0.1mm/r Suitable for internal and external thread processing High stability	aluminum for pipe fittings and mechanical bolts
Grooving Insert	Material: WC 90% + Co 8% Hardness HV 1600 Geometry: Narrow groove / wide groove Width 0.5-5mm R angle 0.1-0.5mm Coating: CVD TiC (excellent wear resistance) Cutting speed 100-250m/min High rigidity Suitable for deep groove machining Accuracy ±0.01mm	Applicable materials for grooving and cutting : steel, stainless steel , used for shaft parts, bearing grooves, sealing ring grooves
Cemented Carbide Indexable Insert	Material: WC + Co Hardness HV 1500 1700 Geometry: Polygonal (SNMG TNMG) 4 8-edge ISO standard Coating: CVD Al_2O_3 / TiN or PVD TiAlN High wear resistance Cutting speed: 100 350m/min Feed rate 0.1 0.4mm/r High versatility High cost-effectiveness	Turning, milling, drilling, multi-purpose Applicable materials: steel, cast iron, aluminum For mass production General machining
Carbide 30 ° Rhombic Insert	Material: WC 85% + Co 10% Hardness HV 1550 Geometry: 30° diamond (VCMT) Positive rake angle (5° 10°) Radius 0.2 0.8mm Coating: PVD TiAlN High temperature resistance ≤ 900°C Cutting speed 120 300m/min Suitable for small cutting depth, low cutting force and high precision	High precision turning of steel, stainless steel and aluminum . Used for precision parts of medical devices
Carbide 55 ° Rhombic Insert	+ Co 8% Hardness HV 1600 Geometry: 55° diamond (DCMT) Positive rake angle (7° 12°) Radius 0.4 1.0mm Coating : CVD TiCN / Al_2O_3 High wear resistance Cutting speed 100 280m/min High versatility Suitable for medium cutting	Semi-finishing and finishing of steel and cast iron . General turning for mechanical parts pump bodies
Carbide 80° Rhombic Insert	+ Co 8% Hardness HV 1500 Geometry: 80° diamond (CNMG) Negative rake angle (5° 0°) Radius 0.8 1.6mm Coating: CVD TiC / Al_2O_3 / TiN Impact resistance Cutting speed 80 250m/min High strength Suitable for heavy-duty machining	Rough machining, semi-finishing of steel and stainless steel . Heavy turning for railway wheel forgings
Cemented Carbide Parting and Grooving Insert	Material: WC 90% + Co 8% Hardness HV 1600 Geometry: Straight/Curved Edge Width 1 6mm Depth 2 20mm Coating: PVD TiCN (anti-chipping) Cutting speed 90 220m/min High rigidity Suitable for parting and deep grooving Accuracy ±0.02mm	for deep grooving : steel, stainless steel, and aluminum . Suitable for cutting bars and processing grooves for shaft parts.
Cemented Carbide Wiper Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: With wiper edge (CNMG W WNMG W) Positive rake angle (5° 10°) Coating : CVD Al_2O_3 / TiN Surface finish Ra0.1 0.3μm Cutting speed: 150 350m/min Feed rate 0.05 0.2mm/r	Finishing steel stainless steel high surface quality turning

	Improve surface quality and reduce secondary processing	for shaft parts hydraulic parts
Carbide Profiling Insert	Material: WC 85% + Co 10% Hardness HV 1600 Geometry: Round (RCMX) / Special Profile Positive Rake Angle (5° 15°) Coating: PVD TiAlN Wear-resistant Cutting Speed 120 300 m/min Suitable for complex contours Accuracy ±0.01 mm	Profile turning contour processing Applicable materials: steel, aluminum, cast iron for mold turbine blade complex parts
Triangular External Turning Insert	+ Co 8% Hardness HV 1500 Geometry: Triangle (TNMG) Negative rake angle (5° 0°) Side length 12 25mm Coating: CVD TiC / Al_2O_3 Impact resistant Cutting speed 100 280m/min High strength Suitable for external cylindrical machining	External turning rough machining applicable materials: steel cast iron for shaft parts roller
Boring Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: Triangular (TPGT) / Diamond (CCMT) Positive rake angle (5° 10°) Small size (IC6 12mm) Coating: PVD TiCN Cutting speed 80 200m/min Accuracy H7 H8 Suitable for small hole processing Low cutting force	Internal boring and finishing applicable materials: steel, stainless steel, for hydraulic cylinder hole mold hole
Cemented Carbide Triangular Insert	Material: WC 85% + Co 10 % Hardness HV 1600 Geometry: Triangle (TCMT) Positive rake angle (7° 12°) Side length 6 16mm Coating : CVD TiCN / Al_2O_3 Wear -resistant Cutting speed 100 300m/min Strong versatility Suitable for a variety of processing	Turning, milling, semi-finishing, finishing of stainless steel, for mechanical parts, valves
Hexagonal Insert	Material: WC 90% + Co 8% Hardness HV 1500 Geometry: Hexagonal (WNMG) Negative rake angle (5° 0°) 6-edge edge length 10 20mm Coating : CVD Al_2O_3 / TiN Impact resistant Cutting speed 80 250m/min Highly economical and suitable for heavy loads	Rough machining and semi-finishing of steel and cast iron . Heavy turning . For railway parts and engineering machinery
High Feed Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: Square (SDMX) / Round Strong cutting edge design Feed rate 0.5 2mm / tooth Coating: PVD TiAlN Impact resistance Cutting speed 150 400m/min High removal rate Suitable for efficient machining	High feed milling roughing Applicable materials: steel, stainless steel, titanium alloy . Used for mold blanks and aviation structural parts
Carbide Heavy Duty Turning Insert	Material: WC 85% + Co 12% Hardness HV 1500 Geometry: Square (SNMM) Negative rake angle (6° 2°) Strong cutting edge coating : CVD TiC / Al_2O_3 Impact resistant Cutting speed 60 200m/min Suitable for large cutting depth (	Heavy-duty turning and rough machining Applicable materials: Steel, cast iron,

	4 10mm) High stability	railway wheel hubs, forgings, large shafts
Cemented Carbide Micro Insert	Material: Micro-grained WC Hardness HV 1600 Geometry: Triangular (TCGT) / Diamond (DCGT) Positive rake angle (5° 10°) IC3 6mm Coating: PVD TiCN Accuracy ±0.005mm Cutting speed 50 150m/min Ultra-high precision suitable for micro processing	Micro-boring finishing is applicable to materials such as steel, aluminum, and stainless steel . It is used for electronic components and medical devices.
CBN Turning InsertCubic Boron Nitride Turning Insert	Material: PCBN (CBN 40 100%) Hardness HV 3500 4500 Geometry: Negative rake angle (5° 0°) Chamfered/honed edge R angle 0.2 1.2mm Coating: None/thin TiN (high temperature resistance ≤ 1400°C) Cutting speed 200 800m/min Ultra-high hardness Strong chemical stability Suitable for dry cutting	High-speed turning of hardened steel (≥45HRC) and nickel-based alloy finishing hard turning . Used for bearings, gears, and automobile transmission parts.
Boron Nitride Milling Insert	Material: CBN 50 85% Hardness HV 4000 Geometry: Square (SEKN) / Round (RDKW) 2 4 Edges Diameter 10 50mm Coating: None / TiAlN Very high wear resistance Cutting speed 300 1000m/min Good thermal stability Suitable for high hardness materials	Milling hard steel (≤70HRC) cast iron . Mold finishing . Used for hard molds of aviation parts.
Boron Nitride Drilling Insert	Material: CBN + carbide substrate hardness HV 4000 Geometry: 2 Edge angle 130° 140° Diameter 5 20mm Accuracy H8 Coating: None Strong impact resistance Cutting speed 100 300m/min High precision Suitable for drilling hard materials	Drilling hardened steel ceramic precision hole processing . For tool steel precision machinery
Boron Nitride Grinding Insert	Material: CBN particles hardness HV 4500 Geometry: disc/rod particle size 100-800μm Binder resin/metal Coating: none Wear resistance Long life Grinding speed 20-50m/s Suitable for high-speed grinding Low heat	Grinding carbide mold steel surface finishing . Used for tool grinding optical mold
Cubic Boron Nitride 30° Rhombic Insert	Material: PCBN (CBN 70 90%) Hardness HV 4000 Geometry: 30° diamond (VNMG) Negative rake angle (5° 0°) R angle 0.2 0.8mm Coating: None/thin TiN High temperature resistance ≤ 1400°C Cutting speed 250 800m/min High hardness Suitable for finishing hard materials	Finishing hardened steel (≥50HRC) Nickel-based alloy high-precision hard turning for roller precision gears
Boron Nitride 55° Rhombic Insert	Material: PCBN (CBN 60 80%) Hardness HV 3800 Geometry: 55° diamond (DNMG) Negative rake angle (5° 0°) R angle 0.4 1.0mm Coating: No wear resistance Very high cutting speed 200 600m/min	Semi-finishing and finishing Hard turning of hardened

	Suitable for medium cutting of hard materials	steel for bearing mould parts
CBN Cutting and Grooving InsertsCubic Boron Nitride Parting and Grooving Inserts	Material: CBN + carbide substrate hardness HV 4000 Geometry: straight edge width 1 4mm depth 2 15mm Coating: no impact resistance Cutting speed 150 400m/min Accuracy ±0.01mm Suitable for grooving hard materials High stability	Cutting and grooving hardened steel cast iron precision groove machining for hardened shaft gear groove
CBN Back-Sweep Blade Cubic Boron Nitride Wiper Insert	Material: PCBN (CBN 70%) Hardness HV 4000 Geometry: With wiper edge (DNMG W) Negative rake angle (5° 0°) Surface finish Ra0.1 0.2μm Coating: No Cutting speed 300 800m/min Feed rate 0.05 0.15mm/r Improve surface quality Suitable for hard materials	Finish machining of hardened steel nickel-based alloys . High surface quality hard turning for precision roller aerospace parts
CBN Triangular InsertCubic Boron Nitride Triangular Insert	Material: PCBN (CBN 60 80%) Hardness HV 3800 Geometry: Triangular (TNMG) Negative rake angle (5° 0°) Side length 12 20mm Coating: None/Thin TiN Cutting speed 200 600m/min Suitable for general machining of hard materials	Turning hardened steel, cast iron, semi-finishing, finishing, for die and mould hard rollers
Ceramic Turning Insert	Material: Al_2O_3 / Si_3N_4Hardness HV 2000-2500Geometry : Negative rake angle (6°-8°) ISO shape (SNGA-CNGA) R angle 0.4-1.2mmUncoatedHigh temperature resistance ≤1200 °CCutting speed 300-600m/minHigh chemical stabilityRelatively brittleRequires high rigidity machine tool	High speed turning of cast iron nickel-based alloys . Semi-finishing and finishing for engine blocks and aviation parts
Ceramic Milling Insert	Material: Si_3N_4 + ZrO_2 Hardness HV 2200 Geometry : 2 4 - edge square (SEKN)/circular Diameter 10-40mm Helix angle 15°-25° Uncoated High heat resistance Cutting speed 400-800m/min Low toughness Suitable for stable cutting	High-speed milling of cast iron and high-temperature alloys . Turbine blade pump body processing for aviation energy equipment
Ceramic Drilling Insert	Material: Al_2O_3 + ZrO_2 Hardness HV 2100 Geometry : 2 Edge Angle 120° 135° Diameter 3 15mm Accuracy H7 H8 Uncoated Wear resistance High cutting speed 50 150m/min Low cutting force Suitable for hard and brittle materials	Drilling glass fiber ceramic composite materials . Used in aerospace electronic substrates
Ceramic Grinding Insert	Material: Si_3N_4Hardness HV 2300Geometry : Granularity 50-500μmRod/discBinding ceramicUncoatedHigh corrosion resistanceGrinding speed 15-40m/sSuitable	Grinding ceramic glass optical lens precision mold processing . Used in

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	for precision grinding	medical equipment semiconductors
Ceramic 55 ° Rhombic Insert	Material: Si_3N_4Hardness HV 2200Geometry : 55° rhombus (DNGA) Negative rake angle (6° 2°)R angle 0.4 1.0mmUncoatedHigh temperature resistance ≤1200°CCutting speed 300 600m/minSuitable for high-speed cutting requiring high rigidity machine tools	High-speed finishing of cast iron and high-temperature alloys . High-precision turning for aviation parts and turbines.
Ceramic Parting and Grooving Insert	Material: Al_2O_3 + ZrO_2 Hardness HV 2100 Geometry : Straight edge Width 1.4mm Depth 2.10mm Uncoated Wear-resistant Cutting speed 200-500m/min Accuracy ±0.02mm Suitable for grooving hard and brittle materials	Cutting and grooving cast iron ceramic precision groove processing . Used for ceramic parts composite materials
Ceramic Triangular Insert	Material: Si_3N_4Hardness HV 2200Geometry : Triangle (TNGA) Negative rake angle (6° 2°)Side length 10-20mmUncoatedHigh heat resistanceCutting speed 300-600m/minSuitable for high-speed general processing	Turning cast iron high temperature alloy semi-finishing finishing for pump body aviation housing
Polycrystalline Diamond Turning Insert	Material: PCD (90-95%) Hardness HV 8000-10000 Geometry: Positive rake angle (5°-15°) ISO shape (CCMW-VCMW) Single/multi-edge uncoated Ultra-high hardness Cutting speed 200-1000 m/min High thermal conductivity Suitable for non-ferrous materials	High-speed turning of aluminum alloy copper for finishing of automobile piston and aviation parts
Polycrystalline Diamond Milling Insert	Material: PCD Hardness HV 9000 Geometry: 2 4-edge square (SEKN)/circular diameter 5-20mm uncoated surface finish Ra0.1 0.2μm Cutting speed 500 1500m/min Suitable for high speed and low friction cutting	Milling composite materials and plastics High-precision milling for carbon fiber furniture manufacturing
Polycrystalline Diamond Drilling Insert	Material: PCD + carbide substrate Hardness HV 8500 Geometry: 2 Edge Angle 120° 130° Diameter 3 15mm Accuracy H7 Uncoated Very high wear resistance Cutting speed 100 400m/min Suitable for non-metallic materials	Drilling Precision Holes in Fiberglass Composites for Avionics Components
Polycrystalline Diamond Grinding Insert	Material: PCD Hardness HV 9000 Geometry: Grain size 50-300μm Disc-shaped Metal binder without coating Ultra-long life Grinding speed 20-50m/s Suitable for high-precision grinding	Grinding ceramics and non-ferrous metal surface finishing for optical mold precision parts
Diamond 55° Rhombic Insert	Material: PCD Hardness HV 9000 Geometry: 55° diamond (DCMW) Positive rake angle (5° 10°) R angle 0.2 0.8mm	Finishing aluminum alloy copper

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	Uncoated Cutting speed 300 1200m/min Surface finish Ra0.05 0.2μm Suitable for finishing of non-ferrous materials	high precision turning for automotive wheel hub optical parts
Parting and Grooving Insert	Material: PCD + carbide substrate hardness HV 8500 Geometry: straight edge width 0.5-3mm depth 1-8mm uncoated wear-resistant cutting speed 200-800m/min accuracy ±0.01mm suitable for grooving non-ferrous materials	Cutting and grooving aluminum alloy composite precision groove processing for aviation composite electronic parts
Cermet Turning Insert	Material: Ti(C,N) + Co Hardness HV 1800 2000 Geometry: Positive rake angle (5° 15°) ISO shape (CCMT DCMT) R angle 0.4 1.2mm Coating: PVD TiN Wear resistance High cutting speed 150 400m/min Combining ceramic hardness and metal toughness	High speed turning of stainless steel and finishing for mechanical parts and molds
Cermet Milling Insert	Material: Ti(C,N) + (Ti,Nb,W)(C,N) Hardness HV 1900 Geometry: Square (SEKN) 4 6 Edges Helix Angle 10° 20° Coating: PVD TiAlN Oxidation Resistance Cutting Speed 200 500 m/min Surface Finish Ra0.2 0.4 μm Suitable for Finishing	Milling steel cast iron high precision milling for automotive parts mold
Cermet Drilling Insert	Material: Ti(C,N) + Co Hardness HV 1850 Geometry: 2 Edge Angle 118° 130° Diameter 5 15mm Precision H8 Coating: PVD TiCN High wear resistance Cutting speed 80 200m/min High precision Suitable for stable drilling	Drilling steel and stainless steel precision hole processing for mechanical and aviation parts
Cermet Threading Insert	Material: Ti(C,N) Hardness HV 1900 Geometry: 60° Thread single tooth Pitch 0.5-2mm Coating: PVD TiN Anti-chip Cutting speed 100-250m/min Suitable for high-precision thread processing	Thread machining steel and aluminum finishing for pipe mechanical connectors
Cermet 55 ° Rhombic Insert	Material: Ti(C,N) + Co Hardness HV 1900 Geometry: 55° diamond (DCMT) Positive rake angle (5° 10°) R angle 0.4 0.8mm Coating: PVD TiAlN Wear-resistant Cutting speed 150 400m/min Suitable for finishing with high surface finish	Finishing steel stainless steel high precision turning for precision machinery mold parts
Cermet Parting and Grooving Insert	Material: Ti(C,N) Hardness HV 1900 Geometry: Straight Edge Width 0.5-3mm Depth 1-10mm Coating: PVD TiCN Anti-chip Cutting Speed 120-300m/min Suitable for precision grooving Accuracy ±0.01mm	Cutting and grooving steel and aluminum precision groove processing for shaft parts and electronic parts

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carbide, CBN, ceramic, PCD, and cermet insert names, characteristics, and uses

The following is a comprehensive list of blades made of various materials (including cemented carbide, CBN, ceramics, PCD, and cermets), including the blade name, characteristics (material composition, hardness, coating, geometry, cutting parameters, etc.) and uses (applicable materials, processing scenarios, etc.). Cemented carbide is mainly composed of tungsten carbide (WC) + cobalt (Co), CBN is a superhard material, ceramics include aluminum oxide (Al_2O_3) and silicon nitride (Si_3N_4) , PCD is polycrystalline diamond, and cermets are titanium-based hard particle composites. The table covers a variety of functions such as turning, milling, drilling, grooving, and threading, and adds new blade angle classifications (such as 30-degree diamond blades), processing function classifications (such as cutting and grooving blades, back-sweeping blades), shape classifications (such as triangular external circular blades, hexagonal blades) and other commonly used classifications in the industry (such as high-feed blades, micro blades).

Insert Name	Characteristics	Applications
Carbide Turning Insert	Material: WC 80 90% + Co 6 12% Hardness HV 1500 1800 Geometry: ISO shape (CNMG WNMG) Positive rake angle (5° 15°) / negative rake angle (5° 0°) Radius 0.4 1.2mm Coating: CVD TiC / Al_2O_3 / TiN (wear resistance ≤1050°C) or PVD TiAlN (toughness ≤900°C) Cutting speed: 100 300m/min Feed rate 0.1 0.5mm/r High toughness suitable for various cutting conditions	Turning steel, stainless steel, cast iron, rough machining, semi-finishing, finishing, used for automobile crankshafts, general machinery parts
Cemented Carbide Milling Insert	Material: WC 85 90% + Co 8 10% Hardness HV 1600 Geometry: Square (SEKN) / Round (RDKW) 4 8 Edges Helix angle 15° 30° Edge width 2 10mm Coating: PVD TiAlN (high temperature resistance ≤ 900°C) or CVD MT TiCN (impact resistance) Cutting speed: 150 400m/min Feed rate 0.05 0.3mm/tooth High strength and impact resistance Suitable for large cutting volume	Plane groove profile milling Applicable materials: Steel, aluminum and titanium alloys are used in aerospace parts mold manufacturing
Carbide Drilling Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: Triangular (SPMG) / Square Point angle 118° 140° Internal coolant design Diameter 5 20mm Coating : CVD TiN / Al_2O_3 (wear resistant) Accuracy H7 H9 Cutting speed: 50 150m/min Feed rate 0.05 0.2mm/r High precision suitable for high-speed drilling	Applicable materials for drilling and reaming : steel, stainless steel, cast iron, used in automobile cylinders, energy equipment
Carbide Threading Insert	Material: WC + Co Hardness HV 1500 Geometry: 60° UN/ISO thread single tooth/multi-tooth pitch 0.5-3mm Coating: PVD TiCN (anti-chip) Accuracy ±0.02mm Cutting speed: 80-200m/min Feed rate 0.03-0.1mm/r Suitable for internal and external thread processing High stability	Thread processing (M3 M20 NPT) Applicable materials: steel and aluminum for pipe fittings and mechanical bolts
Grooving	Material: WC 90% + Co 8% Hardness HV 1600	Applicable materials

Insert	Geometry: Narrow groove / wide groove Width 0.5-5mm R angle 0.1-0.5mm Coating: CVD TiC (excellent wear resistance) Cutting speed 100-250m/min High rigidity Suitable for deep groove machining Accuracy ±0.01mm	for grooving and cutting : steel, stainless steel , used for shaft parts, bearing grooves, sealing ring grooves
Carbide Indexable Insert	Material: WC + Co Hardness HV 1500 1700 Geometry : Polygonal (SNMG TNMG) 4 8-edge ISO standard Coating: CVD Al_2O_3 / TiN or PVD TiAlN High wear resistance Cutting speed: 100 350m/min Feed rate 0.1 0.4mm/r High versatility High cost-effectiveness	Turning, milling, drilling, multi-purpose Applicable materials: steel, cast iron, aluminum For mass production General machining
Carbide 30 ° Rhombic Insert	Material: WC 85% + Co 10% Hardness HV 1550 Geometry: 30° diamond (VCMT) Positive rake angle (5° 10°) Radius 0.2 0.8mm Coating: PVD TiAlN High temperature resistance ≤ 900°C Cutting speed 120 300m/min Suitable for small cutting depth, low cutting force and high precision	Finishing steel, stainless steel, aluminum, high-precision turning for precision parts in medical devices
Carbide 55 ° Rhombic Insert	+ Co 8% Hardness HV 1600 Geometry: 55° diamond (DCMT) Positive rake angle (7° 12°) Radius 0.4 1.0mm Coating : CVD TiCN / Al_2O_3 High wear resistance Cutting speed 100 280m/min High versatility Suitable for medium cutting	Semi-finishing, finishing, steel and cast iron , general turning, for mechanical parts, pump bodies
Carbide 80° Rhombic Insert	+ Co 8% Hardness HV 1500 Geometry: 80° diamond (CNMG) Negative rake angle (5° 0°) Radius 0.8 1.6mm Coating: CVD TiC / Al_2O_3 / TiN Impact resistance Cutting speed 80 250m/min High strength Suitable for heavy-duty machining	Roughing, semi-finishing, heavy turning of steel and stainless steel for railway wheel forgings
Cemented Carbide Parting and Grooving Insert	Material: WC 90% + Co 8% Hardness HV 1600 Geometry: Straight/Curved Edge Width 1 6mm Depth 2 20mm Coating: PVD TiCN (anti-chipping) Cutting speed 90 220m/min High rigidity Suitable for parting and deep grooving Accuracy ±0.02mm	Cutting deep groove processing Applicable materials: steel, stainless steel, aluminum, used for bar cutting, shaft parts groove processing
Cemented Carbide Wiper Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: With wiper edge (CNMG W WNMG W) Positive rake angle (5° 10°) Coating : CVD Al_2O_3 / TiN Surface finish Ra0.1 0.3μm Cutting speed: 150 350m/min Feed rate 0.05 0.2mm/r Improve surface quality and reduce secondary processing	Finishing steel stainless steel high surface quality turning for shaft parts hydraulic parts
Carbide Profiling Insert	Material: WC 85% + Co 10% Hardness HV 1600 Geometry: Round (RCMX) / Special Profile Positive Rake Angle (5° 15°) Coating: PVD TiAlN Wear-resistant Cutting Speed 120 300 m/min Suitable for complex contours Accuracy ±0.01 mm	Profile turning contour processing Applicable materials: steel, aluminum, cast iron

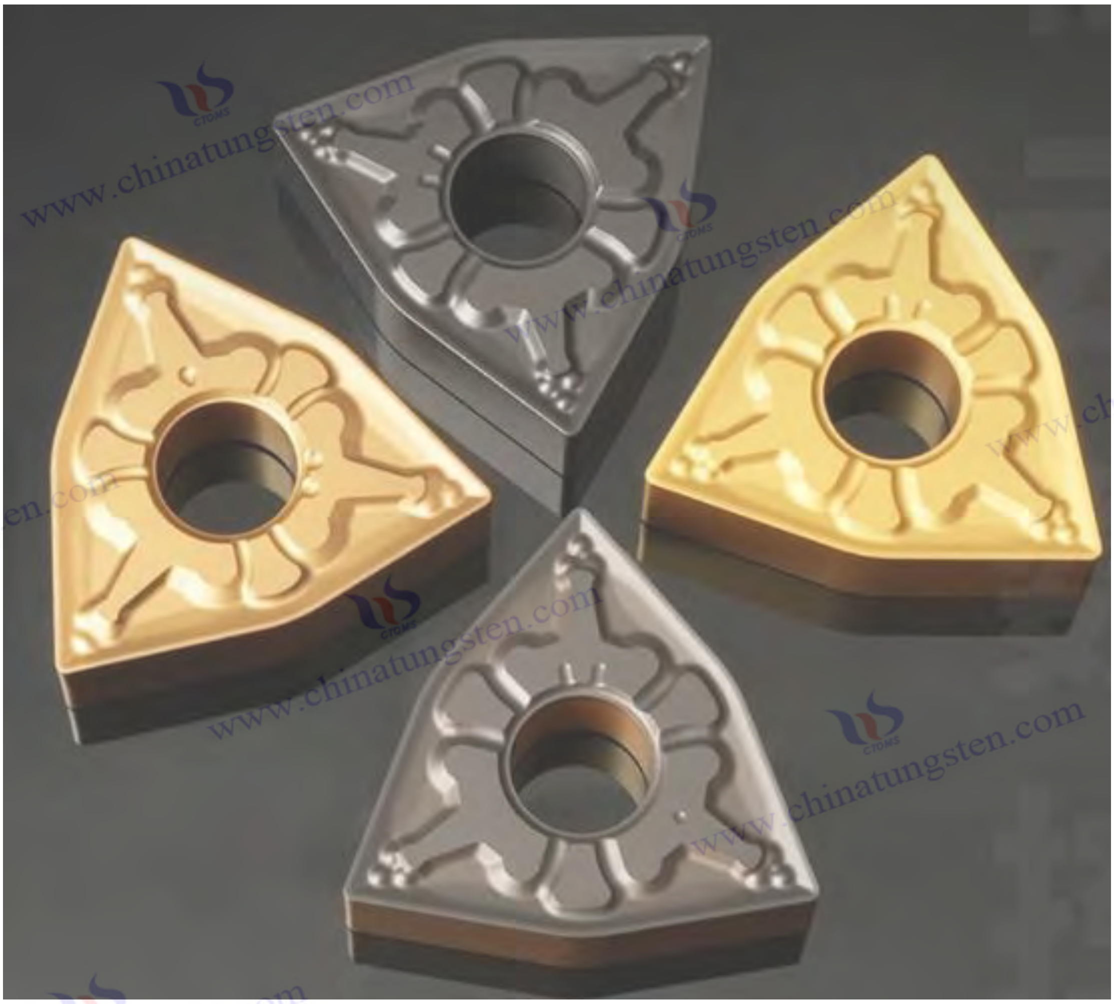
		for mold turbine blade complex parts
Triangular External Turning Insert	+ Co 8% Hardness HV 1500 Geometry: Triangle (TNMG) Negative rake angle (5° 0°) Side length 12 25mm Coating: CVD TiC / Al_2O_3 Impact resistant Cutting speed 100 280m/min High strength Suitable for external cylindrical machining	External turning rough machining applicable materials: steel cast iron for shaft parts roller
Boring Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: Triangular (TPGT) / Diamond (CCMT) Positive rake angle (5° 10°) Small size (IC6 12mm) Coating: PVD TiCN Cutting speed 80 200m/min Accuracy H7 H8 Suitable for small hole processing Low cutting force	Internal boring and finishing applicable materials: steel, stainless steel, for hydraulic cylinder hole mold hole
Carbide Triangular Insert	10 % Hardness HV 1600 Geometry: Triangular (TCMT) Positive rake angle (7°-12°) Side length 6-16mm Coating: CVD TiCN / Al_2O_3 Wear - resistant Cutting speed 100-300m/min Versatile and suitable for a variety of machining	semi-finishing, finishing of stainless steel, for mechanical parts, valves
Hexagonal Insert	Material: WC 90% + Co 8% Hardness HV 1500 Geometry: Hexagonal (WNMG) Negative rake angle (5° 0°) 6-edge edge length 10 20mm Coating : CVD Al_2O_3 / TiN Impact resistant Cutting speed 80 250m/min Highly economical and suitable for heavy loads	Rough machining, semi-finishing, steel and cast iron, heavy turning, for railway parts and engineering machinery
High Feed Insert	Material: WC 88% + Co 10% Hardness HV 1550 Geometry: Square (SDMX) / Round Strong cutting edge design Feed rate 0.5 2mm / tooth Coating: PVD TiAlN Impact resistance Cutting speed 150 400m/min High removal rate Suitable for efficient machining	High feed milling roughing Applicable materials: steel, stainless steel, titanium alloy . Used for mold blanks and aviation structural parts
Carbide Heavy Duty Turning Insert	Material: WC 85% + Co 12% Hardness HV 1500 Geometry: Square (SNMM) Negative rake angle (6° 2°) Strong cutting edge coating : CVD TiC / Al_2O_3 Impact resistant Cutting speed 60 200m/min Suitable for large cutting depth (4 10mm) High stability	Heavy-duty turning and rough machining Applicable materials: Steel, cast iron, railway wheel hubs, forgings, large shafts
Cemented Carbide Micro Insert	Material: Micro-grained WC Hardness HV 1600 Geometry: Triangular (TCGT) / Diamond (DCGT) Positive rake angle (5° 10°) IC3 6mm Coating: PVD TiCN Accuracy ±0.005mm Cutting speed 50 150m/min Ultra-high precision suitable for micro processing	Micro-boring finishing Applicable materials: steel, aluminum, stainless steel for electronic components and medical devices
CBN Turning InsertCubic Boron Nitride Turning Insert	Material: PCBN (CBN 40 100%) Hardness HV 3500 4500 Geometry: Negative rake angle (5° 0°) Chamfered/honed edge R angle 0.2 1.2mm	High-speed turning of hardened steel (≥45HRC) and nickel-based alloy

	Coating: None/thin TiN (high temperature resistance ≤ 1400°C) Cutting speed 200 800m/min Ultra-high hardness Strong chemical stability Suitable for dry cutting	finishing hard turning . Used for bearings, gears, and automobile transmission parts.
Boron Nitride Milling Insert	Material: CBN 50 85% Hardness HV 4000 Geometry: Square (SEKN) / Round (RDKW) 2 4 Edges Diameter 10 50mm Coating: None / TiAlN Very high wear resistance Cutting speed 300 1000m/min Good thermal stability Suitable for high hardness materials	Milling hard steel (≤70HRC) cast iron mold finishing . Used for aviation parts hard mold
Boron Nitride Drilling Insert	Material: CBN + carbide substrate hardness HV 4000 Geometry: 2 Edge angle 130° 140° Diameter 5 20mm Accuracy H8 Coating: None Strong impact resistance Cutting speed 100 300m/min High precision Suitable for drilling hard materials	Drilling hardened steel ceramic precision hole processing . For tool steel precision machinery
Boron Nitride Grinding Insert	Material: CBN particles hardness HV 4500 Geometry: disc/rod particle size 100-800μm Binder resin/metal Coating: none Wear resistance Long life Grinding speed 20-50m/s Suitable for high-speed grinding Low heat	Grinding carbide mold steel surface finishing . Used for tool grinding optical mold
Cubic Boron Nitride 30° Rhombic Insert	Material: PCBN (CBN 70 90%) Hardness HV 4000 Geometry: 30° diamond (VNMG) Negative rake angle (5° 0°) R angle 0.2 0.8mm Coating: None/thin TiN High temperature resistance ≤ 1400°C Cutting speed 250 800m/min High hardness Suitable for finishing hard materials	Finishing hardened steel (≥50HRC) Nickel-based alloy . High precision hard turning for roller precision gears
Boron Nitride 55° Rhombic Insert	Material: PCBN (CBN 60 80%) Hardness HV 3800 Geometry: 55° diamond (DNMG) Negative rake angle (5° 0°) R angle 0.4 1.0mm Coating: None Wear resistance Very high cutting speed 200 600m/min Suitable for medium cutting of hard materials	Semi-finishing and finishing hard turning of hardened steel . Used for bearing mold parts
CBN Cutting and Grooving InsertsCubic Boron Nitride Parting and Grooving Inserts	Material: CBN + carbide substrate hardness HV 4000 Geometry: straight edge width 1 4mm depth 2 15mm Coating: no impact resistance Cutting speed 150 400m/min Accuracy ±0.01mm Suitable for grooving hard materials High stability	Cutting and grooving for hardened steel and cast iron precision groove processing . Used for hard shaft gear grooves
CBN Back-Sweep Blade Cubic Boron Nitride Wiper Insert	Material: PCBN (CBN 70%) Hardness HV 4000 Geometry: With wiper edge (DNMG W) Negative rake angle (5° 0°) Surface finish Ra0.1 0.2μm Coating: No Cutting speed 300 800m/min Feed rate 0.05 0.15mm/r Improve surface quality Suitable for hard materials	Finish machining of hardened steel nickel-based alloys with high surface quality hard turning for precision roller aviation parts

CBN Triangular InsertCubic Boron Nitride Triangular Insert	Material: PCBN (CBN 60 80%) Hardness HV 3800 Geometry: Triangular (TNMG) Negative rake angle (5° 0°) Side length 12 20mm Coating: None/Thin TiN Cutting speed 200 600m/min Suitable for general machining of hard materials	Turning hardened steel, cast iron, semi-finishing, finishing, for die and mould hard rollers
Ceramic Turning Insert	Material: Al_2O_3 / Si_3N_4Hardness HV 2000-2500Geometry : Negative rake angle (6°-8°) ISO shape (SNGA-CNGA) R angle 0.4-1.2mmUncoatedHigh temperature resistance ≤1200 °CCutting speed 300-600m/minHigh chemical stabilityRelatively brittleRequires high rigidity machine tool	High speed turning of cast iron nickel-based alloy semi-finishing and finishing for engine cylinder aerospace parts
Ceramic Milling Insert	Material: Si_3N_4 + ZrO_2 Hardness HV 2200 Geometry : 2 4 - edge square (SEKN)/circular Diameter 10-40mm Helix angle 15°-25° Uncoated High heat resistance Cutting speed 400-800m/min Low toughness Suitable for stable cutting	High-speed milling of cast iron and high-temperature alloy turbine blade pump bodies for aviation energy equipment
Ceramic Drilling Insert	Material: Al_2O_3 + ZrO_2 Hardness HV 2100 Geometry : 2 Edge Angle 120° 135° Diameter 3 15mm Accuracy H7 H8 Uncoated Wear resistance High cutting speed 50 150m/min Low cutting force Suitable for hard and brittle materials	Drilling fiberglass ceramic composite materials for aerospace electronics substrates
Ceramic Grinding Insert	Material: Si_3N_4Hardness HV 2300Geometry : Granularity 50-500μmRod/discBinding ceramicUncoatedHigh corrosion resistanceGrinding speed 15-40m/sSuitable for precision grinding	Grinding ceramic glass optical lens precision mold processing for medical devices semiconductor
Ceramic 55 ° Rhombic Insert	Material: Si_3N_4Hardness HV 2200Geometry : 55° rhombus (DNGA) Negative rake angle (6° 2°)R angle 0.4 1.0mmUncoatedHigh temperature resistance ≤1200°CCutting speed 300 600m/minSuitable for high-speed cutting requiring high rigidity machine tools	High-speed finishing of cast iron and high-temperature alloys, high-precision turning for aviation parts and turbines
Ceramic Parting and Grooving Insert	Material: Al_2O_3 + ZrO_2 Hardness HV 2100 Geometry : Straight edge Width 1.4mm Depth 2.10mm Uncoated Wear-resistant Cutting speed 200-500m/min Accuracy ±0.02mm Suitable for grooving hard and brittle materials	Cutting and grooving cast iron ceramic precision groove processing for ceramic parts composite materials
Ceramic Triangular Insert	Material: Si_3N_4Hardness HV 2200Geometry : Triangular (TNGA)Negative rake angle (6° 2°)Side length 10-20mmUncoatedHigh	Turning cast iron high temperature alloy semi-finishing finishing

	heat resistanceCutting speed 300-600m/minSuitable for high-speed general machining	for pump body aviation housing
Polycrystalline Diamond Turning Insert	Material: PCD (90-95%) Hardness HV 8000-10000 Geometry: Positive rake angle (5°-15°) ISO shape (CCMW-VCMW) Single/multi-edge uncoated Ultra-high hardness Cutting speed 200-1000 m/min High thermal conductivity Suitable for non-ferrous materials	High-speed turning of aluminum alloy copper for finishing of automobile piston and aviation parts
Polycrystalline Diamond Milling Insert	Material: PCD Hardness HV 9000 Geometry: 2 4-edge square (SEKN)/circular diameter 5-20mm uncoated surface finish Ra0.1 0.2μm Cutting speed 500 1500m/min Suitable for high speed and low friction cutting	Milling composite materials and plastics High-precision milling for carbon fiber furniture manufacturing
Polycrystalline Diamond Drilling Insert	Material: PCD + carbide substrate Hardness HV 8500 Geometry: 2 Edge Angle 120° 130° Diameter 3 15mm Accuracy H7 Uncoated Very high wear resistance Cutting speed 100 400m/min Suitable for non-metallic materials	Drilling Precision Holes in Fiberglass Composites for Avionics Components
Polycrystalline Diamond Grinding Insert	Material: PCD Hardness HV 9000 Geometry: Grain size 50-300μm Disc-shaped Metal binder without coating Ultra-long life Grinding speed 20-50m/s Suitable for high-precision grinding	Grinding ceramics and non-ferrous metal surface finishing for optical mold precision parts
Diamond 55° Rhombic Insert	Material: PCD Hardness HV 9000 Geometry: 55° diamond (DCMW) Positive rake angle (5° 10°) R angle 0.2 0.8mm Uncoated Cutting speed 300 1200m/min Surface finish Ra0.05 0.2μm Suitable for finishing of non-ferrous materials	Finishing aluminum alloy copper high precision turning for automotive wheel hub optical parts
Parting and Grooving Insert	Material: PCD + carbide substrate hardness HV 8500 Geometry: straight edge width 0.5-3mm depth 1-8mm uncoated wear-resistant cutting speed 200-800m/min accuracy ±0.01mm suitable for grooving non-ferrous materials	Cutting and grooving aluminum alloy composite precision groove processing for aviation composite electronic parts
Cermet Turning Insert	Material: Ti(C,N) + Co Hardness HV 1800 2000 Geometry: Positive rake angle (5° 15°) ISO shape (CCMT DCMT) R angle 0.4 1.2mm Coating: PVD TiN Wear resistance High cutting speed 150 400m/min Combining ceramic hardness and metal toughness	High speed turning of stainless steel and finishing for mechanical parts and molds
Cermet Milling Insert	Material: Ti(C,N) + (Ti,Nb,W)(C,N) Hardness HV 1900 Geometry: Square (SEKN) 4 6 Edges Helix Angle 10° 20° Coating: PVD TiAlN Oxidation Resistance Cutting Speed 200 500 m/min Surface Finish Ra0.2 0.4 μm Suitable for Finishing	Milling steel cast iron high precision milling for automotive parts mold

Cermet Drilling Insert	Material: Ti(C,N) + Co Hardness HV 1850 Geometry: 2 Edge Angle 118° 130° Diameter 5 15mm Precision H8 Coating: PVD TiCN High wear resistance Cutting speed 80 200m/min High precision Suitable for stable drilling	Drilling steel and stainless steel precision hole processing for mechanical and aviation parts
Cermet Threading Insert	Material: Ti(C,N) Hardness HV 1900 Geometry: 60° Thread single tooth Pitch 0.5-2mm Coating: PVD TiN Anti-chip Cutting speed 100-250m/min Suitable for high-precision thread processing	Thread machining steel and aluminum finishing for pipe mechanical connectors
Cermet 55 ° Rhombic Insert	Material: Ti(C,N) + Co Hardness HV 1900 Geometry: 55° diamond (DCMT) Positive rake angle (5° 10°) R angle 0.4 0.8mm Coating: PVD TiAlN Wear-resistant Cutting speed 150 400m/min Suitable for finishing with high surface finish	Finishing steel stainless steel high precision turning for precision machinery mold parts
Cermet Parting and Grooving Insert	Material: Ti(C,N) Hardness HV 1900 Geometry: Straight Edge Width 0.5-3mm Depth 1-10mm Coating: PVD TiCN Anti-chip Cutting Speed 120-300m/min Suitable for precision grooving Accuracy ±0.01mm	Cutting and grooving steel and aluminum precision groove processing for shaft parts and electronic parts



Carbide, CBN (Cubic Boron Nitride), Ceramics, PCD (Polycrystalline Diamond) and High-Speed Steel (HSS) Drill Bits, Features, and Applications

The following is a comprehensive list of drill bits made of high-speed steel (HSS), cobalt steel, carbide (tungsten carbide-based), CBN (cubic boron nitride), ceramic, and PCD (polycrystalline diamond). The list includes names (including the material type and full English name, with subcategories such as reamer, step drill, and spade drill), characteristics (material composition, hardness, coating, geometry, performance, etc.), and applications (suitable materials, processing scenarios, etc.). These drill bits are used for drilling, reaming, countersinking, positioning, deep hole machining, and other applications, and are suitable for a variety of materials and operating conditions. The table, formatted in three columns, covers all common and specialized drill types and is compiled from online resources to ensure maximum completeness and accuracy.

Drill bit name	Features	use
High-speed steel twist drill Twist Drill Bit	- Material: HSS (M2/M7, containing molybdenum, tungsten, vanadium), hardness HRC 60–62 - Point angle 118° (soft material) or 135° (hard material), helix angle 20°–30°, 2 edges - Coating: TiN (wear-resistant, ≤500°C), black oxide (friction-reducing), or uncoated - High toughness, low cost, average wear resistance, suitable for low speeds	- General purpose drilling, shallow hole processing - Applicable materials: mild steel, aluminum, copper, wood, plastic - For manual drilling, maintenance, education
High-speed steel reaming drill bit Reamer Drill Bit	- Material: HSS, hardness HRC 60–62 - Straight/helical edge, 6–8 flutes, tolerance H7/H8, diameter 3–40 mm - Coating: None, high surface finish - High precision, low cutting forces, requires pre-drilling, prone to wear	- Fine machining of apertures to improve surface quality - Applicable materials: steel, aluminum, copper - Used for mechanical assembly and mold hole processing
High-speed steel step drill Step Drill Bit	- Material: HSS (M2), hardness HRC 60 - Multi-level diameter (4–32 mm), tapered, 2-edge, step spacing 2–4 mm - Coating: TiN , friction reduction, anti-chip - Suitable for thin plates, easy to control hole diameter, anti-vibration	- Stepped holes, hole enlargement, deburring - Applicable materials: thin steel sheets, aluminum, PVC - For electrical installation, automotive sheet metal
High-speed steel countersunk drill bits Countersink Drill Bit	- Material: HSS, hardness HRC 60–62 - Cone angle 60°–120° (common 82°/90°), 2–4 flutes, single/double-ended - Coating: black oxide, smooth surface - Good toughness, suitable for low speed, easy to wear	- Countersinking, chamfering, deburring - Applicable materials: wood, soft metal, plastic - For woodworking, furniture assembly
High-speed steel flat bottom drill bit Flat Bottom Drill Bit	- Material: HSS, hardness HRC 60 - Flat bottom design, 1-2 edges, point angle 180°, diameter 6-50 mm - Coating: None, low cost - Suitable for shallow holes, precise depth control, high cutting force	- Flat bottom blind hole, shallow hole processing - Applicable materials: wood, plastic, soft metal - Used for hinge holes, door lock

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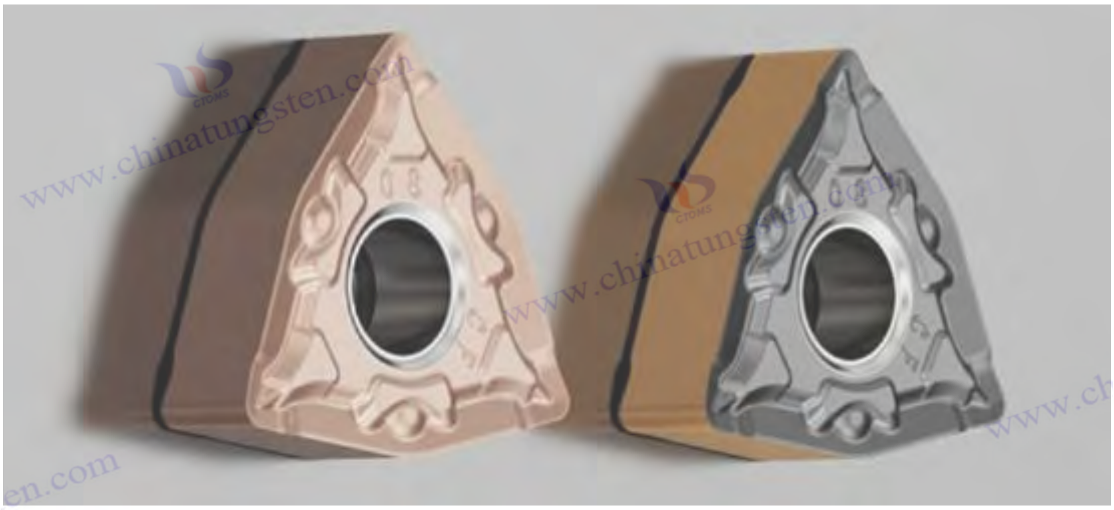
		installation
High-speed steel point drill bit Spotting Drill Bit	- Material: HSS, hardness HRC 60–62 - Point angle 90°–120°, short edge (length 1–2x diameter), 2 edges - Coating: TiN , anti-chipping - High precision, suitable for positioning, reducing deflection	- Positioning drilling, pre-drilling center point - Applicable materials: steel, aluminum, cast iron - For CNC machining, mechanical parts
High-speed steel center drill Center Drill Bit	- Material: HSS, hardness HRC 60 - Double-ended, point angle 60° (guiding) + 118° (drilling), diameter 1–10 mm - Coating: None, good toughness - Short and rigid, suitable for lathe positioning	- Center hole processing to guide subsequent drilling - Applicable materials: steel, cast iron - For lathes and shaft parts
High-speed steel spade drill bits Spade Drill Bit	- Material: HSS, hardness HRC 60 - Flat blade, diameter 10–100 mm, replaceable inserts - Coating: None, low cost - Suitable for large diameter shallow holes, high cutting force	- Large diameter shallow hole drilling - Applicable materials: wood, soft metal - Used for construction, woodworking rough processing
High-speed steel gun drill bit Gun Drill Bit	-Material : HSS, hardness HRC 60–62 -Single -edged, long and thin tubular (length 10–50x diameter), diameter 1–50 mm -Coating : None, requires high-pressure coolant -Suitable for ultra-deep holes, high precision, slow processing	-Ultra -deep hole drilling (>10x diameter) -Applicable materials: steel, aluminum -Used for gun barrels, mold cooling holes
High-speed steel tapered drill bit Taper Drill Bit	- Material: HSS, hardness HRC 60 - Cone angle 1:10–1:50 (Morse taper), diameter 6–50 mm - Coating: None, good toughness - Suitable for tapered holes, low speed required	- Tapered hole processing - Applicable materials: steel, cast iron - For machine tool spindles, tapered pin holes
Cobalt steel twist drill bit Cobalt Twist Drill Bit	- Material: HSS+5–8% cobalt (M35/M42), hardness HRC 62–65 - Point angle 135°, helix angle 25°–35°, 2 flutes, deep groove design - Coating: TiAlN (heat resistant, ≤600°C) or Amber (friction reduction) - High heat resistance, brittle, requires alignment	- Hard metal drilling, shallow/medium-deep holes - Applicable materials: stainless steel, hard steel, titanium alloy - Used in aviation and automotive parts
Cobalt steel step drill bit Cobalt Step Drill Bit	- Material: HSS+cobalt, hardness HRC 63 - Multi-level diameter (6–40 mm), tapered, 2-edge, step spacing 3–5 mm - Coating: TiAlN , high temperature resistant, anti-chip - High hardness, suitable for hard and thin plates, wear resistance	- Stepped holes, expanded holes - Applicable materials: stainless steel, aluminum, hard plastic - For pipe installation, metal processing
Cobalt steel countersunk drill bits Cobalt Countersink Drill Bit	- Material: HSS+Cobalt, hardness HRC 62–64 - Cone angle 82°/90°, 3–4 edges, single-ended design - Coating: TiN , high surface finish - High heat resistance, suitable for hard materials	- Countersunk holes, chamfers - Applicable materials: stainless steel, steel, aluminum - Used for mechanical assembly, aviation parts
Cobalt steel point drill	- Material: HSS+cobalt, hardness HRC 63	- Positioning drilling, pre-drilling center

bits Cobalt Spotting Drill Bit	- Point angle 90°–120°, short edge (length 1–2x diameter), 2 edges - Coating: TiAlN , anti-chipping - High precision, suitable for positioning hard materials	point - Applicable materials: hard steel, stainless steel - Used for CNC machining, aviation parts
Carbide twist drill Carbide Twist Drill Bit	- Material: WC 90–94% + Co 6–10%, hardness HRC 82 - Point angle 118° (general purpose) or 140° (hard material), helix angle 30°–40°, 2–3 edges - Coating: AlTiN (wear resistant, ≤800°C), TiCN (low friction) - Ultra-high hardness, brittle, requires rigid equipment	- Precision drilling, medium/deep holes - Applicable materials: steel, stainless steel, cast iron, aluminum - Used for CNC machining, aviation components
Carbide internal coolant drill Carbide Coolant-Through Drill Bit	- Material: Micro-grained WC, hardness HRC 82 - Point angle 135°–140°, internal coolant hole (1–2 mm), 2 flutes, deep grooves - Coating: PVD AlTiN (heat-resistant, ≤900°C) - Efficient chip evacuation, suitable for deep holes (5–20x diameter)	- Deep hole drilling, high precision - Applicable materials: hard steel, titanium alloy, stainless steel - Used for molds, aircraft engines
Carbide reaming drill bits Carbide Reamer Drill Bit	- Material: WC+Co , hardness HRC 82 - Straight/helical edge, 6–8 edges, tolerance H6/H7, diameter 2–40 mm - Coating: TiCN , high surface finish - High precision, low cutting force, pre-drilling required	- Hole finishing, size control - Applicable materials: steel, aluminum, copper, cast iron - Used for precision machinery, mold hole processing
Carbide countersunk drill bits Carbide Countersink Drill Bit	- Material: WC, hardness HRC 82 - Cone angle 82°/90°, 3–4 flutes, single end, diameter 5–25 mm - Coating: TiCN / AlTiN , high wear resistance - High hardness, suitable for hard materials, smooth surface	- Countersink, chamfer, deburr - Applicable materials: steel, stainless steel, aluminum - Used for mechanical assembly, aviation parts
Carbide point drill bits Carbide Spotting Drill Bit	-Material : WC, hardness HRC 82 -Point angle 90°–120°, short edge (length 1–2x diameter), 2 edges -Coating : AlTiN , anti-chipping, high precision -Strong rigidity, reduce drilling deviation	- Positioning drilling, pre-drilling center point - Applicable materials: steel, cast iron, hard aluminum - For CNC precision machining
Carbide center drill Carbide Center Drill Bit	- Material: Micro-grained WC, hardness HRC 82 - Double-ended, point angle 60° (guiding) + 118° (drilling), diameter 1–12 mm - Coating: TiN , high wear resistance - High precision, suitable for high-speed positioning	- Center hole processing to guide subsequent drilling - Applicable materials: hard steel, cast iron - For lathes and shaft parts
Carbide micro drill bits Carbide Micro Drill Bit	- Material: Ultrafine WC, hardness HRC 82 - Diameter 0.1–3 mm, point angle 120°–135°, 2-edge, short groove - Coating: AlTiN / uncoated, ultra-high precision - anti-fracture, suitable for micro hole processing	- Micro hole processing (≤0.5 mm) - Applicable materials: steel, aluminum, PCB, plastic - Used in electronic components, medical devices

Carbide gun drill bits Carbide Gun Drill Bit	- Material: WC+Co , hardness HRC 82 - Single-edged, long and thin tubular (length 20–100x diameter), diameter 0.5–50 mm - Coating: AlTiN , requires high-pressure coolant - Ultra-deep hole machining, high precision, excellent chip removal	- Ultra-deep hole drilling (>20x diameter) - Applicable materials: steel, cast iron, aluminum - For hydraulic systems, mold cooling holes
Carbide spade drill bits Carbide Spade Drill Bit	- Material: WC, hardness HRC 82 - Flat blade, replaceable blade, diameter 10–150 mm - Coating: TiCN , high wear resistance - Suitable for large diameter shallow holes, high rigidity	- Large diameter shallow hole drilling - Applicable materials: steel, cast iron - Used in heavy machinery, bridge structures
Carbide ring drill Carbide Trepanning Drill Bit	- Material: WC+Co , hardness HRC 82 - Hollow cylinder, peripheral cutting edge, diameter 20–200 mm - Coating: AlTiN , low chipping - Suitable for large diameter shallow holes, high material utilization	- Large diameter annular hole processing - Applicable materials: steel, aluminum - Used for pressure vessels and flange processing
Carbide tapered drill bits Carbide Taper Drill Bit	- Material: WC, hardness HRC 82 - Cone angle 1:10–1:50 (Morse taper), diameter 6–50 mm - Coating: TiN , high wear resistance - High precision, suitable for tapered holes	- Tapered hole processing - Applicable materials: hard steel, cast iron - For machine tool spindles, tapered pin holes
CBN twist drill CBN Twist Drill Bit	- Material: PCBN (CBN 70–95%), hardness HV 3500–4500 - Point angle 130°–140°, helix angle 25°–30°, 2 flutes, deep grooves - Coating: None/thin TiN (high temperature resistant, ≤1400°C) - Super hard, suitable for dry cutting, good thermal stability	- Drilling of hard materials, medium/deep holes - Applicable materials: hardened steel (≥45 HRC), tool steel - used for molds and bearing processing
CBN spot drill CBN Spotting Drill Bit	- Material: CBN + carbide substrate, hardness HV 4000 - Point angle 90°–120°, short edge (length 1–2x diameter), 2 edges - Coating: None, impact resistant, high precision - Strong rigidity, suitable for positioning hard materials	- Hard material positioning drilling - Applicable materials: hard steel, ceramics - used for precision machinery and tool steel processing
CBN reaming drill CBN Reamer Drill Bit	- Material: PCBN, hardness HV 3800–4500 - Straight/helical edges, 6–8 flutes, tolerance H6, diameter 3–30 mm - Coating: None, very smooth surface finish - Ultra-high hardness, suitable for finishing of hard materials	- Hard material hole finishing - Applicable materials: hardened steel, cemented carbide - For molds and precision parts
Ceramic twist drill bit Ceramic Twist Drill Bit	-Material : Al_2O_3 / Si_3N_4 , hardness HV 2000–2500 -Point angle 120 °–135°, helix angle 20°–30°, 2-edge -Coating : None, high temperature resistance (≤1200°C), chemically stable -Low toughness , requires high-rigidity machine tools, low-speed processing	- Composite material drilling, shallow/medium-deep holes - Applicable materials: glass fiber, carbon fiber, CFRP - Used for aviation composite material processing

Ceramic glass drill bits Ceramic Glass Drill Bit	- Material: Si_3N_4 +ZrO_2 , hardness HV 2100 - Spear - shaped tip, diameter 3–10 mm, without spiral grooves - Coating: None, low cutting forces, anti-chipping - Suitable for brittle materials, requires water cooling, low speed	- Glass and ceramic drilling - Applicable materials: glass, tiles, ceramics - for decoration and architectural installation
Ceramic composite drill bits Ceramic Composite Drill Bit	- Material: Al_2O_3 + ZrO_2 , hardness HV 2200 - Point angle 130°–140°, low shear geometry, 2 edges - Coating : None, high wear resistance - Anti-delamination, suitable for laminated materials, requiring low speed	- Composite material drilling - Applicable materials: CFRP, GFRP - For aerospace structural parts
PCD twist drill PCD Twist Drill Bit	- Material: PCD + carbide substrate, hardness HV 7000–8000 - Point angle 118°–135°, helix angle 25°–35°, 2 edges - Coating: None, ultra-low friction, smooth surface - Extremely wear-resistant, suitable for non-ferrous materials	- High-speed drilling, shallow/medium-deep holes - Applicable materials: aluminum, copper, composite materials - Used in automotive pistons and aviation parts
PCD glass drill bits PCD Glass Drill Bit	- Material: PCD, hardness HV 7500 - Spear-shaped/conical tip, diameter 2–12 mm, without spiral groove - Coating: None, high precision, anti-chipping - Suitable for brittle materials, requires water cooling	- Precision glass and ceramic drilling - Applicable materials: glass, ceramic, gemstone - Used for optical lenses and electronic components
PCD composite drill bits PCD Composite Drill Bit	- Material: PCD+WC substrate, hardness HV 7200 - Point angle 130°–140°, special geometry (low shear), 2 edges - Coating: AlCrSi / TiN (wear resistant, ≤600°C) - Anti-delamination, suitable for laminated materials	- Composite material drilling - Applicable materials: Carbon fiber, CFRP-Ti, GFRP - For aerospace structural parts
PCD micro drill PCD Micro Drill Bit	- Material: PCD+WC substrate, hardness HV 7500 - Diameter 0.1–2 mm, point angle 120°–130°, 2 edges - Coating: None, ultra-high precision - wear-resistant, suitable for micro-hole processing	- Micro hole processing (≤0.3 mm) - Applicable materials: aluminum, composite materials, ceramics - Used in electronic components and medical devices



Cemented carbide (tungsten carbide based), CBN (cubic boron nitride), ceramics, tool steel, high speed steel (HSS), Characteristics and uses of titanium zirconium molybdenum (TZM), polycrystalline diamond (PCD), natural diamond, CVD diamond, stainless steel and aluminum molds

The following is a comprehensive list of molds made of cemented carbide (tungsten carbide-based), CBN (cubic boron nitride), ceramics, tool steel, high-speed steel (HSS), titanium-zirconium-molybdenum (TZM), polycrystalline diamond (PCD), natural diamond, CVD diamond, stainless steel, and aluminum. The list includes their names, characteristics (material composition, hardness, surface treatment, precision, etc.), and applications (applicable products, industry scenarios, etc.). These molds are used in stamping, injection molding, forging, die-casting, wire drawing, casting, blow molding, rotational molding, and other processes, covering a wide range of materials and production needs. TZM stands for titanium-zirconium-molybdenum (TZM) in Chinese and titanium-zirconium-molybdenum (TZM) in English.

Mold name	Features	use
Carbide stamping dies Cemented Carbide Stamping Mold	- Material: WC 85–94% + Co 6–15%, hardness HRC 60–65 - Surface treatment: PVD TiN / TiCN (wear-resistant, ≤800°C) - High hardness, impact resistance, long life (millions of punching cycles) - High precision (±0.005 mm), suitable for high-speed punching	- Punching and forming thin plate parts - Applicable products: metal sheets, electronic connectors - Used in the automotive, electronics, and home appliance industries
Carbide drawing dies Cemented Carbide Drawing Mold	- Material: Micro-grained WC, hardness HRC 62 - Surface treatment: DLC coating (low friction, ≤600°C) - High toughness, resistant to tensile deformation - Polished surface (Ra 0.1 μm) to reduce sticking	- Stretched metal shells and tubes - Applicable products: aluminum cans, car shells - used for packaging and automobile manufacturing
Carbide extrusion dies Cemented Carbide Extrusion Mold	- Material: WC + Co, hardness HRC 60 - Surface treatment: CVD Al_2O_3 (high temperature resistant , ≤900°C) - High wear resistance, suitable for high stress extrusion - Cavity accuracy ±0.01 mm	- Extruded aluminum profiles, copper rods - Applicable products: architectural profiles, radiators - used in construction, aerospace
Cemented carbide powder metallurgy molds Cemented Carbide Powder Metallurgy Mold	- Material: WC 90% + Co 10%, hardness HRC 63 - Surface treatment: nitriding (hardness HV 1000) - High compressive strength, wear resistance - Suitable for complex shapes, high density pressing	- Pressed powder parts - Applicable products: magnetic cores, gears - used for magnetic materials, mechanical parts
Carbide wire drawing dies Cemented Carbide Drawing Die	- Material: WC 92% + Co 8%, hardness HRC 62 - Surface treatment: polished (Ra 0.05 μm), CVD coating optional - High wear resistance, hole diameter 0.01–10 mm - Structure: bell mouth, entrance angle, working angle, sizing	- Brushed metal wire - Applicable products: copper wire, steel wire - used in wire and cable, construction industry

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	belt	
Carbide injection mold Cemented Carbide Injection Mold	- Material: WC + Co, hardness HRC 60 - Surface treatment: PVD TiCN (wear-resistant, ≤700°C) - High hardness, wear resistance, suitable for high-precision mold cavities - Polished surface (Ra 0.08 μm)	- Injection molded metal parts - Applicable products: precision metal parts, medical parts - used in medical and precision machinery
Carbide casting molds Cemented Carbide Casting Mold	- Material: WC 90% + Co 10%, hardness HRC 61 - Surface treatment: CVD Al_2O_3 (high temperature resistance, ≤1000°C) - Resistant to thermal shock and molten metal corrosion - Accuracy ±0.015 mm, suitable for small batches	- Casting small metal parts - Applicable products: tungsten alloy parts, precision castings - used in aviation and jewelry industries
CBN stamping dies CBN Stamping Mold	- Material: PCBN, hardness HV 3500–4500 - Surface treatment: None/thin TiN (high temperature resistance, ≤1400°C) - Ultra-high hardness, suitable for punching hard materials - Extremely high precision (±0.002 mm) and long service life	- Punching hard steel and alloy plates - Applicable products: tool steel parts, cutting tools - Used in mold manufacturing, aviation parts
CBN drawing die CBN Drawing Mold	- Material: CBN, hardness HV 4000 - Surface treatment: None, low friction coefficient - High temperature resistance, anti-adhesion - Suitable for stretching high hardness materials, high mold cavity finish	- Stretched carbide parts - Applicable products: precision shafts, mold components - used in precision machinery and tool manufacturing
CBN drawing dies CBN Drawing Die	- Material: PCBN, hardness HV 3800 - Surface treatment: polished (Ra 0.03 μm) - Ultra-high wear resistance, suitable for ultra-fine wires - Hole diameter 0.005–5 mm, extremely high precision	- Drawing ultra-fine hard wire - Applicable products: tungsten wire, molybdenum wire - used for electronic and aviation wire
Ceramic injection mold Ceramic Injection Mold	- Material: Al_2O_3 / Si_3N_4 , hardness HV 2000–2500 - Surface treatment : polished (Ra 0.05 μm) - High temperature resistance (≤1200°C), strong chemical stability - Low toughness, suitable for small batch precision molding	- Injection molded plastics and rubber parts - Applicable products: medical devices, optical lenses - used in the medical and electronics industries
Ceramic die-casting molds Ceramic Die Casting Mold	- Material: Si_3N_4 + ZrO_2 , hardness HV 2200 - Surface treatment: None, thermal shock resistance - High corrosion resistance, resistance to molten metal erosion - Requires high rigidity support, medium life	- Die-cast aluminum, magnesium alloy - Applicable products: automotive parts, lamp housings - Used in the automotive and lighting industries
Ceramic powder metallurgy molds Ceramic Powder Metallurgy Mold	- Material: Al_2O_3 , hardness HV 2100 - Surface treatment: polished, wear-resistant - High temperature resistant, suitable for high-precision pressing	- Pressed ceramic parts - Applicable products: ceramic knives, insulators - used in ceramic products, electronics

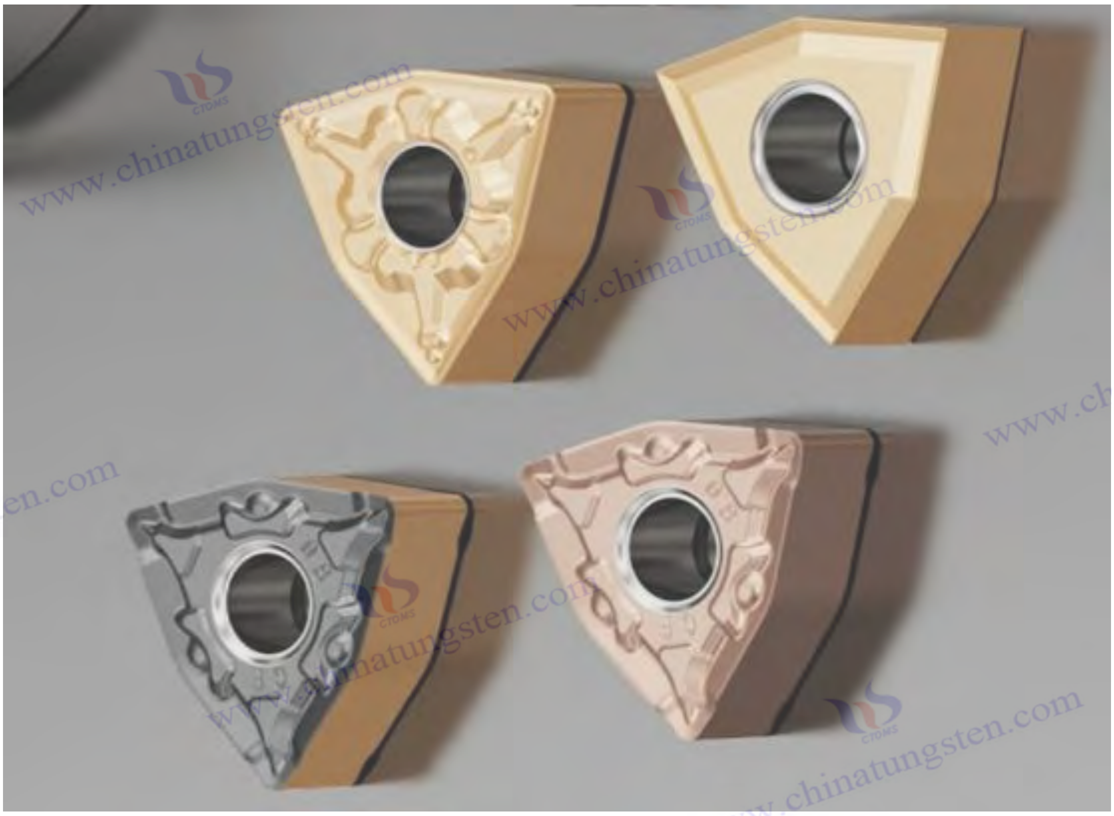
	- Anti-oxidation, suitable for ceramic powder	industry
Ceramic casting molds Ceramic Casting Mold	- Material: Si_3N_4 , hardness HV 2300 - Surface treatment: None, high temperature resistance (≤1300°C) - High resistance to thermal shock and cracking - Suitable for precision casting, short life	- Casting ceramic and glass parts - Applicable products: optical glass and ceramic parts - used in the optical and ceramic industries
Tool steel stamping dies Tool Steel Stamping Mold	- Material: D2/Cr12MoV, hardness HRC 58–62 - Surface treatment: Nitriding/chrome plating (hardness HV 800) - High toughness, impact resistance, easy to repair - Accuracy ±0.01 mm, moderate cost	- Punching and forming steel plates - Applicable products: hardware, automotive panels - used in home appliances and automobile manufacturing
Tool steel injection molds Tool Steel Injection Mold	- Material: P20/718H, hardness HRC 30–40 (pre-hardened) - Surface treatment: polishing/plating (Ra 0.2 μm) - Easy to process, suitable for complex mold cavities - Medium life (500,000 times)	- Injection molded plastic parts - Applicable products: plastic shells, toys - used in consumer goods and electronics industries
Tool steel forging dies Tool Steel Forging Mold	- Material: H13/5CrNiMo, hardness HRC 45–50 - Surface treatment: carburizing (hardness HV 700) - High temperature resistance (≤600°C), thermal fatigue resistance - Suitable for mass forging	- Hot forging and cold forging parts - Applicable products: crankshafts, gears - used in automobile and machinery manufacturing
Tool steel die casting molds Tool Steel Die Casting Mold	- Material: H13, hardness HRC 42–48 - Surface treatment: Nitriding (wear-resistant, ≤700°C) - Thermal shock and crack resistance - Cavity accuracy ±0.02 mm	- Die-cast aluminum, zinc alloy - Applicable products: engine housing, wheel hub - Used in automobile and motorcycle industries
Tool steel casting molds Tool Steel Casting Mold	- Material: H13, hardness HRC 40–45 - Surface treatment: carburizing/polishing (heat resistant, ≤650°C) - High temperature resistant, suitable for large castings - Medium life, easy maintenance	- Casting large metal parts - Applicable products: pump bodies, valves - used in machinery and energy industries
High-speed steel stamping dies HSS Stamping Mold	- Material: HSS (M2/M42), hardness HRC 60–65 - Surface treatment: TiN coating (wear-resistant, ≤500°C) - High toughness, easy to wear - Low cost, medium accuracy (±0.015 mm)	- Low-speed punching of soft materials - Applicable products: copper sheets, aluminum plates - Used for electronics and small parts processing
High-speed steel drawing die HSS Drawing Mold	- Material: HSS, hardness HRC 62 - Surface treatment: polished (Ra 0.3 μm) - Good toughness, suitable for small batches - Low wear resistance, requires frequent maintenance	- Stretching soft metal parts - Applicable products: copper tubes, aluminum shells - Used in hardware and packaging

		industries
High-speed steel powder metallurgy mold (HSS Powder Metallurgy Mold	- Material: HSS, hardness HRC 60 - Surface treatment: chrome plating, wear-resistant - Easy to process, low cost - Suitable for low hardness powder pressing	- Pressed soft powder parts - Applicable products: Iron-based parts - Used for small machinery, DIY manufacturing
High-speed steel drawing dies HSS Drawing Die	- Material: HSS, hardness HRC 62 - Surface treatment: polished (Ra 0.1 μm) - High toughness, medium wear resistance - Suitable for low-speed wire drawing, low cost	- Wire drawing soft wire - Applicable products: aluminum wire, copper wire - used in wire and decoration industries
Titanium zirconium molybdenum stamping die Titanium-Zirconium-Molybdenum Stamping Mold	- Material: TZM (Mo 99% + Ti + Zr), hardness HV 250–300 - Surface treatment: Nitriding (hardness HV 600) - High temperature resistance (≤1700°C), oxidation resistance - High strength, suitable for high temperature blanking	- Punching high temperature alloy plates - Applicable products: aviation parts, titanium alloy parts - used in aerospace, military industry
Titanium zirconium molybdenum extrusion die Titanium-Zirconium-Molybdenum Extrusion Mold	- Material: TZM, hardness HV 280 - Surface treatment: CVD TiC (wear-resistant, ≤1600°C) - High temperature and high pressure resistance, anti-deformation - Cavity accuracy ±0.02 mm	- Extruded high-temperature alloys - Applicable products: titanium tubes, molybdenum rods - used in aviation and nuclear industries
Titanium zirconium molybdenum casting mold Titanium-Zirconium-Molybdenum Casting Mold	- Material: TZM, hardness HV 270 - Surface treatment: None, high temperature resistance (≤1800°C) - Thermal shock resistance, suitable for high temperature molten metal - Shorter lifespan, higher cost	- Casting high-temperature alloy parts - Applicable products: turbine blades, molybdenum alloy parts - used in aviation and energy industries
Polycrystalline diamond wire drawing dies Polycrystalline Diamond Drawing Die	- Material: PCD (synthetic diamond + Si/Ti binder), hardness HV 7000–8000 - Surface treatment: polished (Ra 0.02 μm) - Isotropic, pore size 0.01–5 mm, life span 50–500 times that of cemented carbide - High wear resistance, anti-adhesion	- High-precision wire drawing - Applicable products: copper wire, aluminum wire, tungsten wire - Used in electronics, aviation, and cable industries
Polycrystalline diamond compaction mold Polycrystalline Diamond Compacting Mold	-Material : PCD, hardness HV 7500 -Surface treatment: polished (Ra 0.03 μm) -High hardness, suitable for high-pressure torsion pressing -High precision (±0.001 mm), wear-resistant	-Compacted wire and cable conductors -Applicable products: power cables, automotive wiring harnesses -Used in the power and automotive industries
Polycrystalline diamond peeling die Polycrystalline Diamond Shaving Die	- Material: PCD, hardness HV 7200 - Surface treatment: polished (Ra 0.02 μm) - Ultra-high wear resistance, suitable for surface treatment - Aperture accuracy ±0.002 mm	- Remove oxides and oil stains from the surface of wires - Applicable products: steel wire, copper wire

		- Used in wire processing and electronics industries
Natural diamond drawing dies Natural Diamond Drawing Die	- Material: Natural diamond, hardness HV 9000–10000 - Surface treatment: Polished (Ra 0.01 μm) - Extremely high hardness, pore diameter 0.005–2 mm, prone to anisotropic wear - High cost and difficult to process	- Ultra-fine high-precision wire drawing - Applicable products: gold wire, silver wire - used in jewelry and electronics industries
CVD diamond wire drawing dies CVD Diamond Drawing Die	- Material: CVD diamond coating, hardness HV 8000–9000 - Surface treatment: polished (Ra 0.015 μm) - Overcome anisotropy, high wear resistance, pore size 0.01–3 mm - Lifespan close to natural diamond, lower cost	- Drawing small diameter wire - Applicable products: molybdenum wire, stainless steel wire - used in electronics and precision instruments
stainless steel injection mold Stainless Steel Injection Mold	- Material: 316/420 stainless steel, hardness HRC 45–50 - Surface treatment: polished/plated (Ra 0.15 μm) - Corrosion-resistant, suitable for corrosive plastics - Medium life (300,000 times), moderate cost	- Injection molding chemical containers, medical parts - Applicable products: PVC parts, medical plastics - Used in medical and chemical industries
Stainless steel die-casting molds Stainless Steel Die Casting Mold	- Material: 420 stainless steel, hardness HRC 48–52 - Surface treatment: nitriding (wear-resistant, ≤600°C) - Corrosion-resistant, resistant to molten metal erosion - Accuracy ±0.02 mm, suitable for medium batches	- Die-cast zinc and magnesium alloys - Applicable products: decorative parts, electronic housings - used in home appliances and electronics industries
Aluminum blow mold Aluminum Blow Molding Mold	- Material: 7075 aluminum alloy, hardness HB 130–150 - Surface treatment: anodizing (wear-resistant, ≤300°C) - Light weight, good thermal conductivity, simple processing - Short life (100,000 times), low cost	- Blow molding plastic bottles and containers - Applicable products: beverage bottles, cosmetic bottles - used in packaging and consumer goods industries
Aluminum rotational forming molds Aluminum Rotational Molding Mold	- Material: 6061 aluminum alloy, hardness HB 90–110 - Surface treatment: polished (Ra 0.3 μm) - Lightweight, suitable for complex surface forming - Low heat resistance (≤250°C), short life	- Rotationally molded large hollow parts - Applicable products: storage tanks, amusement facilities - Used in the construction and entertainment industries

电话/TEL：0086 592 512 9696

sales@chinatungsten.com



Detailed table of carbide tap names, characteristics and uses

The following is a comprehensive list of carbide (tungsten carbide-based) taps, including tool name, characteristics (material composition, hardness, coating, geometry, cutting parameters, etc.), and applications (suitable materials and processing scenarios, etc.). Carbide, primarily composed of tungsten carbide (WC) and cobalt (Co), offers high hardness and wear resistance, making it suitable for high-hardness materials and efficient threading. The table covers various tap types, including straight flute, spiral flute, extrusion, and forming, supporting standards such as metric and imperial pipe threads. This comprehensive list is based on industry standards.

Tap Name	Characteristics	Applications
Straight Flute Tap	Material: WC 90 94% + Co 6 10% Hardness HRC 60 65 Geometry: 2 4-slot straight groove design Thread angle 60° (metric) / 55° (BSP) Diameter M1 M20 Coating: TiN (titanium nitride wear resistance ≤ 700°C) or TiCN (anti-chipping) Cutting speed 10 50m/min High rigidity Suitable for through holes and hard materials Accuracy H6 H8	Through hole thread processing Applicable materials: steel, stainless steel, cast iron, hardness ≤ 45HRC, used for mechanical parts and automotive parts
Spiral Flute Tap	Material: WC 88 92% + Co 8 12% Hardness HRC 62 Geometry: 2 4 grooves Helix angle 15° 40° Right-hand/left-hand Diameter M2 M24 Coating: AlTiN (aluminum titanium nitrogen heat resistance ≤ 800°C) Cutting speed 15 60m/min Feed rate 0.05 0.15mm/r Excellent chip evacuation Suitable for blind holes Accuracy H6 H9	Applicable materials for blind hole thread processing : steel, aluminum and titanium alloys with hardness ≤ 50HRC , used for aviation parts mold threads

Thread Forming Tap	Material: Micro-grained WC Hardness HRC 60 Geometry: Slotless arc Extrusion surface diameter M1-M16 Pitch 0.2-2mm Coating: TiCN (low friction) or DLC (diamond-like carbon wear resistance) Cutting speed 20-80m/min Chipless processing of high-strength threads Suitable for soft materials Accuracy H7-H9	Through hole/blind hole thread forming Applicable materials: aluminum, copper, stainless steel Hardness ≤ 30HRC Used for electronic components and automotive aluminum parts
Pipe Thread Tap	Material: WC 90% + Co 8% Hardness HRC 62 Geometry: 3 5 grooves Taper 1:16 (NPT) / Parallel (G) Diameter 1/8 2 inches Coating: TiN / AlTiN Wear-resistant Cutting speed 8 40m/min Accuracy ISO2/3 High durability Suitable for pipe processing Anti-fracture	Pipe thread processing (NPT BSP G) Applicable materials: steel, cast iron, stainless steel, used for pipe fittings, hydraulic systems
Carbide High Performance Tap	Material: WC 92% + Co 8% Hardness HRC 60 Geometry: 3-4 grooves Optimized helix angle 20° 45° Diameter M3 M30 Coating: AlCrN (aluminum chromium nitrogen heat resistant ≤ 1100°C) Cutting speed 20-100m/min Versatile Suitable for high-speed machining Long life Precision H6 H8	Through hole/blind hole high speed thread processing Applicable materials: steel titanium alloy high temperature alloy ≤55HRC for aerospace energy equipment
Micro Tap	Material: Ultrafine WC Hardness HRC 62 Geometry: 2-3 groove straight groove / spiral groove Diameter M0.5 M3 Pitch 0.1 0.5mm Coating: TiCN / No coating Accuracy ±0.005mm Cutting speed 5 30m/min Ultra-high precision suitable for small threads and anti-breakage	Applicable materials for micro thread processing : steel, aluminum, plastic, hardness ≤ 40HRC , used for electronic components and medical devices
Combination Tap	Material: WC 90% + Co 10% Hardness HRC 60 Geometry: 2 4 grooves + drill straight groove / spiral groove Diameter M2 M12 Coating: AlTiN Cutting speed 15 50m/min Accuracy H7 H9 Drilling + threading in one step Reduce tool change and high efficiency	Drilling + threading composite processing Applicable materials: steel, aluminum, cast iron Hardness ≤ 45HRC Used for mass production of automotive parts
Deep Hole Tap	Material: WC 88% + Co 12% Hardness HRC 62 Geometry: 3-4 Flutes Helix Angle 30° 40° Length/Diameter Ratio 10:1 Diameter M4 M20 Coating: TiCN / AlCrN Cutting Speed 10-40m/min Smooth Chip Evacuation Suitable for Deep Hole Machining High Rigidity Precision H6 H8	Applicable materials for deep hole thread processing : steel, stainless steel, titanium alloy, hardness ≤ 50HRC , used for molds and aviation structural parts
Unified Thread Tap	Material: WC 90% + Co 8% Hardness HRC 60 Geometry: 3/4 grooves straight groove/spiral groove UNC/UNF standard	British thread processing (UNC UNF)

	diameter #2 1 inch Coating: TiN / TiCN Cutting speed 10-50m/min Accuracy 2B/3B Suitable for imperial threads High wear resistance Strong versatility	Applicable materials: steel, aluminum, cast iron Hardness ≤ 45HRC For mechanical parts American standard equipment
Knurling Tap	Material: WC 92% + Co 8% Hardness HRC 62 Geometry: Grooved knurled extrusion surface diameter M2 M16 Pitch 0.4 2mm Coating: DLC (low friction) Cutting speed 15 60m/min Accuracy H7 H9 Chipless machining High surface quality High thread strength	Applicable materials for knurled thread forming : aluminum, copper, stainless steel, hardness ≤ 35HRC , used for decorative parts and car handles

Detailed table of carbide measuring tools, cutting tools names, characteristics and uses

The following is a comprehensive list of cemented carbide (tungsten carbide-based) measuring tools and cutting tools, including tool name, characteristics (material composition, hardness, coating, geometry, precision, cutting parameters, etc.), and applications (applicable materials processing or inspection scenarios, industry applications, etc.). Cemented carbide is primarily composed of tungsten carbide (WC) and cobalt (Co), offering high hardness and wear resistance, making it suitable for high-precision measurement and cutting. The table covers measuring tools (plug gauges, ring gauges, thread gauges, gauge blocks, etc.) and cutting tools (reamers, countersinks, drills, scribers, etc.), categorized by standard (metric and imperial pipe threads) and application (high-precision inspection, deep hole machining, micromachining, etc.). It supports standards such as ISO, ANSI, DIN, JIS, NPT, and BSP, and is based on industry standards for comprehensiveness.

Tool Name	Characteristics	Applications
Metric Plug Gauge	Material: WC 90 94% + Co 6 10% Hardness HRC 60 65 Geometry: Cylindrical Diameter 1 100mm Tolerance H5 H7 (ISO 286) Surface finish Ra0.05 0.2μm Coating: None / TiN (wear resistance ≤ 700°C) Accuracy ±0.0005mm Lifespan 100,000 measurements High wear and corrosion resistance Suitable for high-frequency testing	Metric inner hole size tolerance test Applicable materials: steel, stainless steel, aluminum Hardness ≤ 45HRC . Used for automobile cylinder body, aviation turbine hole mold inner hole
Carbide Imperial Plug Gauge	Material: WC 92% + Co 8% Hardness HRC 62 Geometry: Cylindrical Diameter 1/16 4 inches Tolerance Class Z (ANSI B89.1.5) Surface finish Ra0.1 0.3μm Coating: None Accuracy ±0.0008mm Scratch resistance High precision Suitable for British standard testing High durability	Detect the roundness of the imperial inner hole size. Applicable materials: steel, cast iron, copper, used for American standard mechanical parts, aviation fasteners, holes and pump bodies.
Carbide Metric Ring Gauge	Material: WC 90% + Co 10% Hardness HRC 60 Geometry: Circular inner diameter 2 150mm Tolerance H6 H8 (ISO 286) Surface finish Ra0.05 0.15μm Coating: No Accuracy ±0.001mm High thermal stability High hardness Suitable for outer diameter detection Anti-deformation	Detection of metric shaft outer diameter cylindricity Applicable materials: steel, aluminum and titanium alloys for mechanical shafts, aviation bearings, mold pins
Carbide Imperial Ring Gauge	Material: WC 92% + Co 8% Hardness HRC 62 Geometry: Circular inner diameter 1/8 inch Tolerance Class XX (ANSI B89.1.6) Surface finish Ra0.1 0.2μm Coating: None / TiN Accuracy ±0.0012mm Wear-resistant Ultra-high precision Suitable for inch shaft inspection Long life	Detection of imperial outer diameter form and position tolerances Applicable materials: steel, cast iron, stainless steel, used for American standard bolts, aviation shafts, energy equipment

Thread Plug Gauge	Material: WC 90% + Co 10% Hardness HRC 60 Geometry: Thread type Metric M0.5 M50 Pitch 0.2 4mm Accuracy 6H 7H (ISO 1502) Surface finish Ra0.2 0.4μm Coating: TiN (anti-chip) Accuracy ±0.002mm High wear resistance Suitable for high-frequency thread detection Corrosion resistance	Detect the pitch tolerance of metric internal thread size . Applicable materials: steel, aluminum, stainless steel, used for nuts, aviation threaded holes, mechanical parts
Unified Thread Plug Gauge	Material: WC 88 92% + Co 8 12% Hardness HRC 62 Geometry: Thread UNC/UNF #1 2 inches Accuracy 2B 3B (ANSI B1.2) Surface finish Ra0.2 0.5μm Coating: TiCN Accuracy ±0.0025mm Long life and high precision Suitable for imperial thread detection High durability	Testing the form and position tolerances of British internal threads. Applicable materials: steel, cast iron, and copper . Used for American standard nuts, aviation fasteners, pumps, and valves.
Carbide Pipe Thread Plug Gauge	Material: WC 90% + Co 10% Hardness HRC 60 Geometry: Thread type NPT/BSP 1/16 2 inches Taper 1:16 Accuracy L1 L2 (ANSI B1.20.1) Surface finish Ra0.3 0.6μm Coating: TiN Accuracy ±0.003mm Anti-wear Suitable for pipe thread inspection High rigidity Anti-deformation	Detect the inner dimension and sealing of pipe threads . Applicable materials: steel, stainless steel, cast iron. Used in pipe fittings, hydraulic systems, energy equipment.
Thread Ring Gauge	Material: WC 92% + Co 8% Hardness HRC 62 Geometry: Threaded ring metric M1 M60 Pitch 0.25 4mm Accuracy 6g 7g (ISO 1502) Surface finish Ra0.2 0.4μm Coating: None / TiCN Accuracy ±0.002mm Corrosion resistant High hardness Suitable for external thread inspection Anti-scratch	Detect metric external thread size and pitch Applicable materials: steel, aluminum and titanium alloys for bolts, aviation threaded parts, mold screws
Unified Thread Ring Gauge	Material: WC 90% + Co 10% Hardness HRC 60 Geometry: Threaded ring UNC/UNF #2 2 inches Accuracy 2A 3A (ANSI B1.2) Surface finish Ra0.2 0.5μm Coating: None Accuracy ±0.0025mm Long life Ultra-high precision Suitable for imperial thread detection Wear resistance	Detection of British external thread form and position tolerances Applicable materials: steel, cast iron, stainless steel, used for American standard bolts, aviation fasteners, mechanical shafts
Carbide Pipe Thread Ring Gauge	Material: WC 88 92% + Co 8 12% Hardness HRC 62 Geometry: Threaded ring NPT/BSP 1/8 2-inch Taper 1:16 Accuracy L1 (ANSI B1.20.1) Surface finish Ra0.3 0.6μm Coating: TiN Accuracy ±0.003mm Anti-deformation High rigidity Suitable for pipe thread inspection Corrosion resistance	Detect the outer dimensions and sealing performance of pipe threads. Applicable materials: steel, stainless steel, cast iron. Used in pipe joints, hydraulic valves, energy pipelines.

Straight Flute Reamer	Material: WC 90% + Co 8% Hardness HRC 60 Geometry: 6 10-edge straight edge diameter 1 30mm Tolerance h5 h6 (ISO 286) Surface finish Ra0.1 0.3μm Coating: AlTiN (heat resistant ≤ 800°C) Cutting speed 20 80m/min Feed rate 0.05 0.2mm/r High precision suitable for through-hole finishing Long life	Through hole finishing and size calibration Applicable materials: steel, aluminum, copper Hardness ≤ 45HRC . Used for hydraulic valve holes, bearing seats, aviation holes
Spiral Flute Reamer	Material: WC 92% + Co 8% Hardness HRC 62 Geometry: 6 8 Edges Helix Angle 10° 15° Diameter 2 25mm Tolerance h6 h7 Surface Finish Ra0.1 0.2μm Coating: TiCN (wear resistant) Cutting Speed 30 100m/min Feed Rate 0.03 0.15mm/r Excellent chip evacuation Suitable for blind holes High precision	Blind hole finishing size control Applicable materials: steel, stainless steel, titanium alloy, hardness ≤ 50HRC . Used for mold holes, aviation structural parts, pump bodies
Carbide Deep Hole Reamer	Material: WC 88 92% + Co 8 12% Hardness HRC 62 Geometry: 4 6 flutes Helix angle 12° 18° Length/diameter ratio 10:1 Diameter 3 20mm Tolerance h6 Coating: AlCrN (heat resistant ≤ 1100°C) Cutting speed 15 60m/min Surface finish Ra0.1 0.3μm High rigidity Suitable for deep hole machining Smooth chip evacuation	Deep hole finishing dimensional accuracy Applicable materials: steel, stainless steel, cast iron Hardness ≤ 45HRC . Used for mold deep hole aviation skeleton hydraulic cylinder
Carbide Micro Reamer	Material: Ultrafine WC Hardness HRC 62 Geometry: 4 6-edge straight edge / spiral edge Diameter 0.2 3mm Tolerance h4 h5 Surface finish Ra0.05 0.15μm Coating: TiN / None Cutting speed 10 50m/min Accuracy ±0.001mm Ultra-high precision Suitable for micro-hole processing Anti-fracture	Micro-hole precision machining and size calibration Applicable materials: steel, aluminum, plastic hardness ≤ 40HRC . Used for electronic components and medical equipment micro molds
Carbide Countersink	Material: WC 90% + Co 10% Hardness HRC 60 Geometry: 3 6 Edge Angle 60° 90° 120° Diameter 5 40mm Surface Finish Ra0.2 0.5μm Coating: TiCN Cutting Speed 20 80m/min Accuracy ±0.01mm High Rigidity Suitable for Countersinking Strong Wear Resistance	Countersink chamfering is suitable for materials: steel, stainless steel, aluminum, hardness ≤ 45HRC . Used for bolt holes, automotive panel mold edges.
Carbide Zero Degree Countersink	Material: WC 92% + Co 8% Hardness HRC 62 Geometry: 3 5 Edge Cone Angle 0° (Flat Bottom) Diameter 4 30mm Surface Finish Ra0.1 0.3μm Coating: AlTiN Cutting Speed 15 60m/min Accuracy ±0.01mm Suitable for flat countersinking High precision and wear resistance	Applicable materials for plane countersunk seat processing : steel, aluminum, cast iron, hardness ≤ 40HRC . Used for the plane of the mold of the mechanical base of aviation fasteners

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Micrometer Tip	Material: WC 94% + Co 6% Hardness HRC 60 Geometry: Flat/Spherical Diameter 3-10mm Surface finish Ra0.02 0.1μm Coating: None Accuracy ±0.0003mm Scratch resistance Ultra-high hardness Suitable for high-precision measurement Corrosion resistance	Applicable materials for outer diameter thickness gap measurement : steel, ceramic, plastic , used for precision machinery, microelectronics and aviation parts
Caliper Jaw	Material: WC 90% + Co 10% Hardness HRC 62 Geometry: Flat/Tip/Inner groove Length 10-50mm Surface finish Ra0.05 0.15μm Coating: None Accuracy ±0.005mm Strong wear resistance High stability Suitable for frequent measurements Anti-wear	Inner/outer diameter depth and groove width measurement Applicable materials: Steel and aluminum composite materials for molds, aviation parts, general machinery
Carbide Gauge Block	Material: WC 92% + Co 8% Hardness HRC 60 Geometry: Rectangular Size 0.5 200mm Tolerance ±0.00005mm (ISO 3650 Grade 0) Surface finish Ra0.01 0.05μm Coating: None Corrosion resistance Low thermal expansion coefficient Ultra-high precision Suitable for calibration Long life	Length standard calibration machine tool calibration Applicable materials: steel, ceramic, glass, used in metrology room, aviation manufacturing, precision machining
Micro Gauge Block	Material: WC 94% + Co 6% Hardness HRC 62 Geometry: Rectangular Size 0.1 10mm Tolerance ±0.00003mm (ISO 3650 Grade K) Surface finish Ra0.01 0.03μm Coating: None High precision Scratch resistance Suitable for small size calibration Corrosion resistance	Applicable materials for calibration of micro length calibration instruments : steel, ceramics, plastics, used in optical manufacturing of microelectronic medical devices
Carbide Scriber	Material: WC 90% + Co 10% Hardness HRC 62 Geometry: Needle-shaped Tip radius 0.03 - 0.2mm Length 50 - 200mm Coating: None Hardness High precision ±0.005mm High wear resistance Suitable for marking hard materials Anti-fracture	Surface marking and positioning Applicable materials: steel, stainless steel, ceramics Hardness ≤ 50HRC , used for mold manufacturing and aviation parts machining
Carbide Micro Scriber	Material: Ultrafine WC Hardness HRC 62 Geometry: Needle-shaped Tip radius 0.01 - 0.05mm Length 30 - 100mm Coating: None Accuracy ±0.002mm Anti-breakage Ultra-high precision Suitable for small markings Wear-resistant	Micro surface marking and precise positioning Applicable materials: steel, aluminum, glass Hardness ≤ 40HRC . Used in microelectronics , optical components , medical devices

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CTIA GROUP LTD

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Contact Us

Email : sales@chinatungsten.com
Tel : +86 592 5129696
Official website : www.ctia.com.cn