

What Is Tungsten Alloy Bar

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

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

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www.ctia.com.cn

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.



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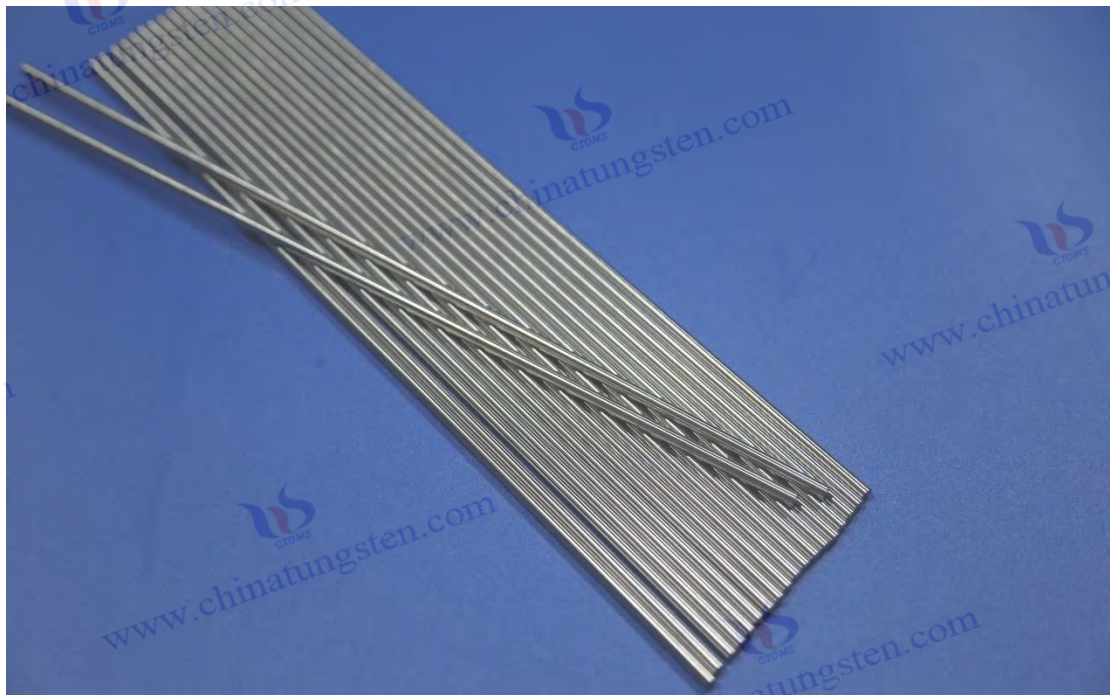
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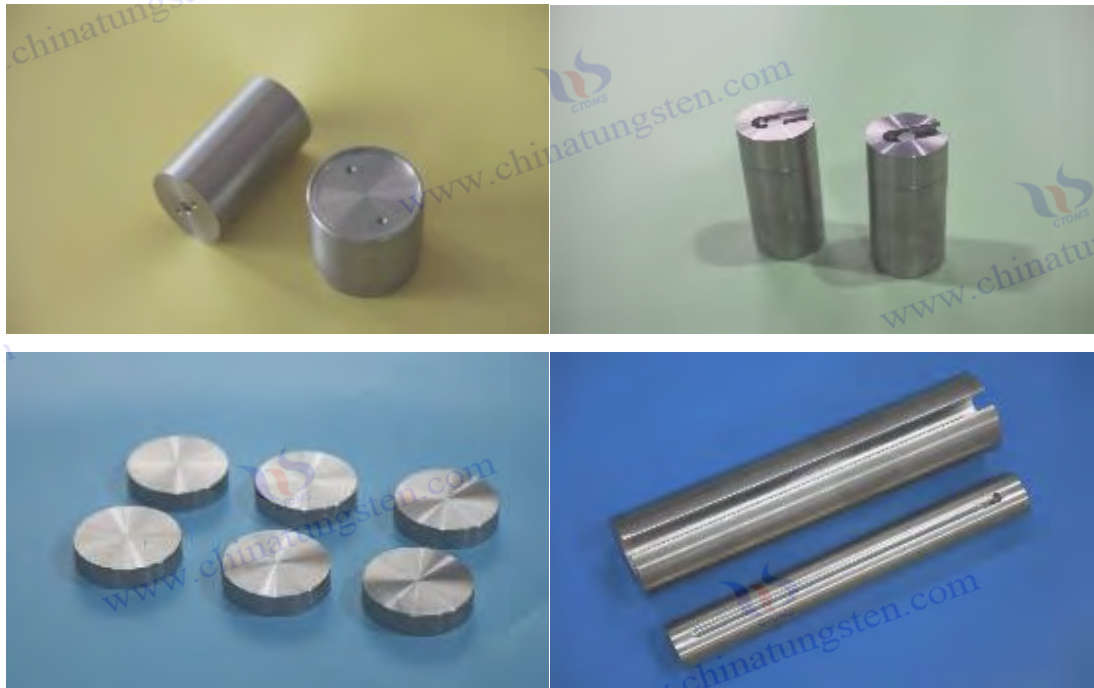
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Contact us

Email: sales@chinatungsten.com

Tel: +86 592 5129696

Official website: www.tungsten-alloy.com



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Chapter 1 Basic Knowledge of Tungsten Alloy Bar

Tungsten alloy rods hold a vital position in numerous fields due to their unique physical and chemical properties. Through a sophisticated production process, this material combines the high density and strength of tungsten with the properties of other metallic elements, resulting in a composite material that combines high hardness, high-temperature resistance, and excellent processing properties. Tungsten alloy rods are widely used in aerospace, medical equipment, electronics, and precision manufacturing. Their high density makes them particularly suitable for applications requiring weight balancing or radiation shielding. The production and application of tungsten alloy rods not only reflects the advancement of modern materials science but also promotes the innovative development of high-tech industries. Their non-toxicity and recyclability further enhance their appeal in environmentally sensitive fields, meeting the needs of sustainable industrial development.

1.1 Definition of Tungsten Alloy Bar

Tungsten alloy bar is a composite material primarily composed of tungsten, with the addition of other metal elements (such as nickel, iron, or copper) and manufactured using a powder metallurgy process. This material is renowned for its high density, strength, and excellent high-temperature resistance, enabling it to maintain stable performance in demanding operating environments. Tungsten alloy bar typically comes in long strips with round, rectangular, or other custom cross-sections, depending on the application. The production process involves powder mixing, pressing, sintering, and precision machining, ensuring the material possesses a uniform microstructure and stable physical properties. The design and manufacture of tungsten alloy bar fully considers its functional requirements for specific applications, such as counterweights in aerospace or radiation shielding in the medical field.

The definition of tungsten alloy bar is not limited to its material composition but also encompasses its functionality and range of applications. In the electronics industry, tungsten alloy bar is used as a heat sink or electrode material due to its high thermal and electrical conductivity; in precision manufacturing, its high hardness and wear resistance make it an ideal tool material. The production process of tungsten alloy bar is flexible, and the composition ratio and processing method can be adjusted according to the specific application to meet the performance requirements of different fields. Its non-toxicity gives it significant advantages in the medical and electronic fields, avoiding potential harm to the environment or human body. In addition, the recyclability of tungsten alloy bar makes it excellent in resource recycling and reduces the environmental impact of the production process. These characteristics make tungsten alloy bar an indispensable multifunctional material in modern industry, providing solid support for technological advancement.

1.2 Characteristics of Tungsten Alloy Bar

The properties of tungsten alloy bar are the core reason for its widespread application in high-tech fields, covering excellent physical, mechanical, and chemical properties. These properties enable it to remain stable under extreme conditions, meeting the demand for high-performance materials in fields such as

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aerospace, electronics, and medicine. The high density of tungsten alloy bar is one of its most outstanding characteristics, allowing it to provide significant weight within a limited volume, making it particularly suitable for applications requiring precise counterweighting. In addition, its high hardness and wear resistance enable it to maintain structural integrity in high-load and friction environments, extending its service life. Tungsten alloy bar also exhibits excellent high-temperature resistance and can maintain performance in high-temperature environments, making it suitable for use in high-temperature processes or equipment components.

In addition to its physical properties, tungsten alloy bar's thermal and electrical conductivity make it an excellent choice for applications in electronics and semiconductors, enabling rapid transfer of heat and current, maintaining stable equipment operation. Its corrosion resistance allows it to withstand the influence of a wide range of chemical environments, making it suitable for use in complex or harsh conditions. Tungsten alloy bar's processability is also noteworthy. Despite its high hardness, advanced powder metallurgy and precision machining processes allow it to be formed into a variety of complex shapes, meeting the demands of high-precision applications. Furthermore, its non-toxicity and recyclability give it advantages in environmentally stringent applications, such as medical device manufacturing and green electronics production. These properties contribute to the versatility of tungsten alloy bar, making it an irreplaceable material in modern industry. In-depth analysis of its properties can provide guidance for optimized design and application, promoting the development of related technologies.

1.3 Material composition of tungsten alloy bars

The material composition of tungsten alloy bars is the key foundation for their superior performance. They are usually composed of tungsten as the main component, supplemented by other metal elements through a specific process. Tungsten, as a high-melting-point, high-density metal, gives the alloy bars excellent physical properties, while the added metal elements further optimize their mechanical properties, processability, and functionality. Common added elements include nickel, iron, copper, or silver, which are mixed with tungsten powder through a powder metallurgy process, pressed, and sintered to form a uniform microstructure. The material composition of tungsten alloy bars not only determines their basic properties, but also affects their performance in specific application scenarios, such as high-density counterweights in the aerospace field or high-thermal conductivity components in the electronics field.

The material composition design of tungsten alloy bars needs to comprehensively consider the performance requirements of the target application. For example, in scenarios where high thermal conductivity is required, the addition of copper can significantly improve the thermal conductivity of the alloy; in scenarios where high strength is required, the combination of nickel and iron can enhance the mechanical strength of the alloy. During the production process, the composition ratio of tungsten alloy bars is achieved by precisely controlling powder mixing and sintering conditions to ensure the uniformity and stability of the material. Its non-toxicity and recyclability give it significant advantages in environmentally sensitive fields, avoiding the environmental problems that may be caused by traditional

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materials such as lead. The material composition of tungsten alloy bars also supports its adaptability in a variety of processing processes, such as cutting, grinding and surface treatment, and can be made into high-precision strip parts.

1.3.1 Logic for the Ratio of Tungsten Matrix to Metal Elements (Nickel, Iron, etc.)

The matching logic between the tungsten matrix and metallic elements (such as nickel, iron, and copper) is central to the design and manufacturing of tungsten alloy bars, directly impacting their physical and mechanical properties and adaptability to specific applications. Tungsten, as the matrix material, forms the primary structure of the alloy bar due to its high melting point and high density, providing the foundation for high density and high-temperature resistance. However, the brittleness and processing difficulty of pure tungsten limit its direct application, necessitating the addition of other metallic elements to optimize its performance. Nickel and iron typically act as binders, strengthening the bond between tungsten particles and enhancing the alloy's toughness and mechanical strength. Copper, due to its excellent thermal and electrical conductivity, is often used in applications requiring efficient thermal management. The matching logic aims to balance density, strength, toughness, and functionality by scientifically adjusting the proportions of each element to meet the needs of specific applications.

In alloy design, tungsten content typically dominates to ensure the high density of the alloy bar, while the proportions of added elements are fine-tuned based on application requirements. For example, in aerospace counterweight applications, the addition of nickel and iron improves the alloy's toughness and prevents fracture in high-stress environments. In electronics, copper optimizes thermal conductivity, making it suitable for heat dissipation components. The alloying process is achieved through a powder metallurgy process involving precise powder mixing, pressing, and liquid-phase sintering to ensure uniform distribution of the elements and a stable microstructure. The alloying logic also considers processability. Appropriate nickel or copper content can reduce the alloy's hardness and improve cutting and grinding efficiency. Furthermore, environmental considerations are crucial in alloy design, with non-toxic elements selected to avoid environmental pollution while ensuring the material's recyclability. The optimized alloying logic for the tungsten matrix and metal elements embodies the meticulous design of materials science, providing both theoretical and practical support for the high performance of tungsten alloy bars in diverse applications and fostering their widespread adoption in modern industry.

1.4 Classification of Tungsten Alloy Bars

The classification of tungsten alloy bars is an important way to understand their application diversity and functional characteristics. Different classification standards can be used to clearly divide their types to meet the needs of specific fields. The classification methods mainly include three dimensions: composition, performance, and specifications. Each classification reflects the different emphasis of tungsten alloy bars in material design, production process or application scenarios. Classification by composition focuses on the chemical composition of tungsten alloy bars, emphasizing the impact of added elements on performance; classification by performance focuses on its physical and mechanical properties, highlighting its applicability in specific functions; classification by specification is based on

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size and shape to meet the assembly requirements of different equipment. These classification methods provide a systematic framework for the selection, design and application of tungsten alloy bars, enabling them to flexibly adapt to the diverse needs of aerospace, electronics, medical and other fields. Through classification, we can better match material properties with actual uses, and promote its widespread application in high-tech fields.

1.4.1 Classification of Tungsten Alloy Bars by Composition

Classification by composition is the basic classification method for tungsten alloy bars. Tungsten alloy bars are divided into several types based on their different chemical compositions, mainly based on the tungsten content and the type and proportion of added metal elements. Tungsten, as the main component, usually occupies a dominant position, while added metal elements such as nickel, iron, copper or silver are combined with tungsten through powder metallurgy to form a composite material with specific properties. Tungsten alloy bars with different compositions have significant differences in physical properties, processing performance and application scenarios, meeting diverse needs such as aerospace counterweights, electronic thermal conductive components or medical radiation shielding. Common composition classifications include tungsten-nickel-iron alloy, tungsten-copper alloy and tungsten-nickel-copper alloy, and each type optimizes its performance by adjusting the element ratio.

Tungsten-nickel-iron alloys are characterized by high density and strength. Nickel and iron act as binders, enhancing the alloy's toughness and mechanical properties. They are suitable for applications requiring high weight and impact resistance, such as counterweights in aerospace. Tungsten-copper alloys are renowned for their high thermal and electrical conductivity. The addition of copper significantly improves thermal conductivity, making them ideal for heat dissipation substrates or electrodes in the electronics industry. Tungsten-nickel-copper alloys combine the advantages of toughness and thermal conductivity, making them suitable for applications requiring high overall performance, such as structural components in precision instruments. The rationale behind the compositional classification is to balance density, strength, toughness, and functionality through a scientifically formulated blend to meet the needs of different applications. During production, the composition ratio is precisely controlled through precise powder mixing and sintering processes to ensure uniform microstructure. Furthermore, environmental considerations are taken into account in composition selection, prioritizing the use of non-toxic elements to avoid potential harm to the environment or human health. This compositional classification provides flexibility in the design and application of tungsten alloy bars, offering customized material solutions for various industries and promoting their widespread application in high-tech fields.

1.4.2 Classification of Tungsten Alloy Bars by Performance

Tungsten alloy bars are classified into different types based on their physical and mechanical properties to highlight their applicability in specific functional scenarios. The properties of tungsten alloy bars mainly include density, strength, thermal conductivity, electrical conductivity, high temperature resistance, and corrosion resistance. These characteristics determine their specific uses in aerospace, electronics, medical and other fields. Through performance classification, it is possible to better match

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material properties with application requirements and optimize equipment design and operating efficiency. Common performance classifications include high-density, high-thermal conductivity, high-strength, and high-temperature resistant types. Each type has performance optimization for specific application scenarios.

High-density tungsten alloy bars, with their excellent weight-to-volume ratio, are ideal for applications requiring precise counterweighting, such as attitude control components in aerospace or rotating counterweights in medical imaging equipment. High-thermal conductivity tungsten alloy bars focus on efficient heat transfer and are widely used in heat dissipation substrates in the electronics industry or thermal management components in semiconductor manufacturing, ensuring stable temperature during high-power operation. High-strength tungsten alloy bars emphasize mechanical properties and wear resistance, making them suitable for high-load or friction environments, such as tool materials or structural support components in precision manufacturing. High-temperature resistant tungsten alloy bars are designed for high-temperature environments, maintaining stable performance under extreme temperatures and suitable for aerospace engine components or high-temperature process equipment. Performance classification is based on enhancing specific properties by adjusting the alloy composition and production process to meet application requirements. For example, increasing the copper content improves thermal conductivity, while the nickel and iron ratio enhances strength and toughness. Performance classification also considers processability and environmental friendliness to ensure that the material meets high-precision and sustainable development requirements during manufacturing and use. This classification provides clear guidance for the selection and application of tungsten alloy bars, promoting their efficient use in diverse applications.

1.4.3 Classification of Tungsten Alloy Bars by Specifications

Tungsten alloy bars are categorized by size, shape, and physical form to meet the assembly requirements of various devices and applications. Tungsten alloy bar specifications primarily include diameter, length, thickness, cross-sectional shape (such as round, rectangular, or custom), and surface quality. These parameters directly impact their fit and performance in practical applications. Specification classification emphasizes the bar's physical form and machining accuracy, ensuring seamless integration into precision systems such as aerospace, electronics, and medical devices. This classification allows for customized tungsten alloy bars to meet diverse design and functional requirements for various industries.

Common specifications include small-diameter tungsten alloy bar (smaller diameter, typically used in electronics and precision instruments), large-diameter tungsten alloy bar (suitable for aerospace counterweights or large structural components), thin bar (thicker thickness, suitable for heat sinks or electrodes), and custom-shaped bar (processed to meet specific equipment requirements). Small-diameter tungsten alloy bar, due to its high precision and compactness, is often used in connectors or thermally conductive components in the electronics industry, requiring extremely high surface finish and dimensional tolerances. Large-diameter tungsten alloy bar, with its high weight capacity as its core advantage, is suitable for applications requiring larger counterweights, such as satellite attitude adjustment systems. Thin tungsten alloy bar excels in heat dissipation and shielding applications,

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delivering high performance at a reduced thickness. Custom-shaped bar is precision-machined to meet specific geometric requirements, such as radiation shielding components in medical devices. Specification classification requires a combination of production processes (such as cutting, grinding, and surface treatment) to ensure dimensional accuracy and surface quality, while also prioritizing material machinability and environmental friendliness. Specification classification provides flexibility and targeted application for tungsten alloy bar, supporting its widespread use in high-precision and high-reliability applications and providing important support for the innovative development of modern industry.

1.5 Differences from similar products

As a composite material, tungsten alloy bar differs significantly from other metal materials (such as pure tungsten, molybdenum alloys, and titanium alloys) in terms of performance and application. These differences primarily manifest in physical properties, mechanical properties, processing capabilities, and adaptability to application scenarios. By adding elements such as nickel, iron, or copper, tungsten alloy bar mitigates the brittleness and processing difficulty of pure tungsten. This material also offers a stark contrast to molybdenum and titanium alloys in density, strength, and functionality. Comparing these materials helps clarify the unique advantages of tungsten alloy bar, such as its high density for counterweight applications, its high thermal conductivity for electronics heat dissipation, and its high-temperature resistance for aerospace components. The following article systematically analyzes the differences in tungsten alloy bar and its applicability in specific applications, comparing its performance and applications to pure tungsten bar, molybdenum alloy bar, and titanium alloy bar.

1.5.1 Comparison of performance and application with pure tungsten rod

The differences in performance and application between tungsten alloy bar and pure tungsten bar primarily stem from differences in material composition and processing. Pure tungsten bar, composed solely of tungsten, possesses extremely high density and melting point, but its brittleness and processing difficulty limit its application. Tungsten alloy bar significantly improves toughness and processing properties by adding elements such as nickel, iron, or copper, while retaining its high density, making it more competitive in a variety of scenarios. In terms of performance, tungsten alloy bar outperforms pure tungsten bar in toughness, thermal conductivity, and electrical conductivity. While pure tungsten bar is prone to fracture under high stress or vibration due to its high hardness and brittleness, tungsten alloy bar, through the introduction of a nickel-iron binder phase, enhances impact resistance and mechanical stability. Furthermore, the thermal and electrical conductivity of tungsten alloy bar (particularly tungsten-copper alloy) makes it more suitable for applications requiring efficient thermal management, such as electronic heat dissipation components. Pure tungsten bar, with its lower thermal conductivity, is primarily used in high-temperature electrodes or heating elements.

In terms of processability, tungsten alloy bar is easier to cut, grind, and form, and can be precision-machined into complex shapes to meet the high-precision requirements of the aerospace and electronics industries. Pure tungsten bar, due to its high hardness and brittleness, is difficult to machine and prone to

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cracking during processing, limiting its use in high-precision components. In terms of application scenarios, tungsten alloy bar is widely used in aerospace counterweights (such as satellite attitude adjustment), medical radiation shielding (such as CT machine components), and electronic heat dissipation substrates. Its diverse properties make it more adaptable. Pure tungsten bar, on the other hand, is primarily used as electrodes for high-temperature environments, such as argon arc welding electrodes or high-temperature furnace components, and has a narrower application range. The non-toxicity and recyclability of tungsten alloy bar further enhance its advantages in environmentally sensitive applications. However, the processing of pure tungsten bar may generate more waste, increasing the environmental burden. In summary, through its optimized performance and processing flexibility, tungsten alloy bar demonstrates wider adaptability and practicality than pure tungsten bar in a variety of applications, providing a more efficient material option for modern industry.

1.5.2 Comparison of performance and application with molybdenum alloy bars

The differences in performance and application between tungsten alloy bars and molybdenum alloy bars are mainly reflected in density, strength, high temperature resistance, and the focus of application scenarios. Molybdenum alloy bars are mainly composed of molybdenum, and elements such as titanium, zirconium, or carbon are usually added. They have high strength and high temperature resistance, but lower density than tungsten alloy bars. The high density of tungsten alloy bars gives them significant advantages in applications that require weight balance, such as counterweight components in aerospace, while the lower density of molybdenum alloy bars makes them more suitable for lightweight design. In terms of performance, the mechanical strength and oxidation resistance of tungsten alloy bars at high temperatures are slightly inferior to those of molybdenum alloy bars. Molybdenum alloy bars can maintain stable performance at higher temperatures and are suitable for extreme high temperature environments, such as high-temperature furnace linings or aerospace engine components. However, the thermal conductivity and electrical conductivity of tungsten alloy bars (especially tungsten-copper alloys) are better than those of molybdenum alloy bars, making them more advantageous in electronic heat dissipation and electrode applications.

In terms of processability, molybdenum alloy bar has a lower hardness than tungsten alloy bar, making it easier to process and suitable for forming thin sheets or complex shapes. However, its strength and wear resistance are inferior to tungsten alloy bar, limiting its application in high-load environments. Tungsten alloy bar, through powder metallurgy, optimizes toughness and processability, enabling it to meet high-precision and wear-resistant requirements, such as rotating components in medical imaging equipment. In terms of application, tungsten alloy bar is widely used in high-density counterweights and shielding applications, such as medical radiation shielding and aerospace attitude control, while molybdenum alloy bar is more commonly used in high-temperature structural components or sputtering targets in semiconductor manufacturing. Molybdenum alloy bar has better corrosion resistance than tungsten alloy bar in certain acidic environments, but is more stable in high-humidity or oxidizing environments. The non-toxicity and recyclability of tungsten alloy bar make it advantageous in environmentally sensitive applications, such as medical devices, while the production of molybdenum alloy bar may involve more chemical processing, which increases environmental costs. These differences

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between tungsten alloy bar and molybdenum alloy bar give them distinct application focuses, providing complementary material options for different industrial scenarios.

1.5.3 Comparison with titanium alloy bars in performance and application

The differences in performance and application between tungsten alloy bar and titanium alloy bar primarily lie in their density, strength, corrosion resistance, and applicability. Titanium alloy bar, primarily composed of titanium with additives such as aluminum and vanadium, offers low density, high strength, and excellent corrosion resistance, making it widely used in lightweight designs. The high density of tungsten alloy bar gives it an advantage in applications requiring weight balancing, such as aerospace counterweights or rotating components in medical devices, while the low density of titanium alloy bar is more suitable for applications requiring weight reduction, such as aerospace structures. In terms of performance, titanium alloy bar offers a superior strength-to-weight ratio, providing higher specific strength in high-stress environments. Its higher absolute strength and hardness make it suitable for wear- and impact-resistant applications. Tungsten alloy bar also offers superior thermal and electrical conductivity (particularly tungsten-copper alloys) compared to titanium alloy bar, making it a better choice for electronic cooling and electrode applications. However, the lower thermal conductivity of titanium alloy bar limits its use in thermal management.

In terms of corrosion resistance, titanium alloy bars excel in marine environments and acidic conditions, making them suitable for use in ships or chemical equipment. Tungsten alloy bars are also stable in general chemical environments, but may be slightly less so in strong acidic environments. In terms of processability, titanium alloy bars are easier to cut and form than tungsten alloy bars, but tungsten alloy bars have improved their machinability through optimized composition (such as the addition of nickel or copper), enabling them to meet high-precision requirements. In terms of application scenarios, tungsten alloy bars are widely used in counterweights and shielding components requiring high density, such as medical radiation shielding and aerospace attitude control, while titanium alloy bars are more commonly used in lightweight structural parts, such as aircraft fuselages or medical implants. The non-toxicity and recyclability of tungsten alloy bars give them advantages in environmentally sensitive applications, while the biocompatibility of titanium alloy bars makes them more common in medical implants. The differences between tungsten alloy bars and titanium alloy bars reflect their different emphasis on weight, strength, and functionality, providing a diverse material choice for industrial design, meeting a wide range of requirements from high density to lightweight.



CTIA GROUP LTD Tungsten Alloy Bar

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Chapter 2 Properties of Tungsten Alloy Bar

Tungsten alloy rods demonstrate extensive application value in aerospace, medical, electronics, and precision manufacturing due to their exceptional physical and mechanical properties. Their performance is attributed to the high density and high melting point of tungsten, combined with additive elements such as nickel, iron, and copper, and optimized through powder metallurgy to create a material with a unique balance of strength, toughness, and functionality. Tungsten alloy rods excel in high-load, high-temperature, and high-precision environments, meeting diverse requirements such as counterweighting, heat dissipation, radiation shielding, and structural support. Their non-toxicity and recyclability give them significant advantages in environmentally stringent applications, aligning with modern industry's pursuit of sustainable development.

2.1 Physical Properties of Tungsten Alloy Bar

The physical properties of tungsten alloy bar are the core foundation for its outstanding performance in a variety of high-tech applications. These properties include high density, high melting point, high temperature resistance, thermal conductivity, and electrical conductivity. These properties enable it to remain stable under extreme conditions, meeting the high material requirements of fields such as aerospace, electronics, and medicine. The physical properties of tungsten alloy bar are derived from the natural properties of its primary component, tungsten. They are also optimized by adding elements such as nickel, iron, or copper to improve the brittleness and processing difficulty of pure tungsten. Compared to other metal materials, tungsten alloy bar has significant advantages in density and high temperature resistance, enabling it to provide high weight within a limited volume or maintain structural integrity in high-temperature environments. Its thermal and electrical conductivity (especially tungsten-copper alloys) further expands its potential in electronic heat dissipation and electrode applications.

2.1.1 High density characteristics of tungsten alloy bars

The high density of tungsten alloy bar is one of its most notable physical properties, making it an irreplaceable advantage in applications requiring weight balance or high mass concentrated in a limited volume. Tungsten, as the primary component, gives the alloy bar its extremely high density. By adding elements such as nickel, iron, or copper, the alloy's microstructure is optimized, retaining its high density while improving toughness and processing performance. This high density allows tungsten alloy bar to provide significant weight within a relatively small volume, making it suitable for applications requiring precise counterweighting in aerospace, medical, and precision manufacturing. Its density advantage is also reflected in radiation shielding applications, where the high-density material can effectively block high-energy radiation, protecting equipment and personnel.

In the aerospace sector, the high density of tungsten alloy bars is widely used in attitude control and counterweight components, such as the balancing systems of satellites and spacecraft, ensuring stability during orbital operation by optimizing weight distribution. In the medical field, high-density tungsten alloy bars are used in rotating components of imaging equipment (such as CT machines), leveraging their

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weight advantage to achieve dynamic balance while also providing radiation shielding. Compared to other high-density materials (such as lead), the non-toxicity of tungsten alloy bars makes them advantageous in the environmentally stringent medical and electronics sectors, avoiding potential environmental pollution risks. During production, the high density of tungsten alloy bars is achieved through a powder metallurgy process, which precisely controls the composition ratio and sintering conditions to ensure material uniformity and density stability. Its processability allows for a variety of shapes and specifications to meet the size and weight requirements of different applications. Its high density also supports its application in precision instruments, such as vibration suppression components, where localized weight is added to reduce vibration during operation. The high density of tungsten alloy bars provides a solid foundation for their application in diverse scenarios, promoting design optimization and performance improvements in high-tech fields.

2.1.2 High Melting Point of Tungsten Alloy Bar

Another key physical property of tungsten alloy bar is its high melting point, derived from the extremely high melting point of tungsten itself, combined with the excellent heat resistance maintained by the addition of elements. This high melting point allows tungsten alloy bar to maintain its structural integrity and mechanical properties in high-temperature environments, making it suitable for use in aerospace engine components, high-temperature electronic electrodes, and industrial high-temperature process equipment. Tungsten's high melting point is preserved through powder metallurgy, while the addition of elements such as nickel, iron, or copper improves the alloy's toughness and workability, making it more practical in high-temperature applications. Compared to other metal materials, tungsten alloy bar's high melting point enables it to remain stable under extreme temperature conditions, avoiding deformation or failure due to thermal stress.

In the aerospace industry, tungsten alloy rod's high melting point makes it an ideal choice for components near engine nozzles or high-temperature structures, capable of withstanding the harsh conditions of high-temperature gases and thermal shock. In the electronics industry, its high melting point supports its use in high-temperature electrodes or heating elements, maintaining stable current conduction in vacuum equipment or welding processes. Its high melting point also allows it to be used as a support structure in high-temperature furnaces or heat treatment equipment, extending the life of the equipment. Tungsten alloy rod's high melting point is optimized through a liquid-phase sintering process. Added elements form a binder phase during the sintering process, strengthening the bond between particles and ensuring structural stability at high temperatures. Its non-toxicity and recyclability make it environmentally friendly for high-temperature applications, avoiding the potential pollution issues associated with traditional high-temperature materials. During processing, its high melting point requires high-performance tools and precision equipment to ensure dimensional accuracy and surface quality.

2.1.3 High temperature resistance of tungsten alloy bars

The high-temperature resistance of tungsten alloy bar is a key manifestation of its physical properties, enabling it to maintain stable performance in high-temperature, high-pressure, or thermal shock

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environments, meeting the demand for heat-resistant materials in the aerospace, electronics, and industrial sectors. This high-temperature resistance stems not only from tungsten's high melting point but also from the optimization of the alloy's microstructure by added elements (such as nickel, iron, or copper), resulting in excellent mechanical strength and oxidation resistance even at high temperatures. Tungsten alloy bar's high-temperature resistance enables it to withstand extreme temperature fluctuations, making it suitable for use as critical components in high-temperature processes or equipment. Its corrosion resistance further enhances its stability in high-temperature chemical environments, preventing performance degradation due to oxidation or chemical reactions.

In the aerospace industry, tungsten alloy bar's high-temperature resistance makes it a preferred material for propulsion systems or high-temperature structural components, enabling it to maintain its shape and strength in the high-temperature environments of combustion chambers or nozzles. In the electronics industry, its high-temperature resistance supports its use in high-temperature heat dissipation components or electrodes, such as in semiconductor manufacturing equipment, where it rapidly dissipates heat and maintains stable operation. Its high-temperature resistance also enables its use as linings or supports in industrial high-temperature furnaces or heat treatment equipment, extending equipment life. Tungsten alloy bar's high-temperature resistance is further enhanced through powder metallurgy and surface treatment processes, such as by adding copper to improve thermal conductivity or coatings to enhance oxidation resistance. During processing, high-temperature resistance requires strict control of sintering temperatures and cooling rates to avoid microcracks caused by thermal stress. Its non-toxicity and recyclability ensure its compliance with environmental standards in high-temperature applications, reducing the environmental impact of production and disposal. Tungsten alloy bar's high-temperature resistance ensures its reliable application in harsh environments and provides important support for technological advancements in the aerospace, electronics, and industrial sectors.

2.1.4 Thermal Expansion Coefficient of Tungsten Alloy Bar

The coefficient of thermal expansion of tungsten alloy bars is an important parameter of their physical properties. It refers to the degree of expansion of the material's volume or size when the temperature changes, and is usually expressed as the linear expansion coefficient. The relatively low coefficient of thermal expansion of tungsten alloy bars stems from the low expansion characteristics of tungsten itself. It is slightly adjusted by adding elements such as nickel, iron, or copper, but still remains at a low level. This property enables it to maintain dimensional stability in environments with large temperature fluctuations and reduce deformation or cracking caused by thermal stress. It is particularly suitable for applications such as aerospace, electronics, and high-temperature process equipment that require high precision and stability. The low coefficient of thermal expansion enables tungsten alloy bars to perform well under thermal cycling conditions and can be well matched with low-expansion materials such as ceramics and glass. It is widely used in the field of precision manufacturing.

In the aerospace industry, tungsten alloy bar's low thermal expansion coefficient makes it an ideal choice for high-temperature components, such as those near engine nozzles. It maintains geometric stability in high-temperature gas environments, preventing structural failure due to differential expansion. In the

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electronics industry, tungsten alloy bar is often used as a heat sink or packaging material in semiconductor manufacturing. Its low thermal expansion coefficient matches the thermal expansion characteristics of silicon chips or other low-expansion materials, reducing cracks or connection failures caused by thermal stress. During production, the thermal expansion coefficient is controlled by optimizing the alloy composition and sintering process. For example, adding copper can slightly increase the thermal expansion coefficient to meet specific requirements, while a nickel-iron combination maintains low thermal expansion characteristics. Tungsten alloy bar's low thermal expansion coefficient also supports its application in precision instruments, such as optical devices or structural components of measuring devices, where high-precision dimensions are required. Its non-toxicity and recyclability make it advantageous in environmentally sensitive applications, meeting green manufacturing standards. Tungsten alloy bar's thermal expansion coefficient characteristics are further optimized through precision machining and surface treatment, ensuring its reliability and stability in high-temperature and high-precision applications, providing key support for innovation in the aerospace and electronics industries.

2.1.5 Thermal conductivity of tungsten alloy bars

The thermal conductivity of tungsten alloy bars reflects their physical properties and refers to their ability to conduct heat, which is particularly prominent in tungsten-copper alloys. Tungsten itself has low thermal conductivity, but by adding copper with high thermal conductivity, the thermal conductivity of tungsten alloy bars is significantly improved, making it a preferred material for thermal management components in the electronics and semiconductor fields. Thermal conductivity enables tungsten alloy bars to quickly disperse heat in high-power devices, preventing local overheating and maintaining stable equipment operation. Its thermal conductivity is also closely related to the alloy composition and microstructure. The powder metallurgy process is used to optimize the particle distribution and bonding phase to ensure heat conduction efficiency. The thermal conductivity of tungsten alloy bars gives them significant advantages in scenarios requiring efficient heat dissipation, and they are widely used in electronic packaging, heat dissipation substrates, and high-power devices.

In the electronics industry, the thermal conductivity of tungsten alloy strips makes them an ideal material for chip heat sinks or power amplifier substrates. They can quickly transfer the large amounts of heat generated during operation to the heat sink, reducing device temperatures and extending service life. In the aerospace sector, the thermal conductivity of tungsten alloy strips supports their use in high-temperature components, such as propulsion system thermal management components, where they quickly dissipate heat, reducing thermal stress and improving system reliability. During production, thermal conductivity is optimized by adjusting the copper content and sintering conditions. For example, increasing the copper ratio significantly improves thermal conductivity while maintaining sufficient mechanical strength. Its processability allows for the manufacture of thin strips or complex shapes, meeting the requirements of high-precision heat dissipation components. The thermal conductivity of tungsten alloy strips, combined with its low coefficient of thermal expansion, ensures a good thermal match with low-expansion materials, reducing stress accumulation during thermal cycling. Its non-toxicity and recyclability make it environmentally friendly in electronics manufacturing, reducing the environmental impact of production and disposal. The thermal conductivity of tungsten alloy strips

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ensures reliable application in high-power and high-heat environments, driving technological advancements in the electronics and aerospace sectors.

2.1.6 Electrical conductivity of tungsten alloy bars

The conductivity of tungsten alloy bars is another key characteristic of their physical properties, referring to their ability to conduct electric current, which is particularly outstanding in tungsten-copper alloys. Pure tungsten has low conductivity, but by adding highly conductive copper, the conductivity of tungsten alloy bars is significantly improved, making them widely used in electrodes, connectors, and conductive components in the electronics and communications fields. The conductivity enables tungsten alloy bars to support high-frequency signal transmission and efficient current conduction, reducing resistance losses, and is suitable for high-precision and high-power electronic devices. Its conductivity is closely related to the alloy composition, microstructure, and processing technology. It is optimized through powder metallurgy and surface treatment to ensure the uniformity and stability of the conductive path. The conductivity of tungsten alloy bars gives them a competitive advantage in scenarios requiring efficient electrical conduction.

In the electronics industry, tungsten alloy bar's conductivity makes it a preferred material for electrodes and connectors in high-frequency devices, such as microwave communications equipment or RF power amplifiers, ensuring stable and low-loss signal transmission. In aerospace, tungsten alloy bar's conductivity supports its use in electrical systems, such as conductive components in satellite communication modules, ensuring reliable current transmission. During production, conductivity is optimized by adjusting the copper content and sintering process. Increasing the copper ratio significantly improves conductivity while retaining the high density and strength of tungsten alloy. Its processability allows for the formation of precision electrodes or connectors, meeting high-precision assembly requirements. Tungsten alloy bar's conductivity, combined with its high thermal conductivity and low coefficient of thermal expansion, creates a comprehensive performance advantage, enabling simultaneous thermal management and electrical conduction during high-power operation. Its non-toxicity and recyclability enable it to meet environmental standards in electronics manufacturing, reducing environmental impact. Tungsten alloy bar's conductivity provides a solid foundation for its widespread application in the electronics and communications fields, driving the advancement of high-performance electronic devices and communication technologies.

2.2 Mechanical properties of tungsten alloy bars

The mechanical properties of tungsten alloy bar, including tensile strength, compressive strength, hardness, toughness, and fatigue resistance, are key to its application in high-load and complex stress environments. These properties enable it to withstand high stress, impact, and wear in fields such as aerospace, electronics, and precision manufacturing, while maintaining structural integrity and performance stability. The mechanical properties of tungsten alloy bar stem from the high strength of tungsten. By optimizing the performance of tungsten by adding elements such as nickel, iron, or copper, the brittleness of pure tungsten is significantly improved, while its toughness and processing properties

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are enhanced. Compared to other metal materials, tungsten alloy bar offers significant advantages in tensile strength, compressive strength, and hardness, maintaining stability in high-load environments and making it suitable for use in structural components, tool materials, and wear-resistant parts. Its mechanical properties are further optimized through powder metallurgy and precision machining to ensure uniform microstructure and consistent performance. The following analysis will focus on its tensile strength, compressive strength, and hardness, exploring the role these properties play in practical applications.

2.2.1 Tensile Strength of Tungsten Alloy Bar

The tensile strength of tungsten alloy bars is an important indicator of its mechanical properties, which refers to the material's ability to resist fracture under tensile loads. By adding binder elements such as nickel and iron, the tensile strength of tungsten alloy bars is significantly improved, overcoming the high brittleness of pure tungsten and enabling it to maintain structural integrity in high-stress environments. The tensile strength makes tungsten alloy bars suitable for scenarios that need to withstand tensile loads, such as structural support components in aerospace or high-strength connectors in precision manufacturing. Its tensile strength is due to the uniform distribution of tungsten particles and the binder phase. The dense microstructure is formed through liquid phase sintering in the powder metallurgy process, which enhances the material's resistance to tensile stress. The tensile strength of tungsten alloy bars is also closely related to the composition ratio and processing technology. For example, optimizing the nickel-iron ratio can further improve toughness and strength.

In aerospace, the tensile strength of tungsten alloy bar makes it an ideal material for attitude control systems or propulsion system components, capable of withstanding the tensile stresses and vibrations experienced during orbital operation, ensuring equipment stability. In the electronics industry, its tensile strength supports its use in high-precision connectors or electrode components, resisting tensile loads during assembly and operation, maintaining structural reliability. During production, tensile strength is optimized by strictly controlling sintering temperatures and cooling rates to avoid microcracks. Its processability allows for complex shapes, meeting the mechanical requirements of high-precision applications. The tensile strength of tungsten alloy bar, combined with its high density and high-temperature resistance, creates a comprehensive performance advantage, capable of maintaining stable performance in high-stress and high-temperature environments. Its non-toxicity and recyclability make it advantageous in environmentally sensitive applications, meeting green manufacturing requirements. The tensile strength of tungsten alloy bar ensures its reliability in high-load applications, driving technological advancements in aerospace and precision manufacturing.

2.2.2 Compressive Strength of Tungsten Alloy Bars

The compressive strength of tungsten alloy bars is another key indicator of its mechanical properties, which refers to the material's ability to resist deformation or damage under compressive loads. The high compressive strength of tungsten alloy bars stems from the high hardness and high density of tungsten, which is further enhanced by the addition of elements such as nickel and iron, enabling it to maintain

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stable shape and performance in high-pressure environments. The compressive strength makes tungsten alloy bars suitable for use in scenarios where they are subjected to heavy loads or compressive stress, such as counterweight components in aerospace or pressure-resistant structural parts in industrial equipment. Its compressive strength is optimized through powder metallurgy technology, where tungsten particles and the binder phase form a dense microstructure that effectively disperses compressive stress and prevents the material from cracking or deforming. The performance of compressive strength is also closely related to the alloy composition and sintering process. The appropriate nickel-iron ratio can improve the material's toughness and compressive resistance.

In aerospace, the compressive strength of tungsten alloy bars makes them a preferred material for satellite counterweights or propulsion system components, capable of withstanding the high-pressure loads of launch and operation, ensuring structural stability. In precision manufacturing, this compressive strength supports the use of tungsten alloy bars in molds or tooling materials, resisting deformation during high-pressure processing and extending their service life. During production, compressive strength is achieved by optimizing sintering conditions and particle distribution to ensure the material is free of porosity or defects. Its processability allows for the manufacture of high-precision bar-shaped components that meet the stringent requirements of pressure-resistant applications.

2.2.3 Hardness characteristics of tungsten alloy bars

The hardness of tungsten alloy bars is a key indicator of their mechanical properties. It refers to the material's ability to resist surface scratches or localized deformation, and is typically expressed in Vickers hardness (HV) or Brinell hardness (HB). The high hardness of tungsten alloy bars stems from the inherently high hardness of tungsten. The addition of elements such as nickel, iron, or copper slightly reduces the hardness to improve machinability, while still maintaining excellent wear resistance and deformation resistance. This hardness enables tungsten alloy bars to maintain surface integrity and stable performance in high-friction or high-load environments, making them suitable for use as tool materials or wear-resistant components in precision manufacturing. Its hardness is optimized through powder metallurgy processes. The uniform distribution of tungsten particles and a binder phase creates a dense microstructure, enhancing the surface's resistance to scratching. Hardness is also related to the composition ratio and surface treatment processes. For example, polishing or coating can further enhance surface hardness and wear resistance.

In precision manufacturing, the high hardness of tungsten alloy rods makes them an ideal material for molds, cutting tools, or wear-resistant components, capable of maintaining surface finish and shape stability in high-friction environments. In aerospace, the hardness of tungsten alloy rods supports their use in structural parts or counterweights, resisting wear and impact during operation and ensuring long-term reliability. During the production process, hardness is optimized by controlling the sintering temperature and cooling rate to avoid brittleness caused by over-hardening. Its processing properties allow high surface hardness and finish to be achieved through precision grinding and polishing, meeting the needs of high-precision applications. The hardness of tungsten alloy rods is also combined with their tensile and compressive strengths to form a comprehensive mechanical performance advantage, capable

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of maintaining stable performance in complex stress environments. Its non-toxicity and recyclability make it more advantageous in environmentally sensitive fields and meet green manufacturing standards. The hardness of tungsten alloy rods ensures its reliability in wear-resistant and durable applications, promoting technological advancement in precision manufacturing and aerospace.

2.2.4 Toughness of tungsten alloy bars

The toughness of tungsten alloy bars is an important manifestation of their mechanical properties, which refers to the material's ability to absorb energy and resist fracture when subjected to impact or stress. Pure tungsten exhibits strong brittleness due to its high hardness and is prone to fracture under high stress. Tungsten alloy bars have significantly improved their toughness by adding binder elements such as nickel and iron, enabling them to maintain structural integrity in high-load or vibration environments. The toughness property makes tungsten alloy bars suitable for scenarios that require impact resistance, such as counterweight components in aerospace or tool materials in precision manufacturing. Its toughness comes from the synergistic effect of tungsten particles and the binder phase. A dense microstructure is formed through liquid phase sintering in the powder metallurgy process. The binder phase effectively disperses stress and prevents crack propagation. The optimization of toughness is also closely related to the composition ratio and sintering process. For example, increasing the nickel content can further improve toughness and balance hardness and impact resistance.

In aerospace, the toughness of tungsten alloy rods makes them ideal for attitude control systems or propulsion system components, capable of withstanding the impact loads of launch and operation, ensuring equipment stability. In precision manufacturing, this toughness supports the use of tungsten alloy rods in high-stress tools or molds, protecting them from the shock and vibration during processing and extending their service life. During production, toughness is achieved by precisely controlling the sintering temperature, cooling rate, and composition ratio to avoid brittleness caused by overhardening. Its processability allows for the formation of complex shapes, meeting the mechanical requirements of high-precision applications. The toughness of tungsten alloy rods, combined with their high density and tensile strength, creates a comprehensive mechanical performance advantage, capable of maintaining stable performance in dynamic stress environments. Its non-toxicity and recyclability make it advantageous in environmentally sensitive applications, meeting green manufacturing standards. The toughness of tungsten alloy rods ensures their reliability in high-impact applications, driving technological advancements in aerospace and precision manufacturing, and providing critical support for the design and operation of high-performance equipment.

2.2.5 Fatigue resistance of tungsten alloy bars

The fatigue resistance of tungsten alloy bars is an important characteristic of its mechanical properties, which refers to the material's ability to resist fatigue damage under cyclic stress or alternating loads. By adding elements such as nickel and iron, the microstructure of tungsten alloy bars is optimized, which significantly improves fatigue resistance and overcomes the brittle fracture problem of pure tungsten under cyclic stress, enabling it to maintain stable performance in long-term dynamic load environments.

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Fatigue resistance makes tungsten alloy bars suitable for scenarios that need to withstand repeated stress, such as rotating parts in aerospace or vibration suppression components in electronic equipment. Its fatigue resistance comes from the uniform distribution of tungsten particles and the binder phase. A dense microstructure is formed through powder metallurgy, which reduces internal defects and stress concentration points, thereby delaying the initiation and propagation of fatigue cracks. The optimization of fatigue resistance is also related to the alloy composition and heat treatment process. For example, the appropriate nickel-iron ratio can improve the toughness and fatigue resistance of the material.

In the aerospace industry, the fatigue resistance of tungsten alloy bars makes them a preferred material for satellite counterweights or propulsion system components, capable of withstanding the cyclic vibration and stress changes experienced during orbital operation, ensuring long-term reliability. In the electronics industry, this fatigue resistance supports their use in high-frequency vibration connectors or heat sinks, resisting dynamic loads during operation and maintaining device performance. During production, fatigue resistance is achieved through optimized sintering conditions and surface treatment processes. For example, polishing reduces surface microcracks and improves fatigue life. Its machinability allows for the manufacture of high-precision components that meet the stringent requirements of dynamic applications. The fatigue resistance of tungsten alloy bars, combined with their high density and toughness, creates a comprehensive performance advantage, capable of maintaining stability in complex stress environments. Its non-toxicity and recyclability make it particularly advantageous in environmentally sensitive applications, meeting green manufacturing requirements. The fatigue resistance of tungsten alloy bars ensures their durability in dynamic load applications, driving technological advancements in the aerospace and electronics sectors and providing important support for the development of high-reliability equipment.

2.2.6 Wear resistance of tungsten alloy bars

The wear resistance of tungsten alloy bars is a reflection of their mechanical properties, which refers to the material's ability to resist surface material loss in a friction or wear environment. The high hardness and optimized microstructure of tungsten alloy bars give them excellent wear resistance, enabling them to maintain surface integrity and stable performance under high friction or high load conditions. Wear resistance is enhanced by adding binder elements such as nickel and iron, overcoming the brittleness of pure tungsten and making it less likely to crack or peel off in a wear environment. Wear resistance makes tungsten alloy bars suitable for scenarios requiring long-term wear resistance, such as tool materials in precision manufacturing or wear-resistant parts in industrial equipment. Its wear resistance stems from the synergistic effect of tungsten particles and the binder phase, which forms a dense microstructure through powder metallurgy technology, enhancing the surface's ability to resist friction. The optimization of wear resistance is also related to surface treatment processes, such as polishing or coating, which can further improve surface hardness and wear resistance.

In precision manufacturing, the wear resistance of tungsten alloy bar makes it an ideal material for molds, cutting tools, or wear-resistant liners. It maintains surface finish and shape stability in high-friction machining environments, extending service life. In aerospace, its wear resistance supports the use of

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tungsten alloy bar in high-load structural components or counterweights, protecting against friction and wear during operation and ensuring long-term reliability. During production, wear resistance is optimized by controlling sintering temperature and particle size distribution to prevent internal porosity or defects from affecting surface properties. Its processing properties allow for high surface quality through precision grinding and polishing, meeting the stringent requirements of wear-resistant applications. Tungsten alloy bar's wear resistance, combined with its high hardness and toughness, creates a comprehensive mechanical performance advantage, capable of maintaining stable performance in high-friction environments. Its non-toxicity and recyclability make it advantageous in environmentally sensitive applications, meeting green manufacturing standards. The wear resistance of tungsten alloy bar ensures its reliability in durable applications, driving technological advancements in precision manufacturing and aerospace, and providing key support for the development of high-performance components.

2.3 Functional adaptability of tungsten alloy bars

The functional adaptability of tungsten alloy bars refers to their ability to meet diverse functional requirements in specific application scenarios by optimizing physical and mechanical properties. This functional adaptability encompasses multiple aspects, including high-density counterweighting, radiation shielding, thermal management, and electrical conductivity, enabling tungsten alloy bars to flexibly adapt to the complex requirements of aerospace, medical, electronics, and precision manufacturing. Its functional adaptability is due to the high density and high melting point of tungsten. This performance is optimized by adding elements such as nickel, iron, and copper, resulting in a material that combines high density, thermal conductivity, electrical conductivity, and mechanical strength. The functional adaptability of tungsten alloy bars is further enhanced through powder metallurgy and precision machining, allowing them to be manufactured into shapes and specifications that meet specific functional requirements. Its non-toxicity and recyclability give it an advantage in environmentally sensitive fields, meeting green manufacturing requirements.

In counterweight applications, the high density of tungsten alloy bar enables it to provide significant weight in a compact package, making it ideal for rotating components in aerospace attitude control or medical imaging equipment, improving device stability by optimizing weight distribution. In radiation shielding applications, the high density and atomic number of tungsten alloy bar enable it to effectively block high-energy radiation. It is widely used in medical radiotherapy equipment and nuclear industry shielding components to protect personnel and equipment. In thermal management applications, the thermal conductivity of tungsten alloy bar (particularly tungsten-copper alloy) makes it an ideal choice for electronic heat dissipation substrates or thermal management components for high-power devices, quickly dissipating heat and maintaining device stability. In conductive applications, the conductivity of tungsten alloy bar enables its use in high-frequency electrodes or connectors, ensuring low signal transmission loss. Its functional adaptability is also reflected in its processing flexibility. Through cutting, grinding, and surface treatment processes, tungsten alloy bar can be manufactured into high-precision components that meet the geometric and performance requirements of various applications. Its comprehensive properties give it unique advantages in multiple fields, providing reliable support for the

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development and operation of high-tech equipment and driving innovation in the aerospace, medical, and electronics industries.

2.3.1 Corrosion resistance of tungsten alloy bars

A tungsten alloy bar's corrosion resistance is a key indicator of its functional adaptability. It refers to the material's ability to resist corrosion, oxidation, or chemical attack in a chemical environment or moisture. Tungsten inherently possesses excellent chemical stability, maintaining its properties in a wide range of chemical environments. The addition of elements such as nickel, iron, or copper further enhances the alloy's corrosion resistance, allowing it to maintain its structural integrity and surface quality even in humid, acidic, or alkaline conditions. This corrosion resistance makes tungsten alloy bar suitable for use in applications subject to long-term exposure to complex chemical environments, such as structural components in aerospace applications or conductive components in electronic equipment. Its corrosion resistance stems from the high chemical inertness of tungsten and the protective effect of the binder phase. The powder metallurgy process creates a dense microstructure that reduces the penetration of corrosive media. Surface treatment processes such as polishing or electroless plating further enhance its corrosion resistance and extend its service life.

In the aerospace industry, the corrosion resistance of tungsten alloy rods makes them ideal for propulsion systems or external structural components. They withstand corrosion from high humidity and chemical gases, ensuring reliability in harsh environments. In the electronics industry, corrosion resistance supports the use of tungsten alloy rods in electrodes or connectors, preventing oxidation and performance degradation over time and maintaining efficient current transmission. During production, corrosion resistance is achieved through optimized alloy composition and surface treatment. For example, the addition of copper improves oxidation resistance, while the nickel-iron combination enhances overall chemical stability. Its processability allows for high-precision components that meet the stringent requirements of corrosion-resistant applications. Tungsten alloy rods' corrosion resistance, combined with their high density and mechanical properties, creates a comprehensive performance advantage, ensuring stability in complex environments. Their non-toxicity and recyclability make them particularly advantageous in environmentally sensitive applications, meeting green manufacturing standards. Tungsten alloy rods' corrosion resistance ensures their reliable use in chemical environments, driving technological advancements in the aerospace and electronics sectors and providing critical support for the development of high-performance devices.

2.3.2 Radiation resistance of tungsten alloy bars

The radiation resistance of tungsten alloy rods is a key characteristic of their functional adaptability. It refers to their ability to block high-energy radiation (such as gamma rays or X-rays), protecting equipment and personnel from the effects of radiation. Tungsten's high density and high atomic number make it an excellent radiation shielding material. By optimizing it with the addition of elements such as nickel and iron, tungsten alloy rods maintain high density while improving toughness and workability, making them suitable for radiation protection in the medical and industrial fields. Their radiation

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resistance enables them to effectively absorb and scatter high-energy radiation, reducing radiation penetration, and is widely used in medical imaging equipment, radiotherapy devices, and nuclear industry components. This radiation resistance stems from tungsten's high electron density and the alloy's dense microstructure. Powder metallurgy ensures material uniformity and enhances shielding effectiveness.

In the medical field, the radiation resistance of tungsten alloy bar makes it an ideal choice for shielding components in CT machines, X-ray equipment, and radiotherapy devices, protecting patients and medical personnel from radiation hazards. Its high density allows for efficient shielding in a compact package. In the industrial sector, its radiation resistance supports its use in shielding components for nuclear reactors or radiation detection equipment, ensuring safe operation. During production, radiation resistance is achieved by optimizing the tungsten content and sintering process, ensuring the material is free of porosity and defects, enhancing shielding performance. Its processability allows for complex shapes to meet the geometric requirements of shielding components. Tungsten alloy bar's radiation resistance, combined with its corrosion resistance and mechanical properties, creates a comprehensive performance advantage, ensuring stability in high-radiation environments. Its non-toxicity further enhances its use in the medical field, allowing it to replace traditional lead-based materials and avoid environmental pollution. Tungsten alloy bar's radiation resistance ensures its reliability in radiation protection applications, driving technological advancements in both the medical and industrial sectors and providing critical support for safe and efficient radiation management.

2.3.3 Electromagnetic properties of tungsten alloy bars

The electromagnetic properties of tungsten alloy bars are a key indicator of their functional adaptability. They refer to their behavior in electromagnetic fields, including conductivity, magnetic properties, and electromagnetic shielding capabilities. The conductivity of tungsten alloy bars (particularly tungsten-copper alloys) is significantly enhanced by the addition of highly conductive copper, making them suitable for use as electrodes or connectors in electronics and communications. Their magnetic properties are modified by the addition of elements such as nickel and iron, typically exhibiting weak or non-magnetic properties, making them suitable for applications requiring low magnetic interference. Their electromagnetic shielding capabilities, derived from their high density and conductivity, effectively shield electromagnetic waves and protect equipment from electromagnetic interference. These electromagnetic properties make tungsten alloy bars widely used in high-frequency communications, electronic packaging, and electromagnetic compatibility equipment.

In the electronics industry, tungsten alloy bar's electromagnetic properties support its use in high-frequency electrodes or connectors, ensuring low loss and high stability in signal transmission. Its electromagnetic shielding capabilities also protect sensitive electronic components from external interference. In aerospace, its electromagnetic properties make it an ideal material for communication modules or sensor components, ensuring stable performance in complex electromagnetic environments. During production, electromagnetic performance is achieved through optimized copper content and surface treatment processes. For example, electroless plating increases surface conductivity and enhances electromagnetic shielding. Its processability allows for the manufacture of precision components that

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meet the stringent requirements of electromagnetic applications. Tungsten alloy bar's electromagnetic properties, combined with its thermal conductivity and mechanical properties, create a comprehensive performance advantage, ensuring stability in high-frequency and high-interference environments. Its non-toxicity and recyclability ensure compliance with environmental standards in electronics manufacturing. Tungsten alloy bar's electromagnetic properties ensure its reliable application in the electronics and communications fields, driving the advancement of high-performance electronic devices and communication technologies.

2.4 Performance Testing of Tungsten Alloy Bars

Performance testing of tungsten alloy bars is a critical step in ensuring their quality and application reliability. This involves comprehensive testing of their physical, mechanical, and functional compatibility. Using standardized equipment and processes, testing methods verify that tungsten alloy bars meet the stringent requirements of aerospace, medical, and electronics industries. Performance testing encompasses density, melting point, coefficient of thermal expansion, conductivity, strength, hardness, and other aspects to ensure consistent and stable material performance. The testing process must adhere to international and domestic standards (such as ASTM B777 and GB/T 3875) and utilize high-precision instrumentation to ensure accurate results. Testing must also consider environmental considerations, minimize waste, and comply with green manufacturing requirements. The following analysis focuses on physical property testing methods for tungsten alloy bars, including testing methods for density, melting point, coefficient of thermal expansion, and conductivity.

2.4.1 Physical property testing methods of tungsten alloy bars

Physical property testing methods for tungsten alloy bars are standardized processes that verify their key properties, such as high density, high melting point, coefficient of thermal expansion, and electrical conductivity. These processes are designed to ensure that the material meets the stringent requirements of aerospace, electronics, and medical applications. These properties are directly related to the bar's performance in counterweight, heat dissipation, radiation shielding, and electrical conductivity applications. These testing methods utilize high-precision instruments such as densitometers, differential scanning calorimeters, thermal expansion meters, and electrical conductivity testers. Through rigorous operating procedures and data analysis, the consistent performance of the tungsten alloy bars is verified. Testing must be conducted in a clean, constant temperature and humidity environment to minimize the impact of external factors (such as temperature, humidity, or contamination) on the results. Detailed record keeping is required to support quality traceability and ensure compliance with industry standards. The design of physical property testing methods must comprehensively consider test accuracy, operational efficiency, and environmental friendliness. Automated equipment and standardized processes are used to improve testing efficiency while reducing waste.

2.4.1.1 Density test method

Density testing is a core part of the physical property testing of tungsten alloy bars, used to verify whether

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their high density characteristics meet the needs of counterweight or radiation shielding applications. The high density of tungsten alloy bars is an important advantage in the aerospace and medical fields, and can provide significant weight or effectively shield high-energy radiation in a smaller volume. Density testing usually uses the Archimedes principle to calculate the density by measuring the weight difference of the sample in air and liquid, ensuring that the result accurately reflects the mass-to-volume ratio of the material. The test process requires the use of a high-precision electronic balance and deionized water as the test medium to ensure measurement accuracy. Sample preparation is a key step in the test, and ultrasonic cleaning equipment must be used to remove surface oil, dust or processing residues to avoid affecting the measurement results. The test environment must be controlled at a constant temperature to reduce the impact of temperature on liquid density and ensure data reliability.

The testing process involves the following steps: First, place the tungsten alloy bar sample on an electronic balance, and record its dry weight in air. Then, completely immerse the sample in deionized water, record the wet weight, and calculate the density using Archimedes' principle (density = dry weight/volume, where volume is calculated from the weight difference and the liquid density). During the test, ensure that no bubbles adhere to the sample; if necessary, use a vacuum pump to remove bubbles. Each test is repeated multiple times, and the average value is taken to improve accuracy. The average value is then compared to a standard density range to verify compliance with aerospace counterweight or medical shielding requirements. After testing, statistical analysis software is used to verify the consistency of the results, and test conditions (such as temperature and humidity) and sample information are recorded to support traceability. The advantages of this density test method are its simplicity and reliability, making it suitable for large-scale testing. However, strict control of environmental conditions and sample cleanliness are required to avoid errors. Optimization measures include using automated density testing equipment with integrated online data logging systems to improve testing efficiency and traceability, and using high-precision balances and regular calibration to ensure measurement accuracy. Density testing provides reliable assurance for the quality of tungsten alloy bars in counterweight and shielding applications, ensuring their performance stability in aerospace satellite attitude control or medical CT machine components, and laying the foundation for their application in high-tech fields.

2.4.1.2 Melting point test method

Melting point testing is a key method for verifying the high-temperature resistance of tungsten alloy bars, confirming their stability and suitability in high-temperature environments. The high melting point of tungsten alloy bars is primarily determined by the high melting point properties of tungsten, with minor influence from the addition of elements such as nickel, iron, or copper, making them suitable for applications such as aerospace engine components and high-temperature electronic electrodes. Melting point testing typically utilizes differential scanning calorimetry (DSC), which measures the change in heat flow during heating to determine the melting point. The test must be conducted in an inert atmosphere (such as argon or nitrogen) to prevent sample oxidation and ensure accurate data. Sample preparation is crucial for testing. Samples must be cut into small pieces (typically a few milligrams) and ultrasonically cleaned to remove surface impurities and prevent contamination that could affect the results. The testing environment must be maintained at a constant temperature and humidity to minimize

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external interference.

The testing process involves placing a cleaned tungsten alloy bar sample in the DSC instrument's sample pan. The temperature is gradually increased under inert gas at a set heating rate (typically 5-10°C/min). The sample's endothermic peak temperature, known as its melting point, is recorded. The instrument is calibrated using a standard sample (such as pure aluminum or pure tungsten) to ensure measurement accuracy. After the test, the heat flow curve is analyzed to determine the melting point, which is then compared with the standard to verify that it meets the performance requirements for high-temperature applications. After testing, the sample is inspected for oxidation or structural changes to ensure the reliability of the results. The melting point test method offers advantages such as high accuracy and repeatability, accurately reflecting the high-temperature performance of the tungsten alloy bar. However, it requires expensive equipment and complex operation, resulting in high testing costs. Optimization measures include using automated DSC equipment with integrated data analysis software to improve testing efficiency, regular instrument calibration, and the use of high-purity inert gas to reduce the risk of oxidation. Melting point testing provides a scientific basis for the reliability of tungsten alloy bars in high-temperature applications, ensuring their stable performance in aerospace propulsion systems or electronic high-temperature electrodes, and providing critical support for the development of high-temperature process equipment.

2.4.1.3 Thermal Expansion Coefficient Testing Method

Testing the coefficient of thermal expansion (CTE) is a crucial method for verifying the dimensional stability of tungsten alloy bars. It confirms their expansion characteristics under temperature fluctuations and ensures their stability in high-precision applications. The low CTE of tungsten alloy bars makes them well-suited for low-expansion materials such as ceramics and glass, making them suitable for aerospace structural components or electronic packaging. CTE testing is typically performed using a dilatometer, which measures the change in length of the sample during heating to calculate the linear expansion coefficient. Prior to testing, the sample must be processed to a standard size (e.g., a long strip, 10-50 mm in length) and ultrasonically cleaned to remove surface impurities and ensure that no defects could affect the measurement. The testing environment must be maintained at a constant temperature and humidity (15-25°C, humidity ≤40%) to minimize external interference. The test temperature range must encompass the application scenario (typically 20-1000°C) to simulate actual use conditions.

The testing process involves the following steps: a cleaned tungsten alloy bar sample is mounted on the test table of a thermal dilatometer. A high-precision displacement sensor is used to record the change in length of the sample during heating. The heating rate is controlled at 2-5°C/min to prevent thermal stress from affecting the results. The instrument records the change in sample length versus temperature, and the linear expansion coefficient is calculated using the formula (thermal expansion coefficient = $\Delta L / (L \cdot \Delta T)$). After the test, the data is analyzed and compared with the standard value to verify that it meets the requirements of the aerospace or electronics industry. Each test is repeated multiple times, and the average is taken to improve accuracy. Test conditions and sample information are recorded to support quality traceability. The advantages of the thermal expansion coefficient testing method lie in its high

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accuracy and wide applicability. It accurately reflects the dimensional stability of the tungsten alloy bar, but strict control of temperature and sample quality is required to avoid errors. Optimization measures include using an automated thermal dilatometer with an integrated multi-point calibration system to improve testing efficiency and regular instrument maintenance to ensure sensor accuracy. Thermal expansion coefficient testing ensures the stability of tungsten alloy bars in high-precision applications, ensuring their reliability in aerospace structures or electronic packaging, and supporting design optimization in high-tech fields.

2.4.1.4 Conductivity testing method

Conductivity testing is a key method for verifying the electromagnetic properties of tungsten alloy bars. It is used to confirm their current conduction capabilities, making them particularly suitable for electrodes or connectors in the electronics and communications fields. The conductivity of tungsten alloy bars (particularly tungsten-copper alloys) is significantly improved by the addition of highly conductive copper, enabling high-frequency signal transmission and efficient current conduction. Conductivity testing typically utilizes a four-point probe method, calculating the conductivity by measuring the resistivity of the sample surface to ensure that the results accurately reflect the material's electrical conductivity. Prior to testing, the sample undergoes polishing and ultrasonic cleaning to remove surface oxides and contaminants, ensuring surface finish and contact consistency. The test environment must be maintained at a constant temperature and humidity to minimize the impact of environmental factors on resistance measurements.

The testing process involves the following steps: a cleaned tungsten alloy bar sample is placed on a four-point probe test stand. Using a high-precision conductivity tester, four probes are placed in uniform contact with the sample surface. A constant current (typically 1-10 mA) is applied and the voltage drop is measured. Conductivity is calculated using the formula ($\text{conductivity} = 1/\text{resistivity}$, $\text{resistivity} = \text{voltage}/\text{current} \cdot \text{geometry factor}$). During the test, consistent probe spacing and uniform contact pressure are required to avoid measurement errors. After the test, the conductivity data is analyzed and compared with standard values to verify that the performance requirements of the electrode or connector are met. Each test is repeated multiple times, and the average is taken to improve accuracy. Test conditions and sample information are recorded to support quality traceability. The conductivity testing method offers advantages such as high precision and ease of operation, making it suitable for large-scale testing. However, consistent probe contact and sample surface quality must be ensured. Optimization measures include the use of automated four-point probe equipment with integrated data analysis systems to improve testing efficiency and regular calibration of the instrument using standard samples to ensure measurement accuracy. Conductivity testing ensures the reliability of tungsten alloy bars in electronic applications, ensuring stable performance in high-frequency electrodes or connectors, and driving the advancement of high-performance electronic devices and communications technologies.

2.4.2 Mechanical Properties Testing Specifications for Tungsten Alloy Bars

The mechanical testing specification for tungsten alloy bars is a standardized process for verifying key

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properties such as tensile strength, hardness, toughness, and fatigue resistance. This ensures that the material meets the requirements of aerospace, electronics, and precision manufacturing applications under high load, impact, or cyclic stress environments. Mechanical testing utilizes high-precision equipment such as universal testing machines, hardness testers, impact testers, and fatigue testers. Stringent operating procedures and data analysis are used to verify the consistent performance of the tungsten alloy bars. Testing must be conducted in a clean, constant temperature and humidity environment to prevent external factors (such as temperature, humidity, or contamination) from influencing the results. Detailed records are maintained to support quality traceability and ensure compliance with industry standards (such as ASTM E8 and GB/T 228.1). The design of mechanical testing specifications must comprehensively consider test accuracy, operational efficiency, and environmental considerations. Automated equipment and standardized processes should be used to improve testing efficiency and reduce waste. The following detailed discussion will explore the specifications for tensile testing, hardness testing, impact toughness testing, and fatigue testing, analyzing their principles, processes, and practical implications.

2.4.2.1 Tensile test specifications

Tensile testing is a core specification for mechanical property testing of tungsten alloy bars. It is used to verify their tensile strength, yield strength, and elongation, and to evaluate the material's performance under tensile loads. The high tensile strength of tungsten alloy bars makes them suitable for aerospace structures or high-stress components in precision manufacturing. Tensile testing adheres to international standards (such as ASTM E8 or GB/T 228.1) and uses a universal material testing machine to measure the mechanical properties of the sample by applying a gradually increasing tensile load. Before testing, the sample must be processed into a standard shape (such as a cylindrical or rectangular specimen) and ultrasonically cleaned to remove surface oil and impurities to ensure a defect-free surface. The testing environment must be controlled at a constant temperature and humidity to minimize the impact of environmental factors on the results.

The testing process includes the following steps: A cleaned tungsten alloy bar sample is secured in the fixture of a universal testing machine, ensuring proper clamping to avoid stress concentration. The tensile rate is set, and load and deformation data are recorded using high-precision force sensors and displacement transducers to generate a stress-strain curve. During the test, the sample's fracture behavior is monitored, and the tensile strength (maximum stress), yield strength, and elongation at break are recorded. After the test, the stress-strain curve is analyzed, and mechanical property parameters are calculated and compared with standard values to verify compliance with aerospace or precision manufacturing requirements. Each test is repeated multiple times, and averages are taken to improve accuracy. Test conditions and sample information are recorded to support quality traceability. The advantages of the tensile test specification lie in its high precision and repeatability, accurately reflecting the tensile properties of the tungsten alloy bar. However, it is important to ensure proper fixture alignment and sample quality to avoid errors. Optimization measures include using automated testing machines with integrated data analysis software to improve testing efficiency, and regular sensor calibration to ensure measurement accuracy. The tensile test specification provides a scientific basis for the reliability

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of tungsten alloy bars in high-stress applications, ensuring their consistent performance in aerospace structural components or precision tools.

2.4.2.2 Hardness test specifications

Hardness testing is a crucial technique for verifying the surface resistance of tungsten alloy bars to scratches and deformation. It is used to assess their wear resistance and mechanical strength, making them suitable for precision manufacturing tools or aerospace wear-resistant components. The high hardness of tungsten alloy bars enables them to maintain surface integrity in high-friction environments. Hardness testing adheres to international standards (such as ASTM E18 or GB/T 230.1), typically employing Vickers (HV) or Brinell (HB) hardness testing methods. Hardness values are measured by pressing an indenter into the sample surface. Prior to testing, the sample is polished and ultrasonically cleaned to remove surface impurities and ensure a smooth surface finish. The testing environment must be maintained at a constant temperature to minimize the effects of temperature on the indenter and sample.

The testing process includes the following steps: Place the cleaned tungsten alloy bar sample on the hardness tester test table, select an appropriate indenter (such as a Vickers diamond indenter) and load, apply the load, and maintain it for a specified time. The diagonal length of the indentation is measured using a microscope, and the hardness value is calculated ($HV = 1.8544 \times \text{load/square of the diagonal length}$). The test is repeated at multiple locations on the sample surface, and the average value is taken to improve accuracy. The hardness is then compared to the standard hardness range to verify that it meets the requirements for wear-resistant applications. After the test is completed, the indentation is inspected for clarity and crack-free conditions, and the test conditions and sample information are recorded to support quality traceability. The advantages of the hardness test specification are simple operation and intuitive results, but it is important to ensure that the sample surface quality and load selection are appropriate. Optimization measures include using automated hardness testers with integrated image analysis systems to improve testing efficiency, and regularly calibrating the indenter and microscope to ensure measurement accuracy. The hardness test specification provides assurance for the reliability of tungsten alloy bars in wear-resistant applications, ensuring their stable performance in precision-manufactured molds or aerospace components.

2.4.2.3 Impact toughness test specifications

Impact toughness testing is a crucial specification for verifying the impact resistance of tungsten alloy bars. It is used to assess their resistance to fracture under dynamic loads and is suitable for high-impact scenarios such as aerospace counterweights or precision manufacturing tools. Tungsten alloy bars improve the brittleness of pure tungsten by adding elements such as nickel and iron, thereby enhancing their impact toughness. Impact toughness testing adheres to international standards (such as ASTM E23 or GB/T 229) and typically utilizes Charpy or Izod impact tests. An impact testing machine applies a transient load and measures the absorbed energy of the sample. Prior to testing, the sample must be processed into a standard specimen (such as a rectangular bar with a V-notch) and ultrasonically cleaned to remove surface impurities and ensure a defect-free environment. The testing environment must be

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maintained at a constant temperature to minimize the impact of temperature on the results.

The testing process includes the following steps: The cleaned tungsten alloy bar sample is fixed in the fixture of the impact testing machine, ensuring that the notch is facing the direction of impact. The pendulum energy is set, the pendulum is released to impact the sample, and the energy absorbed when the sample breaks is recorded. During the test, the fracture surface characteristics are inspected to analyze whether it is a ductile or brittle fracture. After the test is completed, the impact toughness value (absorbed energy/fracture area) is calculated and compared with the standard value to verify whether it meets the requirements of high-impact applications. Each test is repeated multiple times and the average value is taken to improve accuracy. The test conditions and sample information are recorded to support quality traceability. The advantage of the impact toughness test specification is that it can intuitively reflect the impact resistance of the material, but the notch processing accuracy and fixture stability must be ensured. Optimization measures include using an automated impact testing machine with an integrated data recording system to improve testing efficiency; and regularly calibrating the pendulum energy to ensure measurement accuracy. The impact toughness test specification provides a scientific basis for the reliability of tungsten alloy bars in high-impact applications, ensuring their stable performance in aerospace counterweights or precision tools.

2.4.2.4 Fatigue performance testing specifications

Fatigue testing is a crucial process for verifying the cyclic stress resistance of tungsten alloy bars. It is used to assess their ability to resist fatigue damage under alternating loads and is suitable for rotating aerospace components or electronic vibration suppression components. Tungsten alloy bars achieve enhanced fatigue resistance through optimized microstructure, enabling them to remain stable under long-term dynamic loads. Fatigue testing adheres to international standards (such as ASTM E466 or GB/T 3075) and typically employs rotating bending or tensile-compression fatigue testing. Cyclic loads are applied using a fatigue testing machine to measure the fatigue life of the sample. Prior to testing, the sample must be machined into a standard shape (such as a cylindrical specimen), and surface defects must be removed through polishing and ultrasonic cleaning to ensure surface finish. The testing environment must be maintained at a constant temperature and humidity to minimize the impact of environmental factors on the results.

The testing process involves the following steps: a cleaned tungsten alloy bar sample is secured in the fixture of a fatigue testing machine. The cyclic load (tension, compression, or bending stress) and frequency are set, and the number of cycles required for the sample to reach fatigue failure is recorded. During the test, the stress amplitude and number of cycles are monitored to analyze the initiation and propagation behavior of fatigue cracks. After the test, a stress-cycle curve (SN curve) is plotted to determine the fatigue limit and compare it with the standard value to verify that it meets the requirements for dynamic applications. Each test is repeated multiple times to analyze data consistency, and test conditions and sample information are recorded to support quality traceability. The advantage of fatigue performance testing specifications is that they can accurately assess the long-term reliability of materials, but the testing cycle is long and the equipment cost is high. Optimization measures include using high-

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frequency fatigue testing machines with integrated data analysis software to improve testing efficiency and regularly calibrating load sensors to ensure measurement accuracy. Fatigue performance testing specifications provide assurance for the durability of tungsten alloy bars in dynamic loading applications, ensuring their stable performance in rotating aerospace components or electronic vibration suppression components.

2.4.3 Comparison of domestic and international performance standards for tungsten alloy bars

The performance standards of tungsten alloy bars are an important guide for their production, testing, and application. Different countries and regions have developed corresponding standards based on their industrial needs and technological levels. These standards cover the chemical composition, physical properties, mechanical properties, processing requirements, and testing methods of tungsten alloy bars, ensuring the material's high reliability in aerospace, medical, electronics, and precision manufacturing. Differences between domestic and international standards primarily lie in the emphasis on composition requirements, performance indicators, testing methods, and application areas. Chinese standards focus on practicality and cost-effectiveness to meet local industrial needs, while international standards emphasize global compatibility and high precision. Standards in Europe, the United States, Japan, and South Korea, for example, combine their technological advantages and industry characteristics to form diverse requirements. Comparing standards helps clarify the applicability of tungsten alloy bars in the global market and promote the internationalization of material design and application.

2.4.3.1 Chinese Standards

China's performance standards for tungsten alloy bars are primarily developed by the Standardization Administration of China and the Nonferrous Metals Industry Association. These standards are designed to meet the needs of domestic sectors such as aerospace, electronics, medical, and precision manufacturing. Focused on practicality and adaptability, these standards, leveraging China's abundant tungsten resources and mature powder metallurgy technology, regulate the chemical composition, physical properties, mechanical properties, and processing requirements of tungsten alloy bars. Chinese standards typically cover key properties such as the composition ratio (e.g., the ratio of tungsten to elements such as nickel, iron, and copper), density, strength, hardness, and corrosion resistance of tungsten alloy bars, while also specifying production processes and testing methods. These standards are formulated with due consideration of practical domestic industrial applications, such as aerospace counterweights, medical radiation shielding, and electronic heat dissipation substrates, ensuring a balanced performance and cost-effectiveness.

Chinese standards emphasize ease of use and reliable results in testing methods, specifying standardized processes for density testing, tensile testing, hardness testing, and impact toughness testing, making them suitable for mass production and quality control. The standards have a wide range of applications, covering a variety of scenarios from high-density counterweights to high-temperature structural components. They place particular emphasis on the environmental friendliness and recyclability of the material to meet the demands of green manufacturing. Chinese standards also set requirements for the

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processing properties of tungsten alloy bars, such as suitability for cutting, grinding, and surface treatment, to ensure the material can be manufactured into high-precision components. Furthermore, Chinese standards are compatible with international standards to a certain extent, facilitating the promotion of tungsten alloy bar products by domestic companies in the international market. The standard-setting process prioritizes integration with industry needs, ensuring practicality and operability through collaboration with companies in the aerospace, electronics, and medical sectors. Chinese standards are distinguished by their localization advantages, effectively supporting the development of domestic high-tech industries while providing a foundation for international cooperation.

2.4.3.2 International standards

International standards, primarily developed by organizations like the International Organization for Standardization (ISO), aim to provide unified technical specifications for the global production and application of tungsten alloy bars. These standards, centered on universality and high precision, cover the chemical composition, physical properties, mechanical properties, functional compatibility, and testing methods of tungsten alloy bars, making them suitable for international applications in aerospace, medical, electronics, and precision manufacturing. International standards impose stringent performance requirements on tungsten alloy bars, emphasizing the material's stability and reliability in high-load, high-temperature, and high-precision environments. For example, the standards set clear requirements for properties such as density, thermal conductivity, electrical conductivity, and radiation resistance, ensuring the material meets diverse application needs worldwide. International standards also emphasize the scientific and consistent nature of testing methods, prescribing high-precision testing procedures such as differential scanning calorimetry, coefficient of thermal expansion testing, and the four-point probe method to ensure comparability and traceability of test results.

International standards have a wide range of applications, covering a variety of scenarios from aerospace counterweights to medical radiation shielding, and are particularly well-suited for complex projects requiring international collaboration. The standards set high standards for the processing performance of tungsten alloy bars, such as dimensional accuracy, surface quality, and the ability to process complex shapes, to meet the demands of high-tech fields. International standards also emphasize the environmental friendliness and sustainability of the material, requiring production and testing processes to reduce waste generation, in line with the global trend of green manufacturing. Compared with Chinese standards, international standards place greater emphasis on global applicability and technological advancement, making them suitable for high-end markets and international applications. The standard-setting process involves experts from multiple countries and industries, ensuring its authority and broad applicability.

2.4.3.3 Tungsten Alloy Bar Standards in Europe, America, Japan, South Korea, and Other Countries

Tungsten alloy bar standards in Europe, the United States, Japan, and South Korea are developed by national professional standardization organizations, such as ASTM in the United States, EN in Europe,

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JIS in Japan, and KS in South Korea. These standards fully integrate national technological advantages and industry development characteristics to form a system of technical requirements with distinct focuses. Significant differences exist in key dimensions such as chemical composition, physical properties, mechanical properties, and testing methods. These differences reflect the core concerns of different countries in industrial production needs and actual application scenarios .

The core positioning of the US standard is to meet the high-performance requirements of tungsten alloy bars in the aerospace and medical fields, with a particular focus on two major applications: high-density counterweights and radiation shielding. Therefore, it places strict requirements on the material's mechanical properties and processing accuracy. In the aerospace field, tungsten alloy bars that meet this standard are primarily used to ensure the structural balance of aircraft and the stability of precision control systems, and must withstand the test of performance in extreme flight environments. In the medical field, tungsten alloy bars are mainly used as radiation shielding components in radiotherapy equipment, requiring strict composition control to avoid secondary risks caused by harmful impurities while ensuring stable and reliable shielding effects.

A notable feature of the European standard is its emphasis on the environmental friendliness and sustainability of materials, with clear requirements for non-toxicity and recyclability. This orientation gives it a unique advantage in high-precision applications in the medical and electronics fields. In medical device manufacturing, tungsten alloy bars complying with this standard must comply with the relevant EU environmental certification system and meet green requirements throughout their entire life cycle, from production to recycling. In electronics applications, its core value lies in the heat dissipation requirements of precision components such as chip packaging, requiring a balance between high-temperature resistance and environmental properties to ensure no harmful effects during the processing and use of electronic equipment.

The Japanese standard focuses on the needs of high-tech manufacturing and emphasizes the thermal and electrical conductivity of tungsten alloy bars in electronics and precision manufacturing scenarios. This technical approach makes it particularly suitable for the production needs of semiconductor equipment and various heat dissipation components. In the semiconductor industry, tungsten alloy bars that meet this standard are used in wafer processing and core equipment components. They must meet the stringent requirements of high-precision processes for material performance stability and dimensional accuracy to avoid performance fluctuations or dimensional deviations that affect semiconductor product quality. In the precision manufacturing field, tungsten alloy bars are often used in counterweight components of high-end machinery, requiring uniform performance and meticulous surface treatment to ensure the processing accuracy and operational stability of mechanical equipment.

The Korean standard cleverly integrates the dual needs of the aerospace and electronics industries, focusing on the comprehensive performance of the material while balancing cost-effectiveness, forming a technical system that is both practical and economical. In aerospace applications, tungsten alloy bars under this standard are mostly used in balance components and guidance system components of small and medium-sized aircraft. It is necessary to control production costs by optimizing material ratios while

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ensuring mechanical properties and environmental adaptability. In the electronics field, tungsten alloy bars mainly serve as key components of communication equipment, requiring excellent electromagnetic shielding performance and environmental stability to ensure long-term stable operation of communication equipment under different operating conditions, while reducing overall application costs through reasonable process design.

At the testing method level, European, American, Japanese, and Korean standards all rely on high-precision testing instruments and standardized operating procedures to build a rigorous quality verification system. For example, the US standard specifies in detail the operating requirements for tensile testing and hardness testing, with clear guidance from the selection of test equipment to the operating procedures; the European standard has established a dedicated process for thermal expansion coefficient testing, focusing on the changes in material properties under different temperature conditions; the Japanese standard's conductivity test method focuses on accurately measuring the conductive properties of materials, and ensures data accuracy through strict sample processing and test environment control; the Korean standard has established a special standard for impact toughness testing to ensure that the performance of materials under external impact can be accurately evaluated. These standards all make detailed provisions for test environment conditions, sample preparation requirements, and data analysis methods, with the ultimate goal of ensuring the reliability of test results and the comparability of data between different laboratories.

The application scenarios of European, American, Japanese, and Korean standards are clearly defined: the US standard is primarily applicable to aerospace counterweights and medical radiation shielding needs, the European standard is more suitable for the production of medical equipment and environmentally friendly electronic components under the guidance of green manufacturing, the Japanese standard has a significant advantage in the use of semiconductor precision components and high-end precision mechanical counterweights, and the Korean standard provides an adaptation solution for cost-effective aerospace components and key components of communication equipment. The differentiated development of national standards has not only promoted the specialization of domestic tungsten alloy material technology, but also provided diversified options for the global tungsten alloy industry chain. Companies can select the most suitable standard system for material research and development and production based on the performance requirements, environmental standards, and cost budgets of specific application scenarios.

2.5 CTIA GROUP LTD Tungsten Alloy Bar MSDS

The Material Safety Data Sheet (MSDS), now more commonly known as the Safety Data Sheet (SDS), is a crucial document providing safe operating instructions and risk assessment during the production and use of tungsten alloy rods. As a leading supplier of tungsten alloy rods, CTIA GROUP LTD's tungsten alloy rod MSDS provides safety information for workers, emergency personnel, and related practitioners, including chemical composition, physical and chemical properties, potential hazards, protective measures, emergency response methods, and storage and disposal requirements. The MSDS is compiled in accordance with international standards (such as the Global Harmonized System of Classification and

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Labeling of Chemicals (GHS)) and relevant Chinese regulations (such as GB/T 16483), ensuring comprehensive information and compliance with both global and local requirements.

The MSDS for tungsten alloy bars typically includes the following core sections: First, product identification, which clearly states the bar's name, chemical composition (such as the ratio of tungsten, nickel, iron, or copper), and supplier information. Second, hazard identification, which explains the potential risks of tungsten alloy bars. Tungsten alloy bars are solid materials with high chemical stability, generally posing no significant health hazards. Third, composition information, which lists the bar's main components and their concentrations, emphasizes its non-toxicity and low environmental risk.

The MSDS also includes handling and storage recommendations, recommending that tungsten alloy bars be stored in a dry, ventilated environment and avoid contact with strong acids or strong oxidizers to prevent surface corrosion. The MSDS also covers toxicology information, ecological information, and disposal precautions, emphasizing the non-toxicity and recyclability of tungsten alloy bars, supporting their green applications in medical and electronics. Shipping information clearly states that they are non-hazardous and comply with international shipping regulations.

2.6 Factors affecting the performance of tungsten alloy bars

The performance of tungsten alloy bars is influenced by a combination of factors, including composition ratio, production process, subsequent processing, microstructure, and usage environment. These factors together determine its physical properties, mechanical properties, and functional adaptability. The composition ratio determines the basic properties of tungsten alloy bars, such as density, strength, and thermal conductivity; the production process directly affects performance stability by controlling the microstructure and material density; and subsequent processing has a significant impact on surface quality, dimensional accuracy, and functional properties. Understanding these influencing factors helps optimize material design, production processes, and processing procedures, ensuring the high reliability of tungsten alloy bars in fields such as aerospace, medical, electronics, and precision manufacturing. Optimizing these factors requires comprehensive consideration of performance requirements, production costs, and environmental friendliness, achieving a balance between performance and practicality through scientific design and advanced technology.

2.6.1 Effect of composition ratio on the properties of tungsten alloy bars

The composition ratio is the primary factor influencing the performance of tungsten alloy bars, directly determining their physical, mechanical, and functional suitability. Tungsten alloy bars are primarily composed of tungsten, supplemented by binder elements such as nickel, iron, and copper, formed into a composite material through a powder metallurgy process. Tungsten's high density and high melting point give the alloy bars an excellent mass-to-volume ratio and high-temperature resistance, while the type and ratio of added elements further optimize toughness, thermal conductivity, electrical conductivity, and processability. For example, tungsten-nickel-iron alloys are known for their high density and tensile strength, making them suitable for aerospace counterweights. Tungsten-copper alloys, due to their high

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thermal and electrical conductivity, are widely used in electronic heat dissipation substrates and electrodes. Even small changes in the composition ratio can significantly affect performance. For example, increasing the nickel content improves toughness and impact resistance but may slightly reduce density. Increasing the copper content significantly improves thermal and electrical conductivity but may sacrifice some hardness and strength.

The composition ratio design must be optimized based on the application scenario. For example, in aerospace counterweight applications, high density and strength are prioritized, requiring a high tungsten content and an appropriate nickel-iron binder. In electronics heat dissipation applications, an increased copper content is required to improve thermal conductivity while maintaining sufficient mechanical strength. The composition ratio also influences the material's microstructure. A uniform element distribution reduces internal defects (such as pores or inclusions) and improves performance stability. During production, the composition ratio is achieved through high-precision powder mixing equipment and strict batching control to ensure a precise and uniform ratio of elements. Environmental protection is a key consideration in composition ratio design. Non-toxic elements such as nickel and copper are preferred to replace traditional lead-based materials to reduce potential harm to the environment and human health. Composition ratio optimization also considers processability. An appropriate binder ratio can reduce hardness and improve cutting and grinding efficiency. The influence of the composition ratio on tungsten alloy bar properties permeates every stage of material design, production, and application, providing flexibility to meet the diverse needs of the aerospace, medical, and electronics sectors and providing critical support for the development of high-performance devices.

2.6.2 Effect of production process on the properties of tungsten alloy bars

The production process is a key factor influencing the performance of tungsten alloy bars. It mainly includes powder metallurgy, sintering, heat treatment, and forming processes, which directly determine the material's microstructure, density, and performance stability. Powder metallurgy is the primary method for preparing tungsten alloy bars. It forms a dense material by mixing tungsten powder with elemental powders such as nickel, iron, or copper, pressing, forming, and sintering. Each step of the production process has a significant impact on performance. For example, the uniformity of the powder mixing determines the uniformity of the element distribution and microstructure, which directly affects density, strength, and thermal conductivity. Pressure control in the pressing process affects the initial density of the billet, which in turn affects the sintering effect. The sintering process (especially liquid phase sintering) optimizes the bonding between tungsten particles and the binder phase by controlling temperature and time, forming a high-density microstructure and improving tensile strength and toughness.

The sintering process is a core step in the production process. Precise control of sintering temperature and holding time directly impacts material properties. Excessively high sintering temperatures can lead to excessive grain growth, reducing toughness and fatigue resistance; excessively low temperatures can cause porosity or incomplete sintering, affecting density and strength. Heat treatment processes (such as annealing or aging) can further optimize the microstructure, eliminate internal stresses, and improve

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toughness and fatigue resistance. For example, appropriate annealing can improve the toughness of tungsten-nickel-iron alloys, making them suitable for high-stress aerospace components. Optimizing sintering conditions can enhance the thermal conductivity of tungsten-copper alloys, making them suitable for electronic heat dissipation substrates. The production process must also consider environmental and cost-effectiveness, optimizing process parameters to reduce energy consumption and waste generation, meeting green manufacturing requirements. Advanced production equipment (such as high-precision presses and vacuum sintering furnaces) can improve process stability and ensure consistent performance. The impact of the production process on the properties of tungsten alloy bars is reflected in its precise control of the microstructure, which ensures high-reliability applications in aerospace, medical, and electronics, and promotes the production and application of high-performance materials.

2.6.3 Effect of subsequent processing on the properties of tungsten alloy bars

The impact of subsequent processing on the performance of tungsten alloy bars is primarily reflected in surface quality, dimensional accuracy, and functional properties, which are directly related to their performance in high-precision applications. Subsequent processing, including cutting, grinding, polishing, surface treatment (such as electroless plating or physical vapor deposition), and precision forming, can optimize the geometry, surface finish, and functional performance of tungsten alloy bars. The high hardness and strength of tungsten alloy bars make them difficult to process, but the addition of elements such as nickel, iron, or copper improves their processing properties, allowing them to be precision machined into complex shapes that meet the requirements of aerospace counterweights, medical shielding components, and electronic connectors. The impact of subsequent processing on performance is mainly reflected in the following aspects: surface quality, mechanical properties, and functional adaptability.

Surface quality is the core goal of subsequent processing. A high-quality surface can improve wear resistance and conductivity, reducing friction loss and contact resistance. For example, in the electronics industry, the polished surface of tungsten-copper alloy strips can improve conductivity, making them suitable for high-frequency electrodes. In the medical field, tungsten alloy strips with high surface quality can reduce surface defects in radiation shielding components and improve shielding effectiveness. Cutting and grinding processes require the use of high-performance tools and precision equipment to avoid microcracks or surface stress caused by over-processing, which can affect toughness and fatigue resistance. Surface treatment processes (such as electroless nickel plating or PVD coating) can further enhance corrosion resistance and oxidation resistance, extending the service life of tungsten alloy strips in harsh environments, such as resisting high humidity or chemical media corrosion in aerospace components. Precision molding processes can ensure dimensional accuracy and meet high-precision assembly requirements, such as electronic packaging or medical imaging equipment.

Subsequent processing also needs to consider environmental protection and optimize the process flow to reduce the generation of metal chips and waste materials, in line with green manufacturing standards. For example, the use of dry cutting or recycling of processing waste can reduce environmental impact.

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Process parameters such as cutting speed, feed rate and cooling method need to be strictly controlled during the processing to ensure performance stability. The impact of subsequent processing on the performance of tungsten alloy bars provides a guarantee for its performance in high-precision and high-reliability applications by optimizing surface quality and functional properties. For example, in aerospace counterweight components, high-precision processing ensures uniform weight distribution; in electronic heat dissipation substrates, polishing and plating improve thermal conductivity and corrosion resistance. The optimization of subsequent processing requires advanced processing equipment and strict quality control to ensure the best performance of tungsten alloy bars in the aerospace, medical and electronic fields, and promote the development and application of high-tech equipment.

2.7 Matching Tungsten Alloy Bar Performance and Application

Matching the performance and application of tungsten alloy rods refers to the precise alignment of their physical, mechanical, and functional properties with the requirements of specific application scenarios. By optimizing material design and production processes, we ensure their efficient application in aerospace, medical, and industrial fields. Tungsten alloy rods' high density, high strength, high temperature resistance, corrosion resistance, and radiation resistance enable them to meet the diverse material performance requirements of different fields. For example, their high density and high strength are suitable for counterweight components requiring weight balance, their corrosion resistance and radiation resistance are suitable for medical radiation shielding, and their high temperature resistance and wear resistance meet the needs of industrial high-temperature processes and wear-resistant components.

2.7.1 Military Industry's Need for High Density and High Strength

The application of tungsten alloy bars in the military industry is primarily due to their high density and high strength, which enable them to meet stringent requirements for weight balance, structural strength, and durability. Military equipment, such as aerospace components, often requires precise weight distribution within a limited volume to ensure dynamic balance and operational stability. The high density of tungsten alloy bars enables them to provide significant weight within a relatively small volume, making them suitable for counterweight components such as satellite attitude control systems or aircraft balancing devices. This high density is achieved through a high tungsten content, supplemented by optimized binders such as nickel and iron, ensuring the material maintains structural integrity in high-stress environments. Its high strength allows it to withstand high loads and vibration, making it suitable for use in structural supports or high-stress components.

In military applications, the high strength of tungsten alloy bars is significantly enhanced by adding elements such as nickel and iron, overcoming the brittleness of pure tungsten and enhancing its tensile strength and toughness. For example, tungsten-nickel-iron, with its excellent tensile strength and impact resistance, maintains stable performance under dynamic loads, making it suitable for aerospace counterweight components. During production, powder metallurgy processes optimize sintering conditions and particle distribution to ensure uniform high density and strength, preventing internal defects from impacting performance. Machining accuracy is crucial for military applications. High-

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precision cutting and grinding enable tight dimensional tolerances to meet complex assembly requirements. The non-toxicity and recyclability of tungsten alloy bars make them environmentally friendly in the military sector, reducing the environmental impact of production and disposal. Its high density and strength, precisely matched to the needs of the military sector, ensure high reliability and operational stability, driving advancements in aerospace technology and providing key support for the development of high-performance equipment.

2.7.2 Performance requirements for radiation resistance and corrosion resistance in the medical field

The application of tungsten alloy bars in the medical field is primarily due to their radiation resistance and corrosion resistance, meeting the needs of radiation shielding and long-term use. Medical equipment (such as CT machines and radiotherapy devices) requires efficient shielding of high-energy radiation (such as X-rays and gamma rays) to protect the safety of patients and medical staff. The high density and high atomic number of tungsten alloy bars make them excellent radiation shielding materials, effectively absorbing and scattering radiation, reducing penetration. Radiation resistance is achieved through a high tungsten content and a dense microstructure, and optimized powder metallurgy processes ensure the stability of shielding performance. Compared with traditional lead-based materials, the non-toxicity of tungsten alloy bars makes them more advantageous in the medical field, avoiding the potential environmental and health risks of lead and meeting green manufacturing requirements.

Corrosion resistance is another key requirement for tungsten alloy bars in the medical field. Medical equipment is often exposed to high humidity or chemical sterilization environments, requiring the material to resist corrosion to maintain performance and surface quality. Tungsten alloy bars are enhanced for corrosion resistance by adding elements such as nickel, iron, or copper. The inherent chemical inertness of tungsten further enhances its resistance to oxidation and chemical attack. Surface treatments such as polishing or electroless plating can further enhance corrosion resistance and extend service life. For example, in medical imaging equipment, tungsten alloy bars, used as rotating components or shielding components, must remain stable in high-humidity environments, preventing surface degradation that could affect performance. During production, powder metallurgy processes control sintering conditions and component ratios to ensure uniform microstructure and reduce corrosion points. Processing precision is crucial for optimal compatibility with medical applications. High surface finish and dimensional accuracy enhance shielding effectiveness and assembly compatibility. The radiation resistance and corrosion resistance of tungsten alloy bars, precisely matched to the needs of the medical field, ensure the safety and reliability of equipment and promote advancements in medical imaging and radiotherapy technologies.

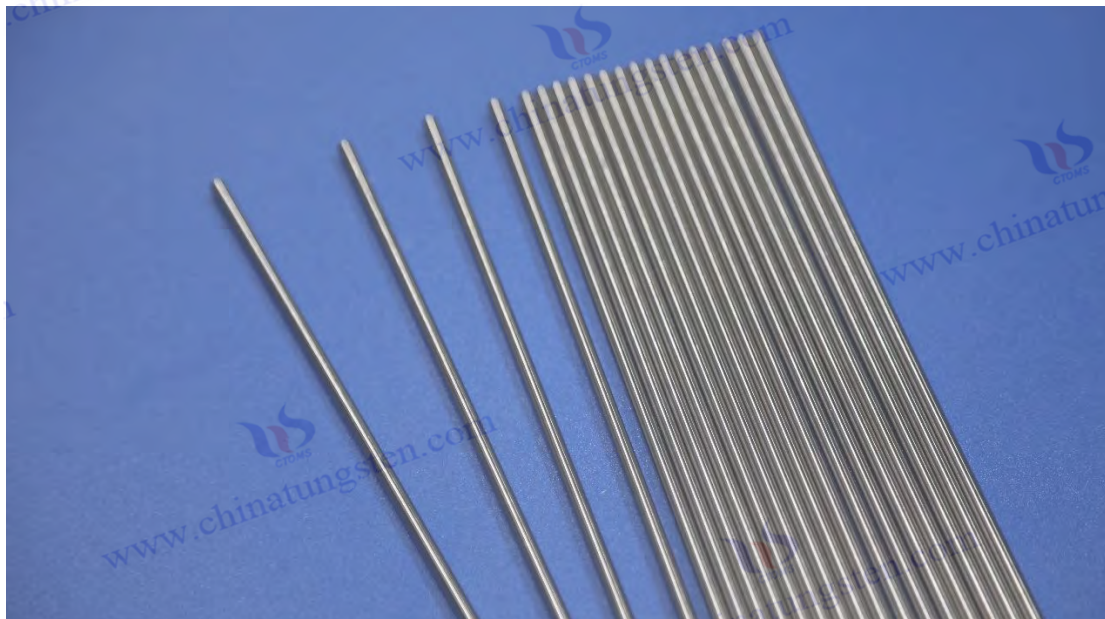
2.7.3 Industrial Adaptation Logic for High Temperature Resistance and Wear Resistance

The industrial application of tungsten alloy rods is primarily due to their high-temperature resistance and wear resistance, meeting the demands of high-temperature processes and wear-resistant components. High-temperature environments in industry, such as heat treatment furnaces and industrial cutting

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equipment, place stringent heat resistance requirements on the material. The high melting point and high-temperature resistance of tungsten alloy rods enable them to maintain stable performance in extreme temperatures, avoiding deformation or performance degradation. This high-temperature resistance stems from tungsten's high melting point. By optimizing the microstructure through the addition of elements such as nickel and iron, resistance to thermal stress and oxidation is enhanced. For example, tungsten-nickel-iron alloys maintain strength and toughness in high-temperature environments, making them suitable for use as supports in high-temperature furnaces or structural components in heat treatment equipment.

Wear resistance is another key requirement for tungsten alloy rods in the industrial sector, particularly in high-friction or high-load environments such as cutting tools, molds, and wear-resistant liners. The high hardness and optimized microstructure of tungsten alloy rods resist surface wear and scratching, extending their service life. Wear resistance is achieved through a powder metallurgy process, where the uniform distribution of tungsten particles and a binder phase creates a dense microstructure, enhancing the surface's resistance to friction. Surface treatments such as PVD coating or polishing further enhance wear resistance and reduce frictional losses. For example, in industrial cutting equipment, tungsten alloy rods can maintain sharpness and surface quality as cutting tools, improving machining efficiency. During production, sintering and heat treatment optimize the material's hardness and toughness, minimizing the impact of internal defects on wear resistance. Machining accuracy is crucial for optimal industrial application. High-precision machining enables the creation of complex shapes and surface finishes that meet the stringent requirements of molds and tools. Tungsten alloy rods' non-toxicity and recyclability make them environmentally friendly in the industrial sector, reducing the environmental impact of production and disposal. Its high temperature resistance and wear resistance are precisely matched with the needs of the industrial field, ensuring the reliability of high-temperature processes and wear-resistant components, and promoting the advancement of precision manufacturing and industrial technology.



CTIA GROUP LTD Tungsten Alloy Bar

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www.ctia.com.cn

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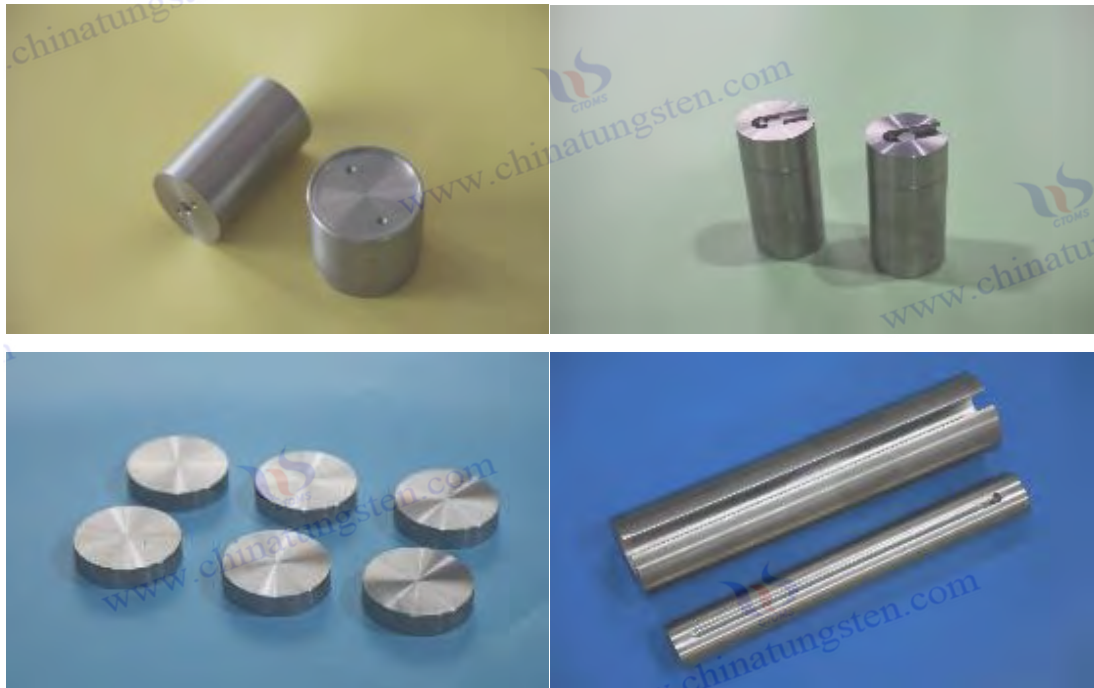
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Email: sales@chinatungsten.com

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

Chapter 3 Production Technology and Process of Tungsten Alloy Bar

Tungsten alloy rods ' physical, mechanical, and functional adaptability properties are directly determined by their production processes. They have broad application value in aerospace, medical, electronics, and precision manufacturing. The production of tungsten alloy rods relies on powder metallurgy technology. Through raw material preparation, powder mixing, pressing, sintering, and subsequent processing, the high density and high melting point of tungsten are combined with the advantages of elements such as nickel, iron, and copper to form a material with strength, toughness, and functionality. The production process requires strict control of parameters at each stage to ensure the stability and consistency of material properties. At the same time, it emphasizes environmental friendliness and sustainability, reducing waste and energy consumption during the production process.

3.1 Production of Tungsten Alloy Bars

The production of tungsten alloy bars encompasses multiple steps, from raw material preparation to finished product processing, primarily including raw material preparation, powder mixing, pressing, sintering, heat treatment, and subsequent processing. These steps are achieved through powder metallurgy technology, where tungsten powder is mixed with other metal elements such as nickel, iron, and copper powders, and then pressed and sintered at high temperatures to form a dense composite material. Each step has a significant impact on the final performance. For example, raw material preparation determines the purity and uniformity of the composition, pressing affects the initial density of the blank, and the sintering process determines the stability of the microstructure and the consistency of performance. The production process requires the use of high-precision equipment and strict process control to ensure the high density, high strength, and functional adaptability of the tungsten alloy bars. The production process must also take environmental considerations into account. By optimizing process parameters and recycling waste materials, energy consumption and environmental impact can be reduced, thus complying with green manufacturing requirements.

3.1.1 Preparation of raw materials for tungsten alloy bars

Raw material preparation is a fundamental step in tungsten alloy bar production, directly impacting the material's chemical composition, microstructure, and ultimate properties. Raw material preparation involves the selection, screening, and pretreatment of tungsten powder and other metal elements, such as nickel, iron, and copper, to ensure that the raw material's purity, particle size, and uniformity meet production requirements. Tungsten powder, as the primary component, provides high density and a high melting point, while binder elements such as nickel, iron, and copper improve toughness, thermal conductivity, and processing properties. Raw material preparation requires high-precision equipment (such as screening machines and analytical instruments) and rigorous quality control procedures to ensure that the raw materials meet the stringent requirements of the aerospace, medical, and electronics industries. Raw material selection and processing must also consider environmental considerations, prioritizing non-toxic raw materials and minimizing waste generation. Optimizing raw material preparation processes lays the foundation for subsequent mixing, pressing, and sintering, ensuring the

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stability and consistency of tungsten alloy bar performance.

3.1.1.1 Tungsten powder selection criteria and screening process

The selection criteria and screening process for tungsten powder are central to raw material preparation, directly determining the density, strength, and microstructural uniformity of tungsten alloy bars. As the primary component of tungsten alloy bars, tungsten powder must meet the requirements of high purity, appropriate particle size, and uniform morphology to ensure the stability of material properties. The selection criteria primarily encompass the following aspects: First, the tungsten powder must be of high purity to minimize the impact of impurities (such as oxygen, carbon, or other metallic elements) on performance. Impurities can cause pores or inclusions during sintering, reducing density and strength. Second, the particle size must be controlled within an appropriate range. Fine, uniform particles enhance mixing uniformity and sintered density, thereby enhancing mechanical properties and thermal conductivity. Furthermore, the morphology of the tungsten powder (e.g., spherical or irregular) must be compatible with the production process. Spherical particles generally exhibit better flowability and facilitate compaction.

The screening process is a critical step in ensuring tungsten powder quality. It typically involves the following steps: First, the powder's purity and impurity content are tested through chemical analysis (such as ICP-MS or XRF) to ensure it meets the stringent requirements of the aerospace and medical industries. After testing, the powder is screened using a high-precision vibrating screen or airflow classifier to separate powder within the target size range and remove oversized and undersized particles to ensure uniformity. The screening process must be conducted in a clean environment to avoid dust contamination and the introduction of impurities. The screened tungsten powder undergoes surface treatment (such as deoxidation) to reduce surface oxygen content and enhance sintering activity. The screening process also prioritizes environmental considerations, reducing energy consumption and dust emissions through recycling screening waste and optimizing equipment operation. Optimization measures include the use of automated screening equipment and online quality monitoring systems to improve screening efficiency and accuracy. Strict adherence to tungsten powder selection criteria and screening processes ensures the high density and strength of tungsten alloy bars, ensuring stable performance in aerospace counterweights and medical shielding components, and laying a solid foundation for subsequent production processes.

3.1.1.2 Purity requirements for other metal elements (nickel, iron, copper, etc.)

The purity requirements of other metallic elements (such as nickel, iron, and copper) are crucial in the preparation of tungsten alloy bar raw materials, directly impacting the material's toughness, thermal conductivity, electrical conductivity, and corrosion resistance. Nickel, iron, and copper, acting as binder elements, are mixed with tungsten powder through a powder metallurgy process to form a dense composite material, significantly improving the brittleness of pure tungsten and optimizing its functional properties. Purity requirements primarily encompass the following aspects: First, the purity of elements such as nickel, iron, and copper must be high to minimize the impact of impurities (such as sulfur,

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phosphorus, and oxygen) on performance. Impurities can cause microstructural defects and reduce toughness and corrosion resistance. Second, the chemical stability of the elements must meet production process requirements. For example, copper must possess high thermal and electrical conductivity, while nickel and iron must exhibit good bonding and toughness. Furthermore, the particle size and morphology of the elements must match the tungsten powder to ensure mixing uniformity and optimal sintering.

The purity control process includes the following steps: First, the purity and impurity content of nickel, iron, copper, and other powders are tested through chemical analysis (such as ICP-OES or atomic absorption spectroscopy) to ensure compliance with industry standards (such as ASTM B777 or GB/T 3459). After testing, the powders are screened for particle size using high-precision screening equipment to control particle size distribution and improve mixing uniformity. The screening process must be performed under inert gas or in a clean environment to avoid oxidation and contamination. The screened powders require pretreatment (such as deoxidation or surface activation) to improve compatibility with tungsten powder and sintering activity. Enforcing purity requirements also requires environmental considerations. Recycling screening waste and optimizing processing processes can reduce waste generation and environmental impact. Optimization measures include the use of automated analysis and screening equipment and the integration of online quality monitoring systems to improve the efficiency and accuracy of purity control. The purity requirements of metal elements such as nickel, iron, and copper are strictly controlled to ensure the toughness, thermal conductivity, and corrosion resistance of tungsten alloy bars, ensuring their stable performance in electronic heat dissipation substrates, medical shielding components, and aerospace structures, and providing key support for the production and application of high-performance materials.

3.1.1.3 Calculation method for the ratio of tungsten powder to other metal elements

Calculating the ratio of tungsten powder to other metal elements, such as nickel, iron, and copper, is a core step in raw material preparation, directly affecting the density, strength, toughness, and functional properties of the resulting tungsten alloy bar. This ratio calculation determines the proportions of each element based on the target application (such as aerospace counterweights, medical shielding, or electronic cooling) to optimize performance. For example, high-density counterweight applications require a high tungsten content to ensure a high weight-to-volume ratio, while electronic cooling applications require increased copper content to improve thermal conductivity. Ratio calculation methods are typically based on mass percentage or volume percentage, combining target performance and production process requirements to determine the optimal ratio through theoretical calculation and experimental verification.

The mix ratio calculation process involves the following steps: First, target performance is determined based on application requirements, such as high density (aerospace counterweights), high thermal conductivity (electronics cooling), or high toughness (structural parts). Next, the mass ratios of elements such as tungsten, nickel, iron, and copper are determined, referring to industry standards (such as ASTM B777 or GB/T 3459) or application requirements. For example, tungsten-nickel-iron alloys are often used in high-density applications, with a high tungsten content, so the nickel-iron ratio needs to balance

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toughness and strength. Tungsten-copper alloys are used for thermal conductivity, so the copper content needs to be appropriately increased. The calculation takes into account the density and chemical properties of each element. Using the principle of conservation of mass, the mass of each component is calculated using the formula (total mass = tungsten mass + nickel mass + iron mass + copper mass). Experimental verification is crucial for the mix ratio calculation. Small batches of samples are prepared and tested for density, strength, and thermal conductivity to verify the appropriateness of the mix ratio. Microstructural influences must be considered when adjusting the mix ratio. For example, a high tungsten content may increase hardness but reduce toughness, necessitating the addition of nickel or copper to optimize performance.

Ratio calculations must also consider environmental friendliness and cost-effectiveness, prioritizing the use of non-toxic elements (such as nickel and copper) to replace hazardous materials like lead to minimize environmental impact. High-precision analytical software (such as material ratio simulation software) is used to assist in the calculation process, ensuring accurate ratios and compliance with target performance. Optimization measures include establishing a ratio database to quickly access optimal ratio solutions based on application scenarios; and continuously optimizing ratios based on experimental feedback to improve performance stability. Scientifically designed and experimentally validated methods for calculating the ratios of tungsten powder and other metal elements provide a foundation for optimizing the performance of tungsten alloy bars, ensuring their reliable application in aerospace, medical, and electronics fields.

3.1.1.4 Mixing equipment and mixing uniformity control

Mixing equipment and mixing uniformity control are important links in raw material preparation, which directly affect the microstructural uniformity and performance consistency of tungsten alloy bars. Tungsten powder and powders of metal elements such as nickel, iron, and copper need to be evenly distributed through efficient mixing to ensure the formation of a dense microstructure after sintering and avoid performance fluctuations. Mixing uniformity has a significant impact on properties such as density, strength, thermal conductivity, and toughness. Uniform mixing can reduce porosity and inclusions and improve material properties. Mixing equipment must be highly precise and efficient. Common equipment includes planetary ball mills, V-type mixers, and high-energy vibration mixers. Appropriate equipment must be selected based on powder characteristics and production scale.

The mixing process includes the following steps: First, the screened tungsten powder and nickel, iron, copper and other powders are weighed according to the ratio and placed in a mixing device. The mixing equipment needs to operate in a clean environment to avoid contamination by impurities, and is usually carried out under the protection of an inert gas (such as argon) to prevent oxidation. The mixing time and speed need to be optimized according to the powder particle size and fluidity. For example, fine particles require a longer mixing time to ensure uniformity. The mixing uniformity is verified by sampling and testing. The elemental distribution of the powder is analyzed using a scanning electron microscope (SEM) or energy dispersive spectroscopy (EDS) to ensure that the components are evenly dispersed. The operating status of the equipment needs to be monitored during the mixing process to avoid excessive

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mixing that may cause particle breakage or overheating that may affect the activity of the powder. After mixing is completed, the powder needs to be stored in a sealed container to avoid moisture absorption or oxidation.

Optimizing mixing uniformity control includes using high-precision mixing equipment equipped with an online monitoring system for real-time element distribution monitoring; employing a multi-stage mixing process, starting with low-speed pre-mixing followed by high-speed fine mixing to improve uniformity; and regularly maintaining the equipment to ensure the cleanliness of the rotor and mixing chamber. Environmental protection is a key consideration in the mixing process, and environmental impact is reduced by recycling waste powder generated during the mixing process and optimizing equipment energy consumption. Scientifically designed and rigorously implemented mixing equipment and uniformity control ensure the microstructural uniformity and performance stability of tungsten alloy bars, ensuring their high reliability in aerospace counterweights, medical shielding, and electronic heat dissipation components.

3.1.2 Forming process of tungsten alloy bars

The forming process of tungsten alloy bars is a critical step in the production process, directly affecting the initial density, shape accuracy, and subsequent sintering results of the blank. The forming process presses a uniformly mixed powder into a blank of a specific shape, laying the foundation for sintering and subsequent processing. Common forming processes include cold pressing, hot pressing, and isostatic pressing. Cold pressing is widely used in tungsten alloy bar production due to its simplicity and low cost. The forming process requires the use of high-precision molds and presses to ensure the geometric accuracy and density of the blank, while optimizing process parameters to reduce defects such as cracks or delamination. The forming process also needs to consider environmental considerations, meeting green manufacturing requirements by recycling waste and optimizing energy consumption.

3.1.2.1 Cold Pressing Die Design and Specification Adaptation

The mold design and specification adaptation of cold pressing are the core of the tungsten alloy bar forming process, which directly determines the shape, dimensional accuracy and density of the blank, and affects the performance of subsequent sintering and processing links. Cold pressing uses a hydraulic press or a mechanical press to press the mixed powder into a bar-shaped blank. The mold design needs to consider the powder fluidity, pressing pressure and blank shape requirements. The mold design includes the following key aspects: First, the mold material must have high strength and high wear resistance, and is usually made of high-hardness steel or cemented carbide to withstand high pressure and reduce wear. Secondly, the geometry of the mold cavity needs to match the specifications of the target tungsten alloy bar, such as round, rectangular or customized shapes, to ensure the dimensional accuracy of the blank. In addition, the mold needs to have good demolding properties, and surface polishing or coating (such as lubricating coating) can be used to reduce powder adhesion and improve demolding efficiency.

Specification matching is a crucial step in mold design. The mold's size and shape must be determined

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based on the application scenario, such as aerospace counterweights, medical shielding, or electronic cooling. For example, aerospace counterweights require large-diameter, high-density billets, requiring mold design to ensure high density. Electronic cooling substrates require thin strip billets, requiring optimized cavity depth and surface finish. During the pressing process, pressure control (typically 100-300 MPa) is crucial for specification matching. Pressure distribution must be optimized based on powder properties and mold design to avoid billet delamination or cracking. The mold also requires precise positioning and guiding systems to ensure uniform powder filling and consistent billet shape during the pressing process. Optimization measures include using CAD/CAM software to design the mold, simulate powder flow and pressure distribution, and improve design accuracy. Automated presses with integrated pressure sensors and online monitoring systems improve pressing efficiency and billet quality. Environmental protection is achieved by recycling pressing waste and optimizing mold life to reduce resource waste. The mold design and specification adaptation of cold forming are scientifically designed and strictly controlled, which ensures the high precision and high performance of tungsten alloy bars, ensuring their reliable application in aerospace, medical and electronics fields.

3.1.2.2 Pressure parameters and holding time for cold pressing

The pressure parameters and holding time of cold pressing are key factors affecting the density and quality of tungsten alloy bar billets, directly determining the initial density, strength, and subsequent sintering effect of the billet. Cold pressing uses a hydraulic or mechanical press to press a uniformly mixed tungsten powder with powders such as nickel, iron, and copper into a bar billet. The pressure parameters and holding time must be optimized based on the powder properties, mold design, and target performance. The pressure parameters are typically controlled within the range of 100-300 MPa, with the specific value depending on the powder particle size, fluidity, and target billet density requirements. Smaller particle sizes and better fluidity require lower pressures, while powders with high tungsten content may require higher pressures to ensure density. Excessive pressure may cause mold wear or billet cracks, while too low pressure may cause the billet to become loose, affecting sintering quality.

Dwell time is another important parameter in cold pressing. It refers to the time pressure is held after application, typically ranging from 5 to 30 seconds. An appropriate dwell time promotes close bonding of powder particles, reduces internal porosity, and increases the initial density of the blank. Dwell time should be optimized based on powder properties and mold design. For example, high-flow powders require shorter dwell times, while powders with fine particles or high binder content may require longer dwell times to ensure uniform compaction. The process involves loading the mixed powder into the mold cavity, applying a set pressure using the press, holding the pressure for a specified time, and then slowly releasing the pressure to avoid cracking in the blank caused by rapid pressure release. During the pressing process, the pressure distribution and blank shape must be monitored, using high-precision pressure sensors and control systems to ensure consistency. Optimization measures include using automated presses with integrated real-time pressure monitoring and feedback systems to improve pressing efficiency, and using simulation software (such as finite element analysis) to optimize pressure and dwell time to reduce trial-and-error costs. Environmental protection is achieved by recycling pressing waste and optimizing energy consumption to reduce resource waste. The pressure parameters and holding time

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of cold forming are scientifically designed and strictly controlled, which guarantees the high density and quality of tungsten alloy bar blanks, ensuring their stable performance in aerospace counterweights and medical shielding components.

3.1.2.3 Differences between wet bag and dry bag isostatic pressing operations

Isostatic pressing is an advanced process used to produce high-precision, high-density billets in tungsten alloy bar production. By applying uniform pressure in a liquid or gaseous medium, the powder billet is subjected to uniform force in all directions, resulting in a billet with high density and a uniform microstructure. Isostatic pressing is divided into wet bag and dry bag methods, which differ significantly in their operation methods, application scenarios, and process characteristics. Both wet bag and dry bag methods are suitable for forming tungsten alloy bars, particularly in the production of high-precision components in the aerospace and electronics fields, but their operation processes and applicability differ.

The wet bag method is to put the evenly mixed tungsten powder and nickel, iron, copper and other powders into a flexible mold (such as a rubber or polyurethane bag), seal it, and place it in a high-pressure liquid medium (such as water or oil). The isostatic press applies uniform pressure to compact the powder blank in all directions. The characteristics of the wet bag method are high mold flexibility, which is suitable for complex shapes and small batch production. It can produce blanks with high density and uniformity, and is suitable for aerospace counterweights or medical shielding components. The operation process includes powder bagging, sealing, placing in a high-pressure container, applying pressure, unloading pressure and demolding. The pressure and sealing must be strictly controlled to avoid liquid leakage. The advantages of the wet bag method are molding flexibility and high density, but the operation is complicated, the mold replacement frequency is high, and the production efficiency is low.

The dry bag method involves loading powder into a prefabricated rigid mold (with a flexible inner liner). An isostatic press applies uniform pressure in a dry environment, securing the mold in place. This method is suitable for mass production and the production of standardized billets. The dry bag method boasts durable molds and ease of operation, making it suitable for producing strips or regularly shaped tungsten alloy billets, widely used in electronic heat dissipation substrates and industrial structural components. The process includes powder loading, mold securing, pressure application, pressure relief, and demolding. The elasticity and pressure resistance of the mold liner must be ensured. The dry bag method offers advantages such as high production efficiency and long mold life, but is less adaptable to complex shapes. The main differences between the two methods lie in mold type (flexible vs. rigid), production efficiency (small vs. large batches), and shape adaptability (complex vs. regular). Optimization measures include using automated isostatic presses with integrated pressure control systems to improve production efficiency and optimizing mold design to balance flexibility and durability. Environmental protection is achieved through waste powder recycling and energy optimization.

3.1.2.4 Pressure Control and Green Density Requirements for Isostatic Pressing

Isostatic pressing pressure control and green density requirements are key to ensuring the quality of

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tungsten alloy bar blanks, directly affecting their microstructure, performance stability, and subsequent sintering results. Isostatic pressing applies uniform pressure (typically 100-400 MPa) in a liquid or gas medium, subjecting powder particles to omnidirectional forces to produce a highly dense and uniform blank. Pressure control must be optimized based on powder properties (such as particle size and flowability) and the target application. For example, powders with high tungsten content require higher pressure to ensure density, while powders with high binder content may require lower pressure to avoid over-compaction and cracking. Pressure control is achieved using a high-precision isostatic press equipped with pressure sensors and an automatic control system to ensure uniform and stable pressure.

Green density is a key performance indicator for isostatic pressing, typically requiring 60-80% of theoretical density to ensure a dense microstructure during subsequent sintering. High green density reduces sintering shrinkage, porosity, and defects, thereby improving the density, strength, and thermal conductivity of the final product. Controlling green density is achieved through the following steps: First, the target density is determined based on the powder mix and application requirements (such as aerospace counterweights or electronics cooling). Next, the pressure and pressing time are adjusted (typically 30-60 seconds), and the optimal parameters are verified through experimentation. After pressing, the green density is measured using a densitometer (e.g., using the Archimedes principle) to ensure compliance with the required specifications. During testing, the green body is inspected for cracks or delamination, and pressure, time, and density data are recorded to support quality traceability. Optimization measures include using a real-time pressure monitoring system to dynamically adjust the pressure distribution and employing simulation software (such as finite element analysis) to optimize pressure parameters and reduce trial-and-error costs. Environmental protection is achieved by recycling press waste powder and optimizing equipment energy consumption to minimize resource waste. The pressure control and green density requirements of isostatic pressing are scientifically designed and strictly implemented, which guarantees the high density and performance stability of tungsten alloy bars, ensuring their reliable application in aerospace, medical and electronics fields.

3.1.3 Sintering process of tungsten alloy bars

The sintering process is the core link in the production process of tungsten alloy bars. Through high-temperature treatment, the pressed blanks are subjected to particle bonding and densification to form a material with high density, high strength and uniform microstructure. The sintering process usually adopts vacuum sintering or hydrogen sintering, which are suitable for different performance requirements and application scenarios. Vacuum sintering reduces oxidation and promotes densification by heating in a low-pressure environment, which is suitable for the production of high-precision and high-quality tungsten alloy bars; hydrogen sintering uses the reducing effect of hydrogen to reduce the oxide content and is suitable for alloys requiring high toughness and conductivity. The sintering process requires strict control of parameters such as vacuum degree, heating curve, holding time, hydrogen purity and dew point to ensure the stability and consistency of material properties. The sintering process also needs to consider environmental protection and reduce environmental impact by optimizing energy consumption and waste gas treatment.

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3.1.3.1 Vacuum Degree Control and Temperature Rise Curve of Vacuum Sintering

Vacuum sintering involves controlling the vacuum level and heating curve, which are crucial for ensuring the sintering quality of tungsten alloy bars. This directly impacts the material's density, microstructure, and performance stability. Vacuum sintering involves heating in a low-pressure environment to reduce the presence of oxygen and other gases, preventing oxidation and promoting the bonding of tungsten particles with binder elements such as nickel, iron, and copper, ultimately forming a dense microstructure. Vacuum control typically requires achieving a high vacuum level to minimize the impact of residual gases on the sintering process. This high vacuum environment effectively prevents oxide formation, ensuring high material purity and performance stability.

The vacuum control process includes the following steps: First, a high-performance vacuum pump (such as a turbomolecular pump) is used to evacuate the vacuum level in the sintering furnace to a specified range, and then a vacuum gauge is used for real-time monitoring to ensure that the vacuum level is stable. The sintering furnace requires regular maintenance to ensure sealing and vacuum pump performance. The heating curve is another key parameter for vacuum sintering. A staged heating curve needs to be designed according to the composition and target performance of the tungsten alloy to control the particle bonding and densification process. The heating curve usually includes the following stages: a low-temperature stage to remove volatile impurities and moisture from the billet; a medium-temperature stage to promote particle surface activation; and a high-temperature stage to achieve liquid phase sintering, so that the binder elements melt and fill the gaps between the tungsten particles. The heating rate needs to be controlled within a reasonable range to avoid cracking or uneven shrinkage of the billet due to excessive heating. The cooling stage also needs to be carried out slowly to reduce thermal stress.

Optimization measures include the use of automated vacuum sintering furnaces with integrated vacuum and temperature control systems for real-time parameter monitoring and adjustment. Simulation software, such as thermodynamic simulation, optimizes the heating curve to reduce trial-and-error costs. Environmental protection is achieved by optimizing vacuum pump energy consumption and exhaust gas treatment to reduce energy consumption. Scientifically designed and executed vacuum control and heating curves during vacuum sintering ensure high density and high performance of tungsten alloy bars, making them particularly suitable for the production of aerospace counterweights and medical shielding components.

3.1.3.2 Densification process and holding time setting for vacuum sintering

The densification process and holding time during vacuum sintering are central to the sintering process, directly determining the density, strength, and microstructural uniformity of the resulting tungsten alloy bar. Densification, through particle rearrangement and diffusion at high temperatures and the liquid flow of the binder, gradually eliminates pores in the billet, resulting in a highly dense material. The densification process is divided into three stages: primary (particle rearrangement and contact point formation), intermediate (pore contraction and particle bonding), and final (liquid phase filling and microstructural stabilization). A vacuum environment reduces oxidation and gas interference, promoting

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densification and improving material density and performance stability.

The holding time setting needs to be optimized according to the composition, billet size and target performance of the tungsten alloy, and is usually kept warm for several hours in the high temperature stage. A longer holding time can promote liquid phase sintering, enhance the bonding between tungsten particles and binder, and improve density and toughness, but too long may lead to excessive grain growth and reduce strength; too short may cause residual pores, affecting density and performance. The selection of holding time needs to be verified experimentally, and the optimal parameters are determined by combining density testing and microstructure analysis (such as SEM). The process flow includes placing the pressed billet in a vacuum sintering furnace, gradually heating it to the target temperature according to the heating curve, and slowly cooling it after the set holding time to avoid cracks caused by thermal stress. During the test, the shrinkage rate and density change of the billet need to be monitored, and the sintering parameters need to be recorded to support quality traceability.

Optimization measures include the use of a high-precision temperature control system to ensure accurate holding time and the adoption of online density monitoring equipment for real-time evaluation of densification results. Environmentally friendly performance is achieved by optimizing holding time and energy consumption to reduce energy waste. Scientifically controlled densification and holding time settings during vacuum sintering ensure high density and strength of tungsten alloy bars, ensuring stable performance in aerospace structural components and electronic heat dissipation substrates.

3.1.3.3 Hydrogen Purity and Dew Point Control for Hydrogen Sintering

Hydrogen purity and dew point control during hydrogen sintering are crucial factors in ensuring the quality of tungsten alloy bar sintering, directly impacting the material's oxide content, microstructure, and performance stability. Hydrogen sintering utilizes the reducing effect of hydrogen to remove oxides from the billet, promoting particle bonding and densification. It is suitable for tungsten alloy bars requiring high toughness and electrical conductivity (such as tungsten-copper alloys). High hydrogen purity is required to prevent interference from impurities (such as oxygen and nitrogen) during the sintering process. High-purity hydrogen effectively reduces surface oxides, improving material purity and performance.

The hydrogen purity control process includes the following steps: First, a high-purity hydrogen source is used, and impurities are further removed through a gas purifier (such as a molecular sieve or palladium membrane purifier) to ensure hydrogen purity. Dew point control is another key parameter in hydrogen sintering. The dew point needs to be controlled at a low level to reduce the water vapor content and avoid oxidation or hydrogen embrittlement. Dew point control is achieved through real-time monitoring of the dew point meter and the use of a drying system (such as a condenser or adsorbent) to maintain a low dew point environment. The sintering furnace must be equipped with a gas circulation and purification system to ensure the stability and uniformity of the hydrogen flow. The process includes placing the billet in a hydrogen sintering furnace, introducing high-purity hydrogen, heating according to a heating curve, monitoring the hydrogen purity and dew point, and ensuring a stable sintering environment.

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Optimization measures include the use of an automated gas control system to monitor and adjust hydrogen purity and dew point in real time; regular maintenance of the sintering furnace and purification system ensures equipment performance. Environmental protection is achieved through hydrogen recovery and optimized waste gas treatment to reduce emissions. Strict control of hydrogen purity and dew point during hydrogen sintering ensures low oxide content and high performance of tungsten alloy bars, making them particularly suitable for the production of electronic electrodes and heat dissipation substrates.

3.1.3.4 Reduction and oxidation control measures in hydrogen sintering

The reduction effect and oxidation control measures during hydrogen sintering are crucial for ensuring the sintering quality of tungsten alloy bars, directly impacting the material's purity, microstructure, and performance stability. Hydrogen sintering removes oxides from the surfaces of tungsten powder and other metal elements (such as nickel, iron, and copper) through the reducing action of hydrogen, promoting particle bonding and densification, and improving the material's toughness, electrical conductivity, and thermal conductivity. The reducing effect is most pronounced at high temperatures, where hydrogen reacts with oxides to produce water vapor, reducing the material's oxygen content and improving microstructural uniformity.

Oxidation prevention and control measures include the following steps: first, use high-purity hydrogen and a low dew point environment to reduce the possibility of oxide formation ; second, the sintering furnace must be well sealed to prevent air infiltration and oxidation. The process involves placing the billet in a hydrogen sintering furnace, introducing high-purity hydrogen, heating according to a heating curve, and monitoring the atmosphere and temperature in the furnace to ensure that the reduction reaction is sufficient. After sintering, it is necessary to cool slowly to avoid stress concentration or oxidation caused by rapid cooling. During the testing process, an oxygen content analyzer is required to detect the residual oxygen in the material to ensure the reduction effect. Optimization measures include using an online atmosphere monitoring system to adjust the hydrogen flow rate and dew point in real time; and using an anti-oxidation coating to protect the billet surface and enhance the oxidation prevention and control effect. Environmental protection is achieved by optimizing hydrogen usage and waste gas treatment to reduce emissions and energy consumption. The reduction effect and oxidation prevention and control measures of hydrogen sintering, through scientific control, provide guarantees for the high purity and high performance of tungsten alloy bars, ensuring their reliable application in the electronics and precision manufacturing fields.

3.1.4 Subsequent processing of tungsten alloy bars

Subsequent processing is a crucial step in the tungsten alloy bar production process. Through processes such as cutting, grinding, heat treatment, and surface treatment, the material's surface quality, dimensional accuracy, and mechanical properties are optimized to ensure it meets the high-precision requirements of aerospace, medical, electronics, and precision manufacturing. The high hardness and strength of tungsten alloy bars make them challenging to process. However, the addition of elements

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such as nickel, iron, and copper improves their processing properties, enabling precision fabrication into complex shapes. Subsequent processing requires high-performance equipment (such as CNC machine tools, grinders, and heat treatment furnaces) and strict process control to ensure precision and performance stability. Environmental considerations are also crucial during the processing process, with optimized process parameters and waste recycling minimizing resource waste and environmental impact. The following details tool selection, cutting parameters, and precision control for cutting, grinding wheel type and surface roughness requirements for grinding, and heat treatment for optimizing mechanical properties.

3.1.4.1 Tool selection for cutting

The selection of cutting tools is the key to the subsequent processing of tungsten alloy bars, which directly affects the processing efficiency, surface quality and dimensional accuracy. The high hardness and strength of tungsten alloy bars require cutting tools with high wear resistance, high strength and good cutting performance. Common tool materials include cemented carbide (such as tungsten steel), polycrystalline diamond (PCD) and cubic boron nitride (CBN). Cemented carbide tools are widely used in the roughing and semi-finishing of tungsten alloy bars due to their high cost-effectiveness and versatility; PCD tools are suitable for high-precision finishing due to their extremely high hardness and wear resistance, especially in the processing of electronic heat dissipation substrates and medical shielding components; CBN tools are suitable for the processing of high-hardness tungsten alloy bars and can maintain stability during high-speed cutting.

Tool selection must be optimized based on the composition and application of the tungsten alloy bar. For example, tungsten-nickel-iron alloy, due to its high toughness, is well-suited for turning or milling with carbide tools. Tungsten-copper alloy, due to its high thermal conductivity, requires PCD tools to minimize the effects of cutting heat on the material. Tool geometry (such as rake angle, relief angle, and cutting edge radius) must be designed based on machining requirements. For example, a larger rake angle reduces cutting forces and is suitable for high-hardness tungsten alloy bars, while a smaller cutting edge radius improves surface finish. Tool selection also needs to consider machining equipment performance, such as CNC machine tool rigidity and spindle speed. Optimization measures include using coated tools (such as TiAlN or AlCrN coatings) to improve wear resistance and life, and regularly checking tool wear to ensure cutting stability. Environmental protection is achieved by recycling cutting waste and optimizing tool life to reduce resource waste. Scientifically designed and rigorously implemented tool selection for cutting operations ensures high-precision machining of tungsten alloy bars, ensuring stable performance in aerospace counterweights and electronic connectors.

3.1.4.2 Cutting parameters and machining accuracy control

Cutting parameters and machining accuracy control are at the core of tungsten alloy bar cutting, directly impacting surface quality, dimensional accuracy, and machining efficiency. Cutting parameters, including cutting speed, feed rate, and depth of cut, must be optimized based on the composition, hardness, and target precision of the tungsten alloy bar. Cutting speed is typically controlled within a

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reasonable range : lower speeds are suitable for high-hardness tungsten alloy bars to reduce tool wear, while higher speeds are suitable for tungsten-copper alloys to improve efficiency. Feed rate is controlled within a reasonable range ; smaller feed rates can improve surface finish and are suitable for high-precision components. Cutting depth is controlled within a reasonable range and needs to be adjusted based on the type of machining (roughing or finishing) to avoid excessive depth, which can cause vibration or tool damage.

Machining precision control requires the use of high-precision CNC machine tools (such as CNC lathes or milling machines) equipped with high-precision fixtures and measuring systems (such as laser rangefinders) to ensure dimensional tolerances and surface finish. The process includes the following steps: determining cutting paths and parameters based on design drawings, using CAD/CAM software for cutting simulation to optimize machining efficiency; using an online monitoring system to monitor cutting forces and vibrations in real time during machining, adjusting parameters to avoid defects; and verifying dimensional accuracy and form and position tolerances using a coordinate measuring machine (CMM) after machining. Optimization measures include the use of an adaptive control system to dynamically adjust cutting parameters to account for variations in material hardness; and the use of coolants (such as water-based emulsions) to reduce cutting temperatures, improve tool life, and enhance surface quality. Environmental protection is achieved through chip recycling and optimized coolant usage to minimize environmental impact. Scientifically optimized and rigorously enforced cutting parameter and machining precision control ensure the high precision and quality of tungsten alloy bars, meeting the stringent requirements of the aerospace and medical sectors.

3.1.4.3 Grinding wheel type and surface roughness requirements

The type of grinding wheel and surface roughness requirements for grinding are important links in the subsequent processing of tungsten alloy bars, which directly affect the surface quality and functional performance. Grinding removes material through the relative movement of the grinding wheel and the workpiece, optimizes the surface finish and dimensional accuracy of the tungsten alloy bar, and is suitable for the processing of electronic heat dissipation substrates, medical shielding components and precision molds. The type of grinding wheel needs to be selected according to the hardness and composition of the tungsten alloy bar. Commonly used grinding wheels include diamond grinding wheels, CBN grinding wheels and alumina grinding wheels. Diamond grinding wheels are suitable for fine grinding of high-hardness tungsten alloy bars due to their ultra-high hardness and can achieve high surface quality; CBN grinding wheels are suitable for high-speed grinding and suitable for the processing of tungsten-nickel-iron alloys; alumina grinding wheels are used in cost-sensitive rough grinding scenarios.

Surface roughness requirements typically range from Ra 0.2-0.4 μm to meet the high-precision demands of aerospace counterweights and electronic connectors. The grinding process includes the following steps: selecting the grinding wheel grit size and bond type (such as resin or vitrified bond) based on the workpiece requirements; using a high-precision grinding machine (such as a surface grinder or cylindrical grinder) to control the grinding speed and feed rate; and using coolant to reduce the grinding

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temperature during processing to prevent thermal damage. Surface roughness is measured using a surface profilometer to ensure compliance with requirements. Optimization measures include using automated grinding machines with integrated online inspection systems for real-time surface quality monitoring; and regular grinding wheel dressing to maintain cutting performance. Environmental protection is achieved through recycling grinding waste and optimizing coolant usage to reduce environmental impact. Scientifically selected and strictly controlled grinding wheel type and surface roughness requirements ensure the high surface quality and functional performance of tungsten alloy bars.

3.1.4.4 Optimization of mechanical properties by heat treatment

Optimizing the mechanical properties of tungsten alloy bars through heat treatment is an important step in subsequent processing. By controlling the temperature and cooling rate, the microstructure is improved, and the tensile strength, toughness, and fatigue resistance are enhanced. The high hardness and strength of tungsten alloy bars make them prone to internal stress at high temperatures. Heat treatment can eliminate stress, optimize the grain structure, and improve performance stability. Common heat treatment processes include annealing, solution treatment, and aging treatment, which need to be optimized according to the composition and application scenarios of the tungsten alloy. For example, tungsten nickel iron alloy improves toughness through annealing and is suitable for aerospace structural parts; tungsten copper alloy optimizes thermal conductivity and strength through solution treatment and is suitable for electronic heat dissipation substrates.

The heat treatment process involves the following steps: tungsten alloy bars are placed in a heat treatment furnace and heated to a set temperature under an inert gas (such as argon) or vacuum atmosphere. The temperature is then maintained for 1-2 hours to promote grain rearrangement and stress relief. The microstructure is then optimized through controlled cooling rates (such as furnace cooling or water cooling). Annealing eliminates internal stresses and improves toughness through slow cooling, while solution treatment enhances strength and thermal conductivity through rapid cooling. After heat treatment, the performance improvements are verified through hardness testing, tensile testing, and microstructural analysis (such as scanning electron microscopy). Optimization measures include the use of high-precision heat treatment furnaces with integrated temperature control systems to ensure precise heating and cooling, and the use of simulation software to optimize heat treatment parameters and reduce trial-and-error costs. Environmental protection is achieved through optimized energy consumption and exhaust gas treatment to minimize environmental impact. The optimization of mechanical properties during heat treatment, through scientific design and rigorous execution, ensures the reliability of tungsten alloy bars in high-stress applications and ensures their stable performance in aerospace and electronics applications.

3.2 Critical Control Points of Tungsten Alloy Bar Process

The production process of tungsten alloy bars involves multiple links, each of which has critical control points that directly affect the material's microstructure, performance stability, and final quality. Key process control points include the accuracy of raw material ratios, the uniformity of powder mixing, the

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pressure and density of pressing, the temperature and atmosphere control of the sintering process, and the accuracy and surface quality of subsequent processing. These control points require high-precision equipment and strict process parameter management to ensure the high density, high strength, and functional adaptability of tungsten alloy bars. The optimization of key control points requires comprehensive consideration of material composition, application requirements, and production costs, while focusing on environmental protection, reducing environmental impact by recycling waste and optimizing energy consumption. As the core link, the sintering process is particularly important in terms of temperature and atmosphere control, which directly determines the densification, microstructure, and performance stability of the material.

3.2.1 Sintering temperature and atmosphere control

Sintering temperature and atmosphere control are key control points in the tungsten alloy bar production process, directly impacting the material's density, microstructure, and mechanical properties. The sintering process uses high-temperature treatment to bond the tungsten particles in the pressed billet with binder elements such as nickel, iron, and copper, forming a high-density composite material. The sintering temperature must be precisely controlled within an appropriate range to promote liquid-phase sintering and particle bonding, while avoiding excessive grain growth or material performance degradation caused by excessive temperatures. Atmosphere control, using a vacuum or hydrogen environment, reduces the effects of oxidation and impurities, ensuring high material purity and stable performance. Sintering temperature and atmosphere control must be optimized based on the tungsten alloy's composition and application. For example, tungsten-nickel-iron alloys require higher temperatures to ensure high strength, while tungsten-copper alloys require moderate temperatures to maintain thermal conductivity. The process requires the use of high-precision sintering furnaces (such as vacuum or hydrogen sintering furnaces) equipped with temperature and atmosphere monitoring systems to ensure parameter stability.

3.2.1.1 Basis for determining the sintering temperature range

Determining the sintering temperature range is a critical control point in the tungsten alloy bar sintering process, directly affecting the material's density, strength, toughness, and functional properties. The sintering temperature is determined based on the tungsten alloy's composition, the melting points of the binder elements, and the target performance, typically within the 1200-1500°C range. The selection of this temperature range is based on the following considerations: First, tungsten's high melting point is much higher than the sintering temperature, and sintering primarily relies on the formation of a liquid phase of binder elements (such as nickel, iron, and copper) to promote the bonding of tungsten particles and fill pores. For example, the sintering temperature of tungsten-nickel-iron alloys must be close to the melting point of nickel to form a liquid phase and enhance densification; tungsten-copper alloys require lower temperatures to avoid excessive copper volatilization. Second, the temperature range must consider microstructural requirements. Higher temperatures improve density but may lead to grain growth and reduce toughness; lower temperatures may result in residual porosity, compromising strength. The process for determining the temperature range includes the following steps: Based on the tungsten alloy's

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composition and application requirements (such as aerospace counterweights or electronic heat sinks), the sintering temperature range is preliminarily determined by referring to phase diagrams and thermodynamic data. The optimal temperature range is determined through small-batch experiments, testing density, strength, and microstructure at different temperatures (e.g., using SEM analysis). Temperature adjustments are made in accordance with industry standards (such as ASTM B777 or GB/T 3459) to ensure performance meets requirements. A high-precision temperature control system is required throughout the process, monitoring the temperature distribution within the furnace in real time to avoid localized overheating or underheating. Optimization measures include using thermodynamic simulation software to predict the impact of temperature on microstructure and employing a multi-stage temperature curve to gradually increase the temperature to optimize the densification process. Environmental protection is achieved by optimizing temperature control and energy consumption to reduce energy waste. The sintering temperature range, based on scientific design and experimental verification, ensures the high density and high performance of tungsten alloy bars, ensuring their reliability in aerospace structural components and electronic heat sink substrates.

3.2.1.2 Effect of heating rate on grain growth

The heating rate is another key control point in the sintering process, directly affecting the grain growth, microstructure, and mechanical properties of the tungsten alloy bar. The heating rate refers to the rate at which the temperature rises during the sintering process and needs to be optimized based on the tungsten alloy composition, billet size, and target performance. An appropriate heating rate can promote particle bonding and densification while controlling grain growth and avoiding performance degradation. Excessively rapid heating rates can lead to thermal stress concentration, causing billet cracking or uneven shrinkage; excessively slow heating rates can prolong the sintering cycle, increase energy consumption, and potentially cause binder element volatilization, affecting the microstructure.

The influence of heating rate on grain growth is primarily reflected in the following aspects: rapid heating may accelerate the formation of a liquid phase of binder elements, promoting the bonding of tungsten particles, but a short duration at high temperature may limit densification; slow heating prolongs the high-temperature dwell time, potentially leading to excessive grain growth and reduced toughness and fatigue resistance. For example, tungsten-nickel-iron alloys require a slower heating rate to control grain size and ensure high toughness; tungsten-copper alloys can adopt a slightly faster heating rate to improve thermal conductivity while avoiding copper volatilization. The process flow includes the following steps: designing a staged heating profile based on alloy composition and target properties; using a high-precision sintering furnace to monitor the heating rate to ensure temperature uniformity; and post-sintering analysis of grain size and properties through SEM and hardness testing to verify the rationality of the heating rate. Optimization measures include the use of an automated temperature control system to adjust the heating rate in real time to accommodate changes in billet properties; and the use of thermodynamic simulation software to predict the impact of the heating rate on grain growth, reducing trial-and-error costs. Environmental protection is achieved by optimizing the heating cycle and energy consumption to reduce energy waste. The effect of heating rate on grain growth is scientifically controlled and experimentally verified, providing a guarantee for the microstructure optimization and performance

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stability of tungsten alloy bars, ensuring their high reliability in aerospace counterweights, medical shielding components and electronic heat dissipation substrates.

3.2.1 Sintering temperature and atmosphere control

Sintering temperature and atmosphere control are core control points in the tungsten alloy bar production process, directly affecting the material's density, microstructure, and mechanical properties. The sintering process uses high-temperature treatment to combine the tungsten particles in the pressed billet with binder elements such as nickel, iron, and copper to form a high-density composite material. The sintering temperature must be precisely controlled within an appropriate range to promote liquid phase sintering and particle bonding, while avoiding excessive grain growth or material performance degradation caused by excessive temperatures. Atmosphere control uses a vacuum or hydrogen environment to reduce the effects of oxidation and impurities, ensuring the high purity and performance stability of the material. Sintering temperature and atmosphere control need to be optimized according to the composition and application scenarios of the tungsten alloy. For example, tungsten-nickel-iron alloys require higher temperatures to ensure high strength, while tungsten-copper alloys require moderate temperatures to maintain thermal conductivity. The process requires the use of a high-precision sintering furnace equipped with a temperature and atmosphere monitoring system to ensure parameter stability.

3.2.1.3 Leakage Detection and Atmosphere Stability Assurance for Vacuum Sintering

Leak detection and ensuring atmosphere stability during vacuum sintering are critical control points for ensuring the sintering quality of tungsten alloy bars, directly impacting the material's purity, density, and performance stability. Vacuum sintering utilizes heating in a low-pressure environment to reduce interference from oxygen and other gases, prevent oxidation, and promote the bonding of tungsten particles with binder elements, resulting in a highly dense microstructure. Leaks can allow oxygen or other impurities to enter the sintering furnace, triggering oxidation reactions and creating oxide defects, which can reduce the material's strength, toughness, and conductivity. Therefore, leak detection and ensuring atmosphere stability are core aspects of vacuum sintering.

The leak detection process includes the following steps: First, before sintering begins, the vacuum level in the sintering furnace is checked using a high-precision vacuum gauge to ensure that the target vacuum level is achieved. During the inspection process, the integrity of the furnace, seals, and piping is inspected. A helium mass spectrometer leak detector is used to scan for potential leaks and locate small leaks. During the sintering process, vacuum level changes are monitored in real time, and the vacuum pump operation is adjusted via an automated control system to maintain a stable atmosphere. Ensuring atmosphere stability also requires regular calibration of the vacuum system to ensure pump efficiency and sealing performance. The process involves placing the pressed billet in the vacuum sintering furnace, evacuating the vacuum, and heating it according to a heating curve. The vacuum level and furnace atmosphere are continuously monitored to prevent leaks from causing oxidation. Optimization measures include the use of an automated vacuum monitoring system to provide real-time alarms for abnormal conditions and regular maintenance of furnace seals to extend equipment life. Environmental protection

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is achieved by optimizing vacuum pump energy consumption and reducing exhaust emissions. Strictly controlled leak detection and atmosphere stability during vacuum sintering ensure the high purity and stable performance of tungsten alloy bars, making them particularly suitable for the production of aerospace counterweights and medical shielding components.

3.2.1.4 Air Velocity Control and Tail Gas Treatment for Hydrogen Sintering

Airflow velocity control and exhaust gas treatment during hydrogen sintering are crucial for ensuring the sintered quality of tungsten alloy bars, directly impacting the reduction effect, microstructure, and environmental performance. Hydrogen sintering utilizes the reducing effect of hydrogen to remove oxides from the billet, promoting particle bonding and densification. It is suitable for tungsten alloy bars requiring high toughness and electrical conductivity (such as tungsten-copper alloys). Airflow velocity must be precisely controlled to ensure even hydrogen distribution and sufficient contact with the billet surface, thereby improving reduction efficiency. Exhaust gas treatment is crucial for environmental performance, reducing environmental pollution by treating the water vapor and impurities generated during the sintering process.

The airflow rate control process includes the following steps: First, the hydrogen flow rate range is determined based on the billet size and sintering furnace capacity. The airflow rate is then adjusted using a flow controller to ensure a uniform atmosphere within the furnace. The airflow rate must be optimized based on the alloy composition. For example, tungsten-copper alloys require a faster flow rate to enhance thermal conductivity, while tungsten-nickel-iron alloys require a moderate flow rate to balance reduction and densification. During the sintering process, a gas analyzer monitors the furnace atmosphere and adjusts the flow rate in real time to maintain a reducing environment. The exhaust gas treatment process involves removing water vapor from the sintering furnace exhaust through a condenser. Residual impurities are then treated through filters and catalytic devices to ensure emissions meet environmental standards (such as GB/T 30509). The process involves placing the billet in a hydrogen sintering furnace, introducing high-purity hydrogen, and heating according to a heating curve. The airflow rate and exhaust gas composition are monitored to ensure the reduction effect and environmental compliance.

Optimization measures include the use of an automated gas control system to adjust airflow velocity and monitor exhaust gas composition in real time; and the adoption of efficient exhaust gas treatment equipment to recover hydrogen and reduce costs. Environmental protection is achieved by optimizing hydrogen usage and exhaust gas treatment, reducing emissions and energy consumption. Scientifically designed and rigorously implemented airflow velocity control and exhaust gas treatment during hydrogen sintering ensure low oxide content and high performance in tungsten alloy bars, making them particularly suitable for the production of electronic electrodes and heat dissipation substrates.

3.2.2 Tungsten Alloy Bar Processing Precision and Surface Quality Assurance

Processing accuracy and surface quality assurance are key control points in the subsequent processing of tungsten alloy bars, which directly affect their dimensional accuracy, surface finish and functional

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performance. They are suitable for high-precision applications such as aerospace counterweights, medical shielding components and electronic connectors. The high hardness and strength of tungsten alloy bars make them difficult to process, but by optimizing the cutting, grinding and surface treatment processes, high precision and high quality can be achieved. Processing accuracy must ensure that dimensional tolerances and form and position tolerances meet design requirements, and the surface quality must achieve low roughness to improve wear resistance and conductivity. The processing process requires the use of high-precision equipment such as CNC machine tools and grinders, and strict testing and control measures are used to ensure consistency. Environmental protection is achieved by recycling processing waste and optimizing energy consumption, in line with green manufacturing requirements.

3.2.2.1 Dimensional tolerance measurement tools and inspection frequency

The measurement tools and inspection frequency for dimensional tolerances are central to controlling the machining precision of tungsten alloy bars, directly impacting their geometric accuracy and assembly performance. They are suitable for high-precision applications such as aerospace counterweights, medical shielding components, and electronic heat dissipation substrates. Dimensional tolerances are typically required to reach ± 0.01 mm or higher to meet complex assembly and functional requirements. Commonly used measuring tools include coordinate measuring machines (CMMs), laser rangefinders, high-precision micrometers, and profilometers, capable of accurately measuring the length, diameter, straightness, and form and position tolerances of tungsten alloy bars. CMMs provide high-precision measurements through three-dimensional scanning, suitable for complex shapes; laser rangefinders are suitable for fast, non-contact measurement; and micrometers and profilometers are used for surface dimension and form detection.

The frequency of inspections must be determined based on production scale and quality requirements. In mass production, sampling inspections are typically used, with a certain percentage of samples from each batch taken for full-size measurement to ensure tolerances meet design requirements. Key components (such as aerospace counterweights) require 100% full inspection, using automated measuring equipment to improve efficiency. The inspection process includes the following steps: After processing, use a detergent to remove surface oil and ensure measurement accuracy; measure key dimensions using a CMM or micrometer, record the data, and compare it to design tolerances; use statistical process control (SPC) to analyze measurement results and monitor processing stability. Optimization measures include the use of automated measurement systems, integrated online inspection equipment for real-time feedback on dimensional deviations, and regular calibration of measurement tools to ensure accuracy. Environmental protection is achieved by reducing inspection waste and optimizing equipment energy consumption. Scientifically selected and strictly implemented dimensional tolerance measurement tools and inspection frequency guarantee the high precision and reliability of tungsten alloy bars, ensuring their application performance in the aerospace and electronics fields.

3.2.2.2 Control methods for geometric and positional tolerances

Controlling geometric tolerances is a crucial step in ensuring the machining accuracy of tungsten alloy

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bars, directly impacting their geometry and assembly performance. These tolerances are suitable for high-precision applications such as aerospace counterweights, medical shielding components, and electronic heat dissipation substrates. Geometric tolerances, including parallelism, perpendicularity, roundness, coaxiality, and position, must meet stringent standards (such as ISO 1101 or GB/T 1182) to ensure component assembly accuracy and functional reliability. The high hardness and complex shape of tungsten alloy bars make geometric tolerance control challenging, requiring high-precision machining equipment and rigorous process control.

The geometric tolerance control method includes the following steps: First, determine the geometric tolerance requirements based on the design drawings, use CAD/CAM software for processing path planning, and optimize the cutting and grinding processes to reduce geometric deviations. During the processing, high-precision CNC machine tools (such as five-axis CNC machine tools) are used, equipped with high-rigidity fixtures and precision positioning systems to ensure the stability of the workpiece during processing. Cutting parameters need to be optimized, such as using low feed rates and moderate cutting speeds to reduce the effects of vibration and thermal deformation on geometric tolerances. After processing is completed, use a three-dimensional coordinate measuring machine (CMM) or laser scanner to measure the geometric tolerances, record the data, and compare it with the design standards. During the inspection process, ensure that the workpiece surface is clean to avoid oil or particles affecting the measurement accuracy.

Optimization measures include the use of adaptive machining technology, which dynamically adjusts parameters to control geometric deviations through real-time monitoring of machining forces and vibrations. High-precision fixture design, combined with finite element analysis to simulate workpiece forces, reduces clamping deformation. Quality control utilizes statistical process control (SPC) to analyze geometric tolerance data and monitor machining stability. Environmental protection is achieved through chip recycling and optimized machining energy consumption, reducing resource waste. Scientifically designed and rigorously implemented geometric tolerance control methods guarantee the high geometric accuracy and assembly performance of tungsten alloy bars, ensuring their reliable application in aerospace and electronics.

3.2.2.3 Surface defect detection and repair process

Surface defect detection and repair are critical aspects of ensuring the surface quality of tungsten alloy bars, directly impacting their wear resistance, corrosion resistance, and functional performance. Surface defects, including scratches, cracks, pores, and inclusions, can be caused by cutting, grinding, or internal material defects. These defects require high-precision inspection and repair processes to meet the stringent requirements of aerospace counterweights and medical shielding components. These inspection and repair processes combine advanced equipment and scientific methods to ensure surface quality meets the roughness standard of Ra 0.2-0.4 μm .

The surface defect detection process includes the following steps: First, use an optical microscope or scanning electron microscope (SEM) to inspect the surface of the tungsten alloy bar to identify

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microscopic defects such as scratches and cracks, with a magnification of usually 50-500 times; for internal defects, use ultrasonic testing or X-ray flaw detectors to scan and detect pores or inclusions. The inspection must be carried out in a clean environment to avoid dust or oil contamination affecting the results. The inspection frequency is determined according to the production scale. Key components require 100% inspection, and sampling inspection can be used for mass production. The repair process is selected according to the type of defect: for shallow scratches, repair by fine grinding or polishing, using a diamond grinding wheel or polishing liquid to restore the surface finish; for small cracks, they can be repaired by laser cladding or micro welding to fill the cracks and maintain material properties; for pores or inclusions, it is necessary to evaluate whether they affect the performance. Minor defects can be concealed by polishing, while serious defects require rework or scrapping.

Optimization measures include the use of automated inspection equipment, such as online optical scanning systems, to improve inspection efficiency and accuracy; and the adoption of non-destructive repair technologies, such as plasma spraying, to reduce material waste. Environmental protection is achieved through the recycling of repair waste and the optimization of process energy consumption, meeting green manufacturing requirements. Surface defect detection and repair processes utilize scientific methods and strict control, ensuring the high surface quality and functional performance of tungsten alloy bars, ensuring their reliability in electronic connectors and medical shielding components.

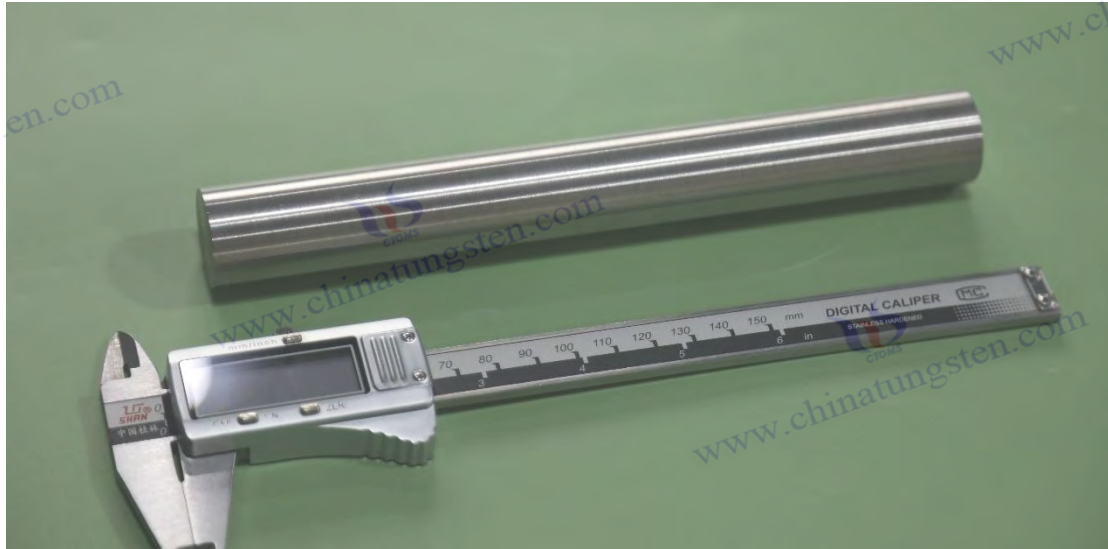
3.2.2.4 Surface treatment and quality acceptance standards

Surface treatment and quality acceptance standards are the final steps in ensuring tungsten alloy bar processing quality, directly impacting its corrosion resistance, wear resistance, and functional adaptability. Suitable for aerospace structural components, electronic heat dissipation substrates, and medical shielding components, surface treatment optimizes the surface properties of tungsten alloy bars through chemical or physical methods. Common processes include polishing, electroless plating (such as nickel plating), physical vapor deposition (PVD) coating, and sandblasting. Quality acceptance standards ensure that the surface treatment and overall quality meet design requirements and industry standards (such as ASTM B777 or GB/T 3459) through a rigorous testing process.

The surface treatment process includes the following steps: Select a treatment process based on application requirements. For example, polishing improves surface finish and is suitable for electronic connectors; electroless nickel plating enhances corrosion resistance and is suitable for medical shielding components; and PVD coatings (such as TiAlN) improve wear resistance and are suitable for industrial molds. Ultrasonic cleaning is required to remove surface oil and particles before treatment to ensure the treatment is effective. During treatment, process parameters such as polishing solution concentration, coating thickness, or coating deposition rate must be controlled to ensure uniformity and adhesion. Quality acceptance criteria include surface roughness, coating adhesion (verified by cross-cut testing), corrosion resistance (assessed by salt spray testing), and appearance consistency (absence of color difference or defects). The acceptance process uses a surface profilometer to measure roughness, a salt spray tester to test corrosion resistance, and a microscope to inspect surface defects. Data is recorded to support quality traceability.

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Optimization measures include the use of automated surface treatment equipment, such as robotic polishing systems, to improve consistency and efficiency; and the implementation of an online quality monitoring system to provide real-time feedback on surface treatment results. Environmental protection is achieved through the recycling and treatment of waste liquids and materials, and the optimization of chemical usage to reduce environmental impact. Scientifically designed and strictly enforced surface treatment and quality acceptance standards ensure the high corrosion resistance and functional performance of tungsten alloy bars, ensuring their reliable application in aerospace, medical, and electronics fields.



CTIA GROUP LTD Tungsten Alloy Bar

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www.ctia.com.cn

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

Chapter 4 Application Fields of Tungsten Alloy Bar

Tungsten alloy rods, with their exceptional high density, high strength, high temperature resistance, and corrosion resistance, have demonstrated widespread application value in multiple high-tech fields. Their unique combination of properties enables them to meet the stringent material performance requirements of industries such as aerospace, medical, electronics, and industrial manufacturing. Tungsten alloy rods are optimized through powder metallurgy processes, combining the high melting point and high density of tungsten with the toughness and functionality of elements such as nickel, iron, and copper to form a composite material with both mechanical properties and functional adaptability. Their non-toxicity and recyclability further enhance their applicability in scenarios with strict environmental requirements, meeting the demands of modern industry for sustainable development. Tungsten alloy rods have diverse applications, ranging from high-precision counterweights to high-temperature-resistant components, and require rigorous production processes and performance testing to ensure quality stability.

4.1 Application of Tungsten Alloy Bars in Military and Aerospace Fields

Tungsten alloy bars are used in the military and aerospace industries thanks to their high density, high strength, and excellent mechanical properties, enabling them to meet high-load, dynamic, and high-precision requirements. The aerospace industry places extremely high demands on material stability, reliability, and environmental adaptability. Through optimized composition and production processes, tungsten alloy bars maintain stable performance under extreme conditions, making them widely used in counterweights, structural components, and functional parts. Their high density provides a significant weight-to-volume ratio, making them suitable for equipment requiring precise balancing; their high strength and toughness ensure structural integrity in high-stress environments. The non-toxicity and recyclability of tungsten alloy bars give them advantages in the aerospace industry, where green manufacturing and environmental protection are stringent requirements. During production, powder metallurgy processes precisely control the raw material ratio, sintering conditions, and subsequent processing to ensure consistent and high-quality performance. Applications require strict adherence to industry standards and high-precision testing to verify their performance and meet the high reliability requirements of aerospace equipment.

4.1.1 Density requirements for tungsten alloy bars used in armor-piercing projectile cores

The density requirement for tungsten alloy rods used in armor-piercing projectile cores is a core performance indicator for its application in the military industry, directly determining its functional performance in high-performance applications. The high density of tungsten alloy rods enables them to provide significant weight within a limited volume, which is crucial for components that require efficient kinetic energy transfer. The density requirement mainly stems from the need for tungsten alloy rods to provide sufficient mass in specific scenarios to ensure their stability and functionality in dynamic environments. Tungsten's high density is its natural advantage. By adding binder elements such as nickel and iron to form a composite material, it is possible to maintain high density while optimizing other properties such as toughness and processability. The density directly affects the weight-to-volume ratio

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of the tungsten alloy rod, which in turn affects its applicability in high-precision equipment.

During the production process, density requirements are achieved through strict raw material selection and process control. Tungsten powder selection must ensure high purity and appropriate particle size, and initial density is optimized through mixing and pressing in the powder metallurgy process. The sintering process is key to achieving high density. By controlling the sintering temperature and atmosphere, the bonding of tungsten particles with binder elements is promoted, forming a dense microstructure. Vacuum sintering or hydrogen sintering can reduce porosity and oxides, ensuring the material's high density and stable performance. Subsequent processing steps, such as cutting and grinding, further optimize size and surface quality to ensure uniform density distribution. During testing, a high-precision densitometer (e.g., using the Archimedes principle) is used to verify material density, combined with microstructural analysis (e.g., scanning electron microscope (SEM)) to ensure the absence of internal defects. Density requirements must also take environmental considerations into account. By optimizing the production process to reduce waste generation and meet green manufacturing standards.

The high density of tungsten alloy rods, precisely matched to application requirements, provides reliable support for their use in the military industry. Its stable density not only enhances component performance but also optimizes equipment design by reducing volume requirements. Quality control and testing during production ensure uniform and consistent density, laying the foundation for high-performance applications. Scientifically designed and rigorously enforced density requirements ensure widespread application in high-tech fields, driving improvements in the performance of related equipment.

4.1.2 Tensile Strength Standards for Tungsten Alloy Strips in Armor-Piercing Projectile Cores

The tensile strength standard is a crucial performance indicator for tungsten alloy rods used in armor-piercing projectile cores in military applications, directly impacting their structural integrity and reliability in high-stress environments. Tungsten alloy rods must withstand dynamic loads and stress under extreme conditions, and their high tensile strength ensures the material remains stable in complex environments, preventing breakage or deformation. Tungsten itself has a high hardness, but the addition of binder elements such as nickel and iron significantly improves its toughness and tensile strength, making it suitable for high-load scenarios. The development of tensile strength standards requires reference to industry specifications to ensure that the material's properties meet the requirements of specific applications while also balancing processability and cost-effectiveness.

During the production process, achieving tensile strength depends on optimizing the raw material ratio, sintering process, and heat treatment. High-precision mixing equipment is used to uniformly mix tungsten powder and binder elements, ensuring microstructural uniformity. The sintering process controls temperature and atmosphere to promote liquid-phase sintering, forming a dense particle bond and enhancing tensile strength. Heat treatment processes (such as annealing or solution treatment) further eliminate internal stresses, optimize grain structure, and improve toughness and tensile properties. Subsequent processing steps precisely control cutting parameters and surface treatment to avoid the introduction of microcracks or stress concentrations, ensuring the stability of tensile strength. During

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testing, a universal material testing machine is used to conduct tensile tests, record stress-strain curves, and verify that the tensile strength meets standard requirements. Microstructural analysis (such as SEM) is used to examine grain size and defects to ensure consistent performance.

Optimizing tensile strength standards requires comprehensive consideration of material composition and process parameters. For example, increasing nickel content can improve toughness and tensile strength, but may slightly reduce density, and performance needs to be balanced according to the application scenario. Automated equipment and online monitoring systems in the production process can improve process control accuracy and reduce performance fluctuations. Environmental protection is achieved by recycling processing waste and optimizing energy consumption, meeting green manufacturing requirements. The tensile strength of tungsten alloy bars is scientifically designed and strictly controlled, ensuring its reliability in high-stress environments. Its excellent mechanical properties support high-performance applications in the military industry, provide key support for the safety and stability of equipment, and reflect the precise matching of materials and applications.

4.1.3 Dimensional Accuracy Control of Tungsten Alloy Bars for Spacecraft Counterweights

Dimensional accuracy control is a key performance requirement for tungsten alloy bars used as spacecraft counterweights in aerospace applications, directly impacting their performance in complex assembly and dynamic balancing. Spacecraft counterweight components require precise geometry and dimensions to ensure even weight distribution and maintain stability during high-precision operation. The high density of tungsten alloy bars enables them to provide significant weight within a small volume, while high dimensional accuracy ensures their compatibility with complex system assemblies. Dimensional accuracy control involves strict management of length, diameter, straightness, and geometric tolerances, meeting the stringent standards of the aerospace industry.

During the production process, dimensional accuracy control begins with press forming, where high-precision mold design ensures the initial shape accuracy of the blank. Cold pressing or isostatic pressing processes achieve high density and uniform shape, laying the foundation for subsequent processing. The sintering process reduces blank deformation and ensures dimensional stability by controlling shrinkage and temperature uniformity. Subsequent processing steps, such as cutting and grinding, utilize high-precision CNC machines and specialized tools (such as PCD or CBN tools) for finishing. Surface treatments, such as polishing, further optimize surface finish and reduce friction and assembly errors. During inspection, coordinate measuring machines (CMMs) and laser scanners are used to measure dimensional and geometric tolerances. Statistical process control (SPC) is used to analyze process stability and ensure that each batch meets product specifications. Optimizing dimensional accuracy control requires a comprehensive consideration of processing equipment, process parameters, and testing methods. Automated processing equipment and online monitoring systems provide real-time feedback on dimensional deviations, allowing dynamic parameter adjustments to improve accuracy. Fixture design is optimized through finite element analysis to ensure workpiece stability and minimize deformation during processing. Environmental protection is achieved through recycling processing waste and optimizing energy consumption, meeting green manufacturing standards. Tungsten alloy bar dimensional

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accuracy control, achieved through scientific design and rigorous execution, ensures high-precision assembly and dynamic balancing of spacecraft counterweight components. Its high-precision properties support the reliability and performance optimization of aerospace equipment, providing critical support for the design and operation of complex systems, and demonstrating the significant value of tungsten alloy bar in the high-tech field.

4.1.4 Operating Temperature Threshold of Tungsten Alloy Bars for High-Temperature-Resistant Spacecraft Components

The application of tungsten alloy bars in high-temperature resistant components of spacecraft relies on its excellent high-temperature resistance, which enables it to maintain structural integrity and functional stability in extreme thermal environments. Spacecraft components, such as propulsion systems or high-temperature exposed structures, need to withstand extreme temperatures. Tungsten alloy bars, due to their high melting point and optimized microstructure, can maintain mechanical properties at high temperatures and avoid thermal degradation or deformation. The high melting point of tungsten is the core of its high-temperature resistance. The toughness and thermal stability of the material are further optimized by adding elements such as nickel, iron or copper, enabling it to adapt to complex working conditions such as cyclic thermal loads and long-term high-temperature exposure. The determination of the operating temperature threshold requires a comprehensive consideration of the material's thermal stability, mechanical properties and specific application scenarios to ensure its reliability in spacecraft operation.

During the production process, achieving high-temperature resistance begins with the selection and proportioning of raw materials. High-purity tungsten powder is mixed with binder elements such as nickel, iron, or copper in appropriate proportions and a powder metallurgy process is used to form a uniform microstructure. The sintering process is a critical step. By precisely controlling the temperature and atmosphere (such as vacuum or hydrogen sintering), the bonding of the tungsten particles and the binder is promoted, forming a high-density material, reducing porosity and defects to improve thermal stability. Heat treatment processes (such as annealing) further optimize the microstructure, eliminate internal stresses, and enhance thermal fatigue resistance. For example, the addition of nickel and iron can increase the material's toughness, making it less susceptible to cracking under high-temperature cyclic loading; the addition of copper improves thermal conductivity and aids in heat dissipation. High-precision cutting and surface treatment during processing ensure the dimensional accuracy and surface quality of components and reduce thermal stress concentration.

Quality control runs through the entire production process, and the material's temperature resistance is verified through high-temperature mechanical property tests and thermal cycle tests. These tests simulate the high-temperature environment of spacecraft operation and evaluate the material's performance stability under long-term heat exposure. Surface treatment processes, such as anti-oxidation coatings, can further improve the material's durability in high-temperature environments and prevent oxidation or thermal corrosion. Environmental protection is an important consideration in the production process. By optimizing energy consumption in sintering and heat treatment, and recycling processing waste, resource

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waste is reduced and green manufacturing standards are met. The high-temperature resistance of tungsten alloy bars is precisely matched to the requirements of high-temperature components in spacecraft, supporting their reliable application in extreme environments. This excellent thermal stability has promoted advances in spacecraft design and operation, and provided a reliable material foundation for the development of high-performance propulsion systems and structural components.

4.2 Application of Tungsten Alloy Bars in Medical Field

Tungsten alloy rods are used in the medical field primarily due to their high density, radiation resistance, and non-toxicity, meeting the stringent requirements of radiation shielding, medical device components, and precision tools. The medical industry has extremely high standards for material safety, reliability, and functionality. Tungsten alloy rods, with their high atomic number and excellent radiation absorption capacity, are ideal for use in radiotherapy and imaging equipment. Compared to traditional lead-based materials, their non-toxicity makes them safer in medical environments, reducing health risks for patients and medical staff. Their high density enables them to provide effective radiation shielding in a compact package, making them suitable for compact medical device designs. During production, powder metallurgy processes optimize raw material ratios and sintering conditions to ensure high material density and stable performance. Subsequent processing, through high-precision cutting and surface treatment, enhances corrosion resistance and surface finish, meeting the hygiene and precision requirements of the medical field. Strict adherence to industry standards and high-precision testing verify performance during application ensure reliability in radiotherapy and imaging equipment.

4.2.1 Lead Equivalent Requirements for Tungsten Alloy Bars for Radiotherapy Shielding

The lead equivalent requirement of tungsten alloy strips for radiotherapy shielding is a core performance indicator for its application in the medical field and directly determines its effectiveness in radiation protection. Radiotherapy equipment, such as linear accelerators or gamma ray devices, requires efficient shielding of high-energy radiation to protect the safety of patients, medical staff, and surrounding equipment. The high density and high atomic number of tungsten alloy strips make them excellent in absorbing and scattering radiation, and can achieve a shielding effect equivalent to that of lead in a smaller volume. The lead equivalent requirement defines the radiation attenuation ability of tungsten alloy strips at a specific thickness that is equivalent to that of lead, ensuring that they meet safety standards in the medical field while supporting compact equipment design.

During the production process, the achievement of lead equivalent requirements depends on the formation of high density and uniform microstructure. High-purity tungsten powder is selected and combined with binder elements such as nickel and copper to prepare high-density alloys through powder metallurgy. The sintering process is key. By controlling the temperature and atmosphere (such as vacuum or hydrogen sintering), the bonding of tungsten particles and binder is promoted, and the porosity is reduced to improve density and radiation shielding performance. The precision machining process uses high-precision cutting and grinding to ensure that the size and surface quality of the tungsten alloy bars meet the design requirements, facilitating assembly and use in radiotherapy equipment. Quality control

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uses radiation attenuation testing to simulate radiation exposure in a clinical environment and verify whether the lead equivalent performance of the material meets the standards. High-precision instruments, such as radiation dosimeters, are required during the test to record the shielding effect and compare it with the design requirements.

Environmental protection is crucial in production. By optimizing energy consumption and reducing waste generation during sintering and processing, we meet green manufacturing requirements. The non-toxicity of tungsten alloy rods makes them particularly advantageous for medical applications, avoiding the potential health and environmental risks of lead-based materials. Meeting lead equivalency requirements through scientific design and strict control ensures that tungsten alloy rods provide effective radiation protection in radiotherapy equipment. This excellent shielding performance supports the design of compact medical devices, improves the safety and precision of radiotherapy, and provides important support for patient care and medical technology advancements.

4.2.2 Radiation Attenuation Coefficient of Tungsten Alloy Strips for Radiotherapy Shielding

The radiation attenuation coefficient (RAC) of tungsten alloy strips used in radiotherapy shielding is a key performance indicator for its medical applications. It reflects the material's ability to attenuate the intensity of high-energy radiation, such as X-rays or gamma rays. This coefficient determines the effectiveness of the strips in shielding radiation in radiotherapy equipment, ensuring the safety of patients and medical staff. Tungsten's high atomic number and high density enable it to effectively scatter and absorb radiation, reducing radiation penetration and making it suitable for compact shielding components. The RAC is influenced by material composition, density, and microstructure, requiring precise production processes and rigorous quality testing to meet the stringent requirements of the medical field.

During the production process, optimizing the radiation attenuation coefficient begins with the selection and proportioning of raw materials. High-purity tungsten powder is mixed with nickel, copper, and other elements in appropriate proportions and formed into a high-density alloy through a powder metallurgy process. The sintering process ensures the material's high density and low porosity by controlling high temperature and atmosphere conditions, enhancing radiation absorption capacity. Precision machining optimizes the dimensional accuracy and surface finish of components through high-precision cutting and surface treatment, ensuring compatibility with radiotherapy equipment. Quality control utilizes radiation attenuation testing, using a high-energy radiation source to simulate a clinical environment, measure the material's attenuation coefficient, and verify its performance. Test data is compared with industry standards to ensure that the material meets shielding requirements.

Environmental protection is a key consideration during the production process. Environmental impact is reduced by optimizing sintering and processing energy consumption, as well as recycling waste materials. The non-toxicity of tungsten alloy rods makes them an ideal alternative to lead-based materials, reducing the environmental risks associated with the production and use of medical devices. The excellent radiation attenuation coefficient achieved through scientific processes and rigorous testing provides highly effective radiation protection for radiotherapy shielding components. This performance supports

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the high safety and precision of medical equipment, promotes advancements in radiotherapy technology, and provides a safer treatment environment for patients.

4.2.3 Purity Standards for Tungsten Alloy Bars for CT Tungsten Targets

The purity standard of tungsten alloy rods used in CT tungsten targets is a key performance indicator for their use in medical imaging equipment, directly impacting the efficiency of X-ray generation and the long-term stability of the equipment. Tungsten targets in CT scanners must produce stable X-rays under high-energy electron bombardment, requiring high material purity to ensure consistent radiation output and reliable equipment operation. The high purity of tungsten alloy rods reduces the impact of impurities on X-ray generation, preventing material degradation or equipment failure. Its high density and high atomic number make it an excellent performer in X-ray generation, while strict control of purity standards ensures the material's stability in high-intensity operating environments. Purity requirements not only impact material performance but also the safety of medical equipment and patient health, requiring high-precision production and testing methods to achieve.

During the production process, the realization of purity standards begins with the selection of raw materials. High-purity tungsten powder is the basis for manufacturing CT tungsten targets. It needs to go through chemical purification and screening processes to remove impurities such as oxygen, carbon, and sulfur to ensure the high purity and stability of the material. The purity of binder elements such as nickel, iron, or copper also needs to be strictly controlled to avoid the introduction of additional impurities. The powder metallurgy process ensures the uniformity and purity of the raw materials through precise proportioning and mixing. The sintering process is a key link. Through vacuum or hydrogen sintering environment, the formation of oxides is reduced, and the uniform bonding of tungsten particles and binder is promoted to form a high-density microstructure. The temperature and atmosphere need to be controlled during the sintering process to avoid the introduction of impurities or fluctuations in material properties. Subsequent processing links use high-precision cutting and polishing to ensure the surface finish and dimensional accuracy of the tungsten target and reduce the interference of residual impurities on X-ray generation.

Quality control utilizes high-precision analytical techniques, such as inductively coupled plasma mass spectrometry or X-ray fluorescence spectroscopy (XRF), to detect impurity levels in tungsten alloy rods and ensure compliance with medical industry standards. Performance testing simulates the operating environment of CT scans to assess X-ray output stability and material durability, verifying compliance with purity standards. Environmental protection is paramount in production, and environmental impact is minimized through optimization of sintering and processing energy consumption, waste recycling, and exhaust gas treatment. The non-toxicity of tungsten alloy rods makes them an ideal alternative to lead-based materials, reducing health risks in the production and use of medical devices. Through scientific design and strict control, the purity standards of tungsten alloy rods for CT tungsten targets ensure efficient X-ray generation and equipment reliability, supporting high-precision diagnostics in CT imaging equipment, promoting advancements in medical technology, and providing patients with a safer and more reliable diagnostic experience.

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4.2.4 High temperature impact resistance of CT tungsten target tungsten alloy bar

The high-temperature impact resistance of tungsten alloy bars used in CT tungsten targets is a critical performance indicator for their use in medical imaging equipment, directly impacting their stability and service life under high-energy electron bombardment. Tungsten targets in CT scanning equipment must withstand the instantaneous impact and high thermal loads of high-intensity electron beams, requiring the material to maintain structural integrity and performance stability under high temperatures and rapid thermal cycling. Tungsten's high melting point and excellent thermal stability make it an ideal material for CT tungsten targets. The addition of elements such as nickel, iron, or copper further optimizes the material's toughness and thermal shock resistance. Achieving high-temperature impact resistance requires precise production processes and rigorous quality testing to ensure the reliability of the tungsten alloy bars in extreme operating environments.

During the production process, optimizing high-temperature impact resistance begins with the raw material ratio. High-purity tungsten powder is mixed with binder elements in appropriate proportions and a uniform microstructure is formed through powder metallurgy. The sintering process, by controlling the high temperature and atmosphere (such as vacuum or hydrogen sintering), promotes the bonding of tungsten particles and the binder, forming a high-density, low-porosity material with enhanced thermal shock resistance. Heat treatment processes (such as annealing or solution treatment) further optimize the microstructure, eliminate internal stresses, and improve the material's toughness and thermal fatigue resistance. For example, the addition of nickel and iron can enhance the material's crack resistance, making it less susceptible to cracking under high-temperature impact; the addition of copper increases thermal conductivity, facilitates rapid heat dissipation, and reduces thermal stress. During the processing phase, high-precision cutting and surface polishing are used to optimize the surface quality of the tungsten target, reduce thermal stress concentration points, and improve high-temperature impact resistance.

Quality control utilizes high-temperature shock testing and thermal cycling testing to simulate the high-energy electron bombardment environment experienced during CT equipment operation and assess the material's performance stability. During testing, surface temperature changes are monitored using infrared thermometers, and microstructures are examined using microscopes to verify the material's integrity under high-temperature shock. Surface treatments, such as antioxidant coatings, further enhance the material's durability in high-temperature environments, preventing oxidation or thermal corrosion. Environmental protection is achieved by optimizing sintering and heat treatment energy consumption and recycling processing waste, meeting green manufacturing requirements. The high-temperature shock resistance of tungsten alloy bars, proven through scientific processes and rigorous testing, ensures the reliability of CT tungsten targets in high-intensity operating environments.

4.3 Application of Tungsten Alloy Bars in Industrial Manufacturing

Tungsten alloy rods are used in industrial manufacturing thanks to their high density, high strength, high-temperature resistance, and wear resistance, meeting the diverse material performance requirements of

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industrial equipment. Industrial manufacturing involves high-temperature processes, wear-resistant components, and precision tools. Tungsten alloy rods, thanks to their excellent mechanical and functional properties, are widely used in components such as molds, cutting tools, heat sinks, and wear-resistant liners. Their high density makes them suitable for industrial equipment requiring weight balancing, such as vibration suppression devices, while their high-temperature and wear resistance enable them to maintain stable performance in high-temperature processes and heavy-load environments. The non-toxicity and recyclability of tungsten alloy rods give them advantages in industrial fields with strict environmental requirements, aligning with the trend of green manufacturing. During production, powder metallurgy processes optimize the raw material ratio, sintering conditions, and subsequent processing to ensure the material's high density and stable performance. High-precision testing is required to verify performance during application to meet the reliability and durability requirements of industrial manufacturing.

In industrial manufacturing, typical applications for tungsten alloy rods include high-precision molds and cutting tools. The high hardness and wear resistance of tungsten alloy rods enable them to withstand high-load cutting and forming processes, extending the service life of molds and cutting tools. For example, in metal forming or plastic injection molding, tungsten alloy molds resist wear and deformation, ensuring machining accuracy. Its high-temperature resistance makes it suitable for high-temperature processes, such as supports in heat treatment furnaces or structural components in high-temperature processing equipment. The high density of tungsten alloy rods also makes them excellent for industrial vibration suppression devices, reducing equipment vibration and improving operational stability through precise weight distribution. During production, raw material selection and proportioning must be optimized according to application requirements. For example, tungsten-nickel-iron alloy is suitable for high-strength molds, while tungsten-copper alloy is suitable for high-thermal conductivity heat dissipation substrates. The sintering process ensures high material density and a uniform microstructure by controlling the temperature and atmosphere. Subsequent processing, through high-precision cutting, grinding, and surface treatment, optimizes dimensional accuracy and surface finish to meet the assembly requirements of industrial equipment.

Quality control utilizes a variety of testing methods, such as hardness testing, tensile testing, and surface roughness measurement, to verify the material's mechanical properties and machining accuracy. High-temperature performance testing and wear resistance testing simulate industrial operating environments to ensure the material's reliability in real-world applications. Environmental protection is achieved through optimized production energy consumption and waste recycling, reducing resource waste and environmental impact. The application of tungsten alloy rods in industrial manufacturing, through their excellent performance and scientific process control, supports the development of high-precision, high-durability equipment.

4.3.1 Operating temperature of tungsten alloy strips for high temperature furnace heating elements

The operating temperature of tungsten alloy bars used as heating elements in high-temperature furnaces is a core performance indicator for their application in industrial manufacturing, directly determining

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their reliability and durability in high-temperature process environments. High-temperature furnaces are widely used in processes such as metal heat treatment, ceramic sintering, and material synthesis, requiring heating elements to maintain structural stability and functional integrity under extremely high temperatures. Tungsten alloy bars, with their high melting point and excellent thermal stability, are ideal materials for high-temperature furnace heating elements. Tungsten's high melting point ensures that it is not easily melted or deformed in high-temperature environments, while the addition of elements such as nickel, iron, or copper further optimizes the material's toughness and resistance to thermal fatigue, enabling it to withstand long-term high-temperature exposure and thermal cycling. The determination of the operating temperature requires a comprehensive consideration of the material's thermal stability, mechanical properties, and specific process requirements to ensure its reliability in high-temperature furnace operation.

During the production process, achieving high-temperature performance begins with the selection of raw materials. High-purity tungsten powder is mixed with binder elements such as nickel, iron, or copper in appropriate proportions and a powder metallurgy process is used to form a uniform microstructure. The sintering process is a key step. Through vacuum or hydrogen sintering, the high temperature and atmosphere are controlled to promote the bonding of tungsten particles and the binder, forming a high-density material and reducing porosity to improve thermal stability. Heat treatment processes (such as annealing) optimize the microstructure, eliminate internal stresses, and enhance thermal fatigue resistance. For example, the addition of nickel and iron can increase the material's toughness, making it less susceptible to cracking under high-temperature cycles; the addition of copper improves thermal conductivity, aids heat dissipation, and reduces thermal stress. High-precision cutting and surface polishing during processing ensure the dimensional accuracy and surface quality of the heating element, reduce thermal stress concentration points, and improve high-temperature stability.

Quality control utilizes high-temperature performance testing and thermal cycling testing to simulate the operating environment of a high-temperature furnace and assess the material's performance stability under prolonged high-temperature exposure. During testing, surface temperature changes are monitored using infrared thermometers, and microstructures are examined using microscopes to verify the material's integrity under high temperatures. Environmental protection is achieved by optimizing sintering and heat treatment energy consumption and recycling processing waste, meeting green manufacturing standards. The high-temperature performance of tungsten alloy rods, proven through scientific processes and rigorous testing, provides reliable support for high-temperature furnace heating elements. Their excellent thermal stability promotes the efficiency and reliability of industrial high-temperature processes, providing a key enabler for advancements in materials processing and manufacturing technologies, and demonstrating the exceptional suitability of tungsten alloy rods for use in extreme environments.

4.3.2 Requirements for Anti-Oxidation Coatings on Tungsten Alloy Bars for High-Temperature Components

The requirements for the anti-oxidation coating of tungsten alloy bars used for high-temperature components are important performance indicators for their application in industrial manufacturing,

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directly affecting their durability and performance stability in high-temperature oxidizing environments. When high-temperature furnaces and other industrial equipment are in operation, the heating elements are often exposed to oxygen-containing atmospheres, which are prone to oxidation reactions, leading to surface degradation or performance degradation of the material. By applying an anti-oxidation coating, tungsten alloy bars can effectively prevent oxidative corrosion and extend their service life while maintaining their mechanical properties and functional characteristics at high temperatures. The selection and application of anti-oxidation coatings must be optimized according to the operating temperature, atmospheric conditions, and application scenarios to ensure adhesion and thermal stability between the coating and the substrate to meet the long-term operation requirements of equipment such as high-temperature furnaces.

During the production process, the realization of anti-oxidation coating involves the selection of coating materials and the application process. Commonly used coating materials include aluminum oxide, silicon nitride or silicon-based coatings. These materials have high thermal stability and oxidation resistance, and can form a protective layer at high temperatures to prevent oxygen from reacting with the tungsten alloy substrate. The coating application process includes physical vapor deposition (PVD), chemical vapor deposition (CVD) or thermal spraying. It is necessary to ensure that the coating is uniform, dense and tightly bonded to the substrate. Substrate preparation is the key. The tungsten alloy bar is formed into a high-density structure through a powder metallurgy process, and the surface is polished or sandblasted to improve the adhesion of the coating. The sintering and heat treatment processes optimize the microstructure of the substrate, reduce surface defects, and ensure the stability of the coating application. Before applying the coating, ultrasonic cleaning is required to remove surface oil and particles to ensure the quality of the coating.

Quality control utilizes high-temperature oxidation testing and coating adhesion testing to simulate the operating environment of a high-temperature furnace and evaluate the coating's oxidation resistance and durability. During testing, the coating surface and interface are examined using a scanning electron microscope (SEM) to verify integrity and adhesion. Coating thickness must be precisely controlled; excessive thickness can cause cracking, while excessive thinness may not provide adequate protection. Environmental protection is achieved by optimizing energy consumption and recycling waste materials during the coating application process, reducing chemical waste and exhaust emissions. Anti-oxidation coatings require scientific design and strict control to ensure the reliability of tungsten alloy bars in high-temperature oxidizing environments. This excellent oxidation resistance supports the long-term operation of high-temperature furnace heating elements, promotes the stability and efficiency of industrial high-temperature processes, and provides key support for the development of high-performance industrial equipment.

4.3.3 Hardness Index of Tungsten Alloy Bars for Mold Inserts

The hardness of tungsten alloy bars used in mold inserts is a core performance requirement for their application in industrial manufacturing, directly determining their durability and machining accuracy during high-load molding and cutting processes. Mold inserts are widely used in processes such as metal

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stamping, plastic injection molding, and precision molding. These materials require high hardness to resist wear and deformation, ensuring long-term mold use and machining consistency. The high hardness of tungsten alloy bars stems from the natural properties of tungsten. The addition of elements such as nickel and iron optimizes toughness, balancing hardness and crack resistance, enabling them to withstand high stress and repeated loads. Achieving this hardness requires precise production processes and rigorous quality testing to ensure the material meets the stringent requirements of mold manufacturing.

During the production process, achieving hardness indicators begins with raw material ratios and process optimization. High-purity tungsten powder is mixed with binder elements such as nickel and iron in appropriate proportions, and a high-density microstructure is formed through powder metallurgy. The sintering process promotes the bonding of tungsten particles and the binder by controlling the high temperature and atmosphere, reducing porosity and increasing hardness. Heat treatment processes (such as quenching or aging) further optimize the grain structure, enhancing hardness and fatigue resistance. For example, the addition of nickel can improve toughness and prevent brittle cracking caused by excessive hardness. The processing stage uses high-precision cutting and grinding, using diamond or CBN tools, to ensure the dimensional accuracy and surface finish of the mold inserts and reduce the impact of surface defects on hardness.

Quality control utilizes hardness tests, such as Vickers (HV) or Rockwell (HRC), to verify that the material meets the hardness requirements for mold inserts. During testing, the microstructure is examined microscopically to assess grain size and defect distribution, ensuring hardness uniformity. Inspection frequency is determined by production scale, with 100% inspection required for key components, while sampling testing may be used for mass production. Environmental protection is achieved through recycling processing waste and optimizing energy consumption, meeting green manufacturing standards. The hardness of tungsten alloy bars for mold inserts is achieved through scientific processes and rigorous testing, ensuring durability and precision in high-load molding. This excellent hardness performance supports the efficiency and reliability of mold manufacturing, making a significant contribution to improving the quality and efficiency of industrial production.

4.3.4 Wear resistance parameters of tungsten alloy bars for mold inserts

The wear resistance of tungsten alloy bars used in mold inserts is a key performance indicator for their application in industrial manufacturing, directly affecting their service life and processing stability in high-friction and heavy-load environments. Mold inserts must withstand high-frequency friction and mechanical impact in processes such as metal stamping and plastic injection molding, requiring the material to have excellent wear resistance to reduce surface wear and deformation and maintain mold processing accuracy and consistency. The high hardness and optimized microstructure of tungsten alloy bars enable them to effectively resist wear, while the addition of elements such as nickel and iron further improves toughness and prevents cracks from occurring during wear. Achieving wear resistance requires scientific process design and strict quality control to ensure the reliability of the material under harsh working conditions. During the production process, optimizing wear resistance begins with raw material selection. High-purity tungsten powder is mixed with binder elements such as nickel and iron in

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appropriate proportions, and a powder metallurgy process is used to form a dense microstructure. The sintering process controls the temperature and atmosphere to ensure uniform bonding between the tungsten particles and the binder, reducing porosity and defects and improving wear resistance. Heat treatment optimizes grain size, enhances hardness and fatigue resistance, and prevents the formation of microcracks during wear. High-precision grinding and surface polishing, using diamond wheels or polishing fluids, optimize surface finish, reduce friction, and further enhance wear resistance. Surface treatments, such as PVD coatings (e.g., TiAlN), create a wear-resistant protective layer, extending the service life of mold inserts.

Quality control utilizes wear resistance testing, such as wear testing machines that simulate high-friction environments to assess the material's wear rate and surface stability. During testing, surface profilometers are used to measure wear depth and roughness changes to verify that the wear resistance meets requirements. Microstructural analysis (such as SEM) examines the worn surface to assess defects and coating integrity. Environmental friendliness is achieved by recycling processing waste and optimizing energy consumption in the coating process to reduce environmental impact. The wear resistance of tungsten alloy bars for mold inserts is scientifically designed and rigorously tested, ensuring their durability and stability in high-friction environments. This excellent wear resistance supports efficient production and long-term use in mold manufacturing, providing key support for improving the precision and efficiency of industrial manufacturing, and demonstrating the wide applicability of tungsten alloy bars in the industrial field.

4.4 Application of Tungsten Alloy Bars in Electronics and New Energy Fields

Tungsten alloy bars are used in the electronics and new energy sectors thanks to their high density, excellent conductivity, and high-temperature resistance, meeting the high-reliability requirements of electronic devices and new energy systems. The electronics industry requires highly conductive and durable materials for electrodes, connectors, and heat sinks, while the new energy sector demands stability under high loads and extreme environments, such as in the conductive components of solar cells or connectors for electric vehicle batteries. Tungsten alloy bars significantly enhance their conductivity by adding highly conductive elements such as copper, while retaining tungsten's high density and high-temperature resistance, making them suitable for high-power electronic devices and new energy systems. Their non-toxicity and recyclability give them advantages in the environmentally stringent electronics and new energy sectors, aligning with the trend toward green manufacturing. During production, powder metallurgy processes optimize raw material ratios, sintering conditions, and subsequent processing to ensure the material's high density, conductivity, and stable performance. High-precision testing is required to verify performance during application to meet the reliability and efficiency requirements of electronics and new energy devices.

4.4.1 Electrical conductivity standards for tungsten alloy strips used as electronic electrodes

The conductivity standard of tungsten alloy bars for electronic electrodes is a core performance indicator for their application in the electronics and new energy fields, and directly determines their current

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transmission efficiency and equipment operation stability in high-power circuits. Electronic electrodes are widely used in semiconductors, vacuum tubes, and new energy battery systems, requiring materials with high conductivity to reduce energy loss while maintaining structural stability and durability. Tungsten alloy bars significantly improve their conductivity by adding highly conductive elements such as copper or nickel, while retaining the high density and high temperature resistance of tungsten, enabling them to operate efficiently in high current and high temperature environments. The formulation of conductivity standards requires comprehensive consideration of the material's composition, microstructure, and application scenarios to ensure that they meet the low resistance and high efficiency requirements of electronic devices.

During the production process, achieving conductivity standards begins with the selection and proportioning of raw materials. High-purity tungsten powder is mixed with highly conductive binder elements such as copper or nickel in appropriate proportions, and a uniform microstructure is formed through a powder metallurgy process. The addition of copper significantly improves conductivity, making it suitable for high-power electrode applications; nickel enhances toughness while improving conductivity, preventing the electrode from cracking under high loads. The sintering process is a key step. By controlling the high temperature and atmosphere in a vacuum or hydrogen sintering environment, the bonding of tungsten particles and the binder is promoted, forming a high-density conductive network, reducing porosity and defects to optimize current transmission efficiency. The processing stage uses high-precision cutting and surface polishing, using diamond or CBN tools, to ensure the surface finish and dimensional accuracy of the electrode and reduce contact resistance. Surface treatments, such as electroless nickel plating or silver coating, can further improve surface conductivity and reduce energy loss at the connection between the electrode and the circuit.

Quality control uses conductivity tests, such as the four-probe method, to accurately measure the resistivity of the material and verify whether it meets the standard requirements for electronic electrodes. During the test, the microstructure is examined by scanning electron microscopy (SEM) to evaluate the uniformity of the distribution of the conductive phase and ensure performance consistency. The inspection frequency is determined according to the production scale. Key electrode components require 100% inspection, and sampling inspection can be used for mass production. Environmental protection is achieved by optimizing sintering and processing energy consumption and recycling waste materials, in compliance with green manufacturing standards. The conductivity of tungsten alloy bars is achieved through scientific processes and strict testing, which ensures efficient current transmission and equipment reliability of electronic electrodes. This excellent conductive performance supports the efficient operation of semiconductor devices and new energy battery systems, provides key support for the advancement of electronics and new energy technologies, and reflects the wide applicability of tungsten alloy bars in high-tech fields.

4.4.2 Arc erosion resistance requirements for tungsten alloy electrode strips

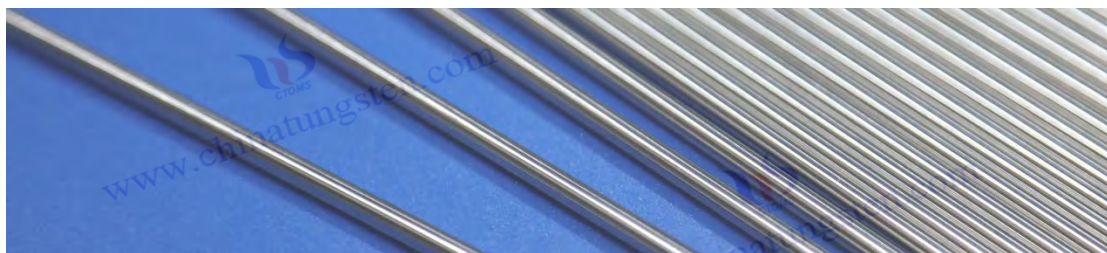
The arc erosion resistance requirement of electrode tungsten alloy bars is an important performance indicator for its application in the fields of electronics and new energy, which directly affects its durability

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and stability in high voltage and high current environments. Electronic electrodes in switches, plasma equipment or new energy battery systems often need to withstand the impact of arc discharge. The high temperature and high energy of the arc can cause surface erosion, wear or performance degradation of the material. Tungsten alloy bars can effectively resist arc erosion due to their high melting point and excellent thermal stability, and the addition of elements such as nickel and copper further improves the toughness and thermal shock resistance, enabling it to maintain structural integrity in arc environments. The realization of arc erosion resistance requires scientific process design and strict quality control to ensure the reliability of the electrode under harsh working conditions.

During the production process, optimizing arc erosion resistance begins with the raw material mix. High-purity tungsten powder is mixed with binder elements such as nickel and copper in appropriate proportions, and a powder metallurgy process is used to create a dense microstructure. The sintering process, by controlling the high temperature and atmosphere (such as vacuum or hydrogen sintering), promotes uniform bonding between the tungsten particles and the binder, reduces porosity and defects, and improves thermal shock resistance. Heat treatment processes (such as annealing or solution treatment) optimize the grain structure, enhance toughness and fatigue resistance, and prevent cracking during arc erosion. For example, the addition of copper improves thermal conductivity, facilitates rapid heat dissipation, and mitigates the effects of high arc temperatures. The addition of nickel enhances toughness and prevents cracking under arc shock. During processing, high-precision grinding and polishing optimize surface finish, reduce arc erosion starting points, and enhance durability. Surface treatments, such as PVD coatings (e.g., TiN or CrN), create an anti-erosion protective layer, further extending electrode life.

Quality control utilizes arc erosion testing to simulate a high-voltage discharge environment and assess the material's surface ablation rate and performance stability. During the test, the ablated surface is examined microscopically, and wear depth and microstructural changes are analyzed to verify whether the arc resistance meets the requirements. Environmental friendliness is achieved by optimizing energy consumption in the sintering and surface treatment processes and recycling processing waste to reduce environmental impact. The arc erosion resistance of the electrode tungsten alloy bar is scientifically designed and rigorously tested, ensuring its durability and stability in high-voltage, high-current environments. This excellent ablation resistance supports the efficient operation of vacuum switches and new energy battery systems, providing important support for technological advancement in the electronics and new energy fields, and demonstrating the exceptional performance of tungsten alloy bars in high-load environments.



CTIA GROUP LTD Tungsten Alloy Bar

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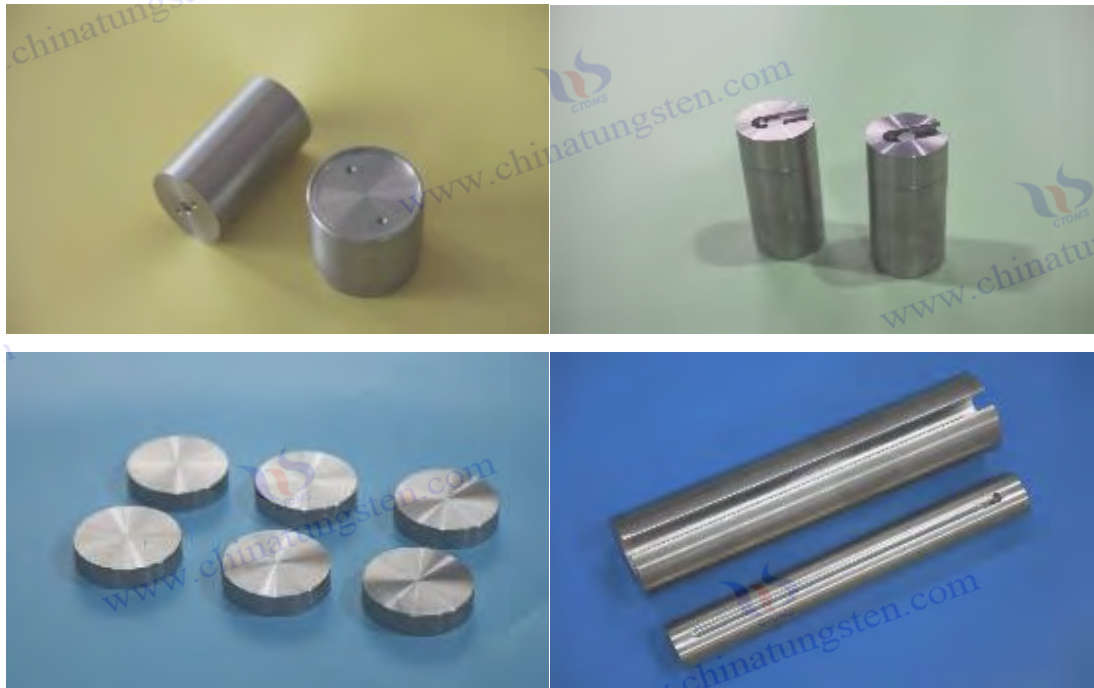
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电话/TEL: 0086 592 512 9696
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sales@chinatungsten.com

Chapter 5 Quality Control of Tungsten Alloy Bars

Tungsten alloy bars require quality control throughout the entire production process, from raw material selection to finished product testing, which directly determines their performance stability, reliability, and application value. Tungsten alloy bars are manufactured through a powder metallurgy process, combining the high density and high melting point characteristics of tungsten with the toughness and functionality of elements such as nickel, iron, and copper. They are widely used in aerospace, medical, electronics, and industrial manufacturing. Quality control requires the use of high-precision equipment and strict testing methods to ensure the high density, mechanical properties, and functional adaptability of the material, while taking into account environmental protection and sustainability, and reducing waste and energy consumption in the production process. Quality control involves raw material end testing, process monitoring, and finished product performance verification. Industry standards must be followed to ensure that the product meets the needs of high-demand scenarios such as aerospace counterweights, medical shielding parts, and electronic electrodes.

5.1 Key points for raw material testing

Raw material testing is a fundamental step in tungsten alloy bar quality control, directly affecting the performance stability of subsequent mixing, pressing, sintering, and processing steps. The raw materials for tungsten alloy bars mainly include tungsten powder and binder elements such as nickel, iron, and copper. They must undergo rigorous testing to ensure that their purity, composition, and particle size distribution meet production requirements. The stability of the raw material quality determines the microstructure, density, and mechanical properties of the tungsten alloy bar, which is directly related to its reliability in high-precision applications. Raw material testing requires the use of high-precision analytical equipment such as spectrometers, particle size analyzers, and microscopes to verify the chemical composition and physical properties of the raw materials through scientific methods. The testing process must comply with industry standards to ensure the accuracy and traceability of the results, while also focusing on environmental protection and reducing resource waste by optimizing the testing process and recycling waste.

5.1.1 Tungsten powder purity testing

Tungsten powder purity testing is a core component of raw material quality control, directly impacting the performance stability and application reliability of tungsten alloy bars. As the primary component of tungsten alloy bars, high purity tungsten powder reduces the impact of impurities on microstructure and mechanical properties, ensuring high performance in applications such as aerospace counterweights, medical shielding components, and electronic electrodes. Impurities such as oxygen, carbon, sulfur, or metallic elements can cause sintering defects, reduced strength, or decreased conductivity. Therefore, tungsten powder purity must be strictly controlled through high-precision testing methods. Purity testing not only impacts material performance but also the environmental and safety aspects of the production process, preventing the impact of harmful impurities on subsequent processes and applications. The tungsten powder purity testing process includes the following steps: First, a tungsten powder sample is

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collected and chemically cleaned to remove surface contaminants to ensure accurate test results. Testing primarily utilizes inductively coupled plasma mass spectrometry (ICP-MS) or X-ray fluorescence (XRF) analysis to accurately measure the content of the main elements and impurities in the tungsten powder, such as oxygen, carbon, iron, and aluminum. Instrument calibration is required during testing to ensure ppm (parts per million) accuracy. Sample preparation must be performed in a clean environment to avoid external contamination. The test results are compared with industry standards to evaluate whether the tungsten powder meets production requirements. The frequency of testing is determined by the raw material batch. Usually, sampling and testing are performed on each batch, and key applications require full testing to ensure consistency. Optimization measures include the use of automated testing equipment to improve testing efficiency and accuracy; establishing a raw material database to record the purity data of each batch of tungsten powder to support quality traceability. Environmental protection is achieved by optimizing the testing process and reducing the use of chemical reagents and waste liquid emissions. Tungsten powder purity testing uses scientific methods and strict control to lay the foundation for the microstructural uniformity and performance stability of tungsten alloy bars. This high purity guarantee supports the reliability of the material in high-precision applications, promotes technological advancement in the aerospace, medical and electronics fields, and provides key support for the production of high-quality tungsten alloy bars.

5.1.2 Verification of the composition ratio of metal elements (Ni/Fe/Cu)

Verifying the composition ratio of metallic elements (nickel, iron, and copper) is a crucial step in raw material quality control, directly impacting the mechanical properties, electrical conductivity, and functional compatibility of tungsten alloy bars. Binder elements such as nickel, iron, and copper enhance the toughness, electrical conductivity, and processing properties of tungsten alloys. Their composition ratio must be precisely controlled to meet specific application requirements, such as the high density of aerospace counterweights, the high conductivity of electronic electrodes, or the radiation resistance of medical shielding components. Inaccurate composition ratios can lead to performance fluctuations, such as insufficient toughness, decreased conductivity, or substandard density. Therefore, high-precision testing is required to verify the accuracy of the composition ratio. Composition ratio verification also takes environmental considerations into account, ensuring that the raw materials are free of harmful impurities and minimizing the environmental impact of the production process.

The composition ratio verification process includes the following steps: First, tungsten powder and metal powders such as nickel, iron, and copper are weighed according to the designed ratio, and the mass of each component is recorded. The elemental content of the mixed powder is analyzed using X-ray fluorescence spectroscopy (XRF) or atomic absorption spectroscopy (AAS) to verify that the component ratios meet the target ratio. During testing, sample homogeneity must be ensured, and multiple sampling (such as random or stratified sampling) is used to enhance the representativeness of the results. Test results are compared with the designed ratio, and deviations must be kept to a minimum to ensure consistent performance. Testing frequency is determined by production scale; random sampling can be used for batch production, and full inspection of key components is required to ensure consistent quality. Optimization measures include the use of automated batching systems to precisely control the weighing

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and mixing of raw materials and the implementation of online spectral analysis equipment to monitor ratio deviations in real time and improve testing efficiency. Environmental protection is achieved by recycling testing waste and optimizing the use of analytical reagents to reduce resource waste. Verification of the metal element composition ratio, through scientific methods and strict control, ensures the optimized performance of tungsten alloy bars. This precise ratio control supports the material's high performance in aerospace counterweights, medical shielding components, and electronic electrodes, providing a reliable foundation for applications in high-tech fields and demonstrating the key role of quality control in production.

5.1.3 Raw material particle size distribution testing

Testing raw material particle size distribution is a crucial step in raw material quality control, directly impacting the mixing uniformity, compaction density, and sintering properties of tungsten alloy bars. The particle size distribution of tungsten powder and binder elements such as nickel, iron, and copper determines the powder's fluidity, filling properties, and particle bonding during sintering. Proper particle size distribution improves mixing uniformity and billet density, reduces porosity and defects, and ensures the mechanical properties and functional stability of the final product. Uneven particle size distribution can lead to uneven mixing, compaction defects, or inconsistent sintering shrinkage, compromising the quality of tungsten alloy bars. Therefore, strict particle size distribution control through high-precision testing is essential to ensure that the raw materials meet production requirements.

The particle size distribution testing process involves the following steps: First, samples of tungsten powder and binder elements are collected and the particle size distribution is measured by sieving or using a laser particle size analyzer. The particle size range and distribution characteristics are recorded. Laser particle size analyzers provide highly accurate particle size distribution data, typically measuring from submicron to tens of microns. Instrument calibration is required during the testing process to ensure measurement accuracy, and multiple sampling is performed to enhance the representativeness of the results. Test results are compared with process requirements to assess whether the particle size distribution meets mixing and pressing requirements. Testing frequency is determined by the raw material batch, typically sampling each batch, with increased testing frequency required for critical applications to ensure consistency. Optimization measures include the use of automated particle size analysis equipment to improve testing efficiency and data accuracy; and the establishment of a particle size distribution database to record the particle size characteristics of each raw material batch to support process optimization and quality traceability. Environmental protection is achieved by optimizing the testing process to reduce waste generation and energy consumption. Raw material particle size distribution testing, through scientific methods and strict control, ensures the mixing uniformity and sintering performance of tungsten alloy bars.

5.2 Key points for finished product testing

Finished product testing is the final step in tungsten alloy bar quality control, directly verifying whether its performance meets the application requirements of fields such as aerospace, medical, electronics, and

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industrial manufacturing. Finished product testing covers key indicators such as density, mechanical properties, appearance, and dimensions. High-precision testing equipment and scientific testing methods are required to ensure that the product's density, strength, surface quality, and geometric accuracy meet design standards. The high density and high strength of tungsten alloy bars enable them to perform well under high loads and extreme environments, but this also places higher demands on the accuracy and reliability of testing. The testing process requires the use of advanced equipment such as densitometers, universal material testing machines, and three-dimensional coordinate measuring machines to verify performance consistency through a systematic testing process. Testing must also take environmental considerations into account, reducing resource waste by optimizing the testing process and recycling waste.

5.2.1 Finished product density testing

Finished product density testing is a core component of tungsten alloy bar quality control, directly impacting its performance in applications such as aerospace counterweights, medical shielding components, and electronic electrodes. Density is a key characteristic of tungsten alloy bar, determining its weight-to-volume ratio and functional suitability, such as providing precise balance in counterweight components or achieving efficient radiation absorption in shielding components. Insufficient density can lead to performance degradation, such as insufficient counterweighting or weakened shielding capabilities; while uneven density can cause stress concentrations or microscopic defects, compromising material reliability. Therefore, finished product density testing requires high-precision methods to verify the material's density and uniformity to ensure it meets specific application requirements.

The finished product density testing process includes the following steps: First, a sample of finished tungsten alloy bars is ultrasonically cleaned to remove surface oil and particles to ensure accuracy. The test primarily utilizes the Archimedean principle, using a high-precision densitometer to measure the sample's mass and volume and calculate the density. During the testing process, the instrument is calibrated to ensure an accuracy of $\pm 0.01 \text{ g/cm}^3$, and multiple measurements are performed to enhance the reliability of the results. For large or complex-shaped tungsten alloy bars, X-ray computed tomography (CT) can be used to examine the internal density distribution and identify defects such as porosity and inclusions. The test results are compared with design specifications to assess whether the density meets the requirements. The frequency of testing is determined by production scale and application scenarios. Key components require 100% inspection, while sampling testing (e.g., 5-10% per batch) may be used for mass production.

Optimization measures include the use of automated density testing equipment to improve testing efficiency and accuracy; establishing a density database to record density data for each batch of finished products to support quality traceability and process optimization. Environmental protection is achieved by optimizing the testing process to reduce the use of cleaning fluids and waste generation. Finished product density testing, through scientific methods and strict control, ensures the high density and performance stability of tungsten alloy bars. This high density supports the material's efficient application in aerospace counterweights and medical shielding components, providing critical support for reliability

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in high-tech fields and demonstrating the importance of quality control in finished product testing.

5.2.2 Mechanical properties random inspection

Mechanical property spot checks are a crucial step in quality control for finished tungsten alloy bars. They directly verify their strength, toughness, and reliability in high-load environments, making them suitable for applications such as aerospace structural components, medical shielding components, and industrial molds. Tungsten alloy bars must withstand high stress, impact, or cyclic loads, and their mechanical properties, such as tensile strength, hardness, and toughness, directly impact their service life and safety. Fluctuations in mechanical properties can lead to component failure or performance degradation, so spot checks are necessary to verify that the mechanical properties of finished products meet design requirements. Spot checks balance testing costs and quality assurance, making them suitable for mass production while ensuring the performance stability of key components.

The mechanical properties sampling process includes the following steps: First, samples are randomly selected (e.g., 5-10% of each batch) based on the production batch and application requirements, and ultrasonic cleaning is used to remove surface contaminants to ensure test accuracy. The test mainly includes tensile strength, hardness, and impact toughness tests. A universal material testing machine is used to perform tensile tests to measure tensile strength and elongation; a Vickers hardness (HV) or Rockwell hardness (HRC) tester is used to measure hardness; and an impact testing machine is used to evaluate the impact resistance of the material. During the test, the equipment needs to be calibrated to ensure accuracy, and the stress-strain curve and hardness value are recorded to evaluate performance consistency. For critical applications, a scanning electron microscope (SEM) can be used to analyze the fracture morphology and check for microstructural defects. The test results are compared with industry standards to verify whether they meet the application requirements.

Optimization measures include the use of automated testing equipment to improve sampling efficiency and data accuracy; statistical process control (SPC) is used to analyze sampling results and monitor performance fluctuation trends. Environmental protection is achieved by recycling test waste and optimizing equipment energy consumption to reduce resource waste. Mechanical property sampling, through scientific sampling and rigorous testing, ensures the strength and reliability of tungsten alloy bars. This precise control of mechanical properties supports the material's stable performance in high-load environments, providing a reliable foundation for applications in aerospace, medical, and industrial fields, and promoting the development and use of high-performance components.

5.2.3 Appearance and Dimension Inspection

Appearance and dimensional inspection are key aspects of quality control for finished tungsten alloy bars, directly impacting their assembly performance, surface quality, and functional compatibility. They are suitable for high-precision applications such as aerospace counterweights, medical shielding components, and electronic electrodes. Tungsten alloy bars must possess precise geometric dimensions and an excellent surface finish to ensure compatibility with complex systems and long-term reliability.

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Appearance defects such as scratches, cracks, or color variations can affect corrosion resistance and aesthetics, while dimensional deviations can lead to assembly difficulties or functional failure. Therefore, high-precision inspection is required to verify that the finished product's appearance and dimensions meet design standards.

The appearance and dimensional inspection process includes the following steps: First, conduct a visual inspection of the finished product to identify surface defects such as scratches, cracks, oxidation or color difference, use an optical microscope to magnify and observe, and evaluate the surface quality. Dimensional inspection uses a three-coordinate measuring machine (CMM) or a laser scanner to measure length, diameter, straightness and form and position tolerances. The surface roughness is measured using a profilometer to ensure that the Ra value meets the application requirements. The inspection process must be carried out in a clean environment to avoid dust or oil contamination affecting the results. The inspection results are compared with the design drawings and industry standards, deviations are recorded and compliance is evaluated. The inspection frequency is determined according to the production scale and application scenarios. Key components require 100% inspection, and sampling inspection can be used for mass production.

Optimization measures include using automated testing equipment, such as online optical scanning systems, to improve inspection efficiency and accuracy; establishing a dimensional and appearance database to record inspection data and support quality traceability. Environmental protection is achieved by optimizing cleaning and inspection processes, reducing chemical reagents and energy consumption. Appearance and dimensional inspection, through scientific methods and strict control, ensures the geometric accuracy and surface quality of tungsten alloy bars. This high-precision appearance and dimensional control supports the material's reliability in high-precision assembly and functional applications, providing important support for technological advancements in the aerospace, medical, and electronics fields, and demonstrating the critical role of finished product inspection in quality control.

5.3 Solutions to Common Quality Problems

Addressing common quality issues is a crucial step in tungsten alloy bar quality control. Through process optimization and parameter adjustment, the goal is to eliminate issues such as molding cracking, uneven density, and surface defects that may arise during production, thereby ensuring stable and consistent performance of the finished product. These issues may stem from improper control of raw material quality, process parameters, or equipment performance, directly impacting the mechanical properties, geometric accuracy, and surface quality of the tungsten alloy bar, and thus its reliability in applications in aerospace, medical, and electronics. Addressing these issues requires scientific analysis, experimental verification, and process improvement, combined with high-precision testing equipment, to identify the root causes and develop targeted measures. Environmental considerations must also be taken into account during the resolution process, reducing resource waste and environmental impact through optimizing process parameters and recycling waste materials. The following analysis focuses on solutions to molding cracking, uneven density, and surface defects.

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5.3.1 Molding cracking: Adjust pressing pressure and mold lubrication

Forming cracking is a common quality issue in the tungsten alloy bar production process, primarily occurring during the pressing and forming stage. This can lead to insufficient billet strength or even scrap, directly impacting the quality of subsequent sintering and processing. Cracking is typically caused by improper pressing pressure, insufficient die lubrication, or poor powder flowability. Excessive pressing pressure can lead to stress concentration within the billet, initiating cracks; while excessively low pressure can cause insufficient density, impacting billet strength. Insufficient die lubrication increases friction between the powder and the die wall, leading to demolding difficulties or surface cracking. Addressing forming cracking requires adjusting the pressing pressure and optimizing die lubrication to improve the billet's forming quality and ensure its performance stability in subsequent processes.

Measures to resolve molding cracking include the following steps: First, analyze the cause of cracking, observe the crack morphology through a microscope, and combine the pressing parameter records to determine whether it is caused by pressure or lubrication problems. Adjustment of the pressing pressure needs to be optimized according to the powder characteristics and mold design. Use a high-precision press to control the pressure range to ensure uniform density of the billet and avoid stress concentration. Mold lubrication reduces friction and improves demolding performance by adding an appropriate amount of lubricant (such as zinc stearate) or using a surface coating (such as PTFE coating). Lubricant selection must take environmental protection into consideration to avoid harmful substances affecting subsequent processes or the environment. The process flow includes redesigning the pressing parameters, applying pressure in stages (such as progressive pressing), and preheating and lubricating the mold before pressing. Experimental verification is carried out through small-batch trial pressing to test the integrity and density of the billet, and after optimizing the parameters, it is applied to mass production.

Optimization measures include using automated pressing equipment to monitor pressure and die conditions in real time, improving parameter control accuracy; and employing simulation software (such as finite element analysis) to predict billet stress distribution and optimize the pressing process. Environmental protection is achieved through recycling scrap billets and optimizing lubricant usage, reducing resource waste. Forming cracking is addressed by adjusting pressing pressure and die lubrication, ensuring the quality of tungsten alloy bar billets. This process improvement improves billet integrity and density, laying the foundation for subsequent sintering and processing, supporting the reliability of high-precision applications such as aerospace counterweights and medical shielding components, and demonstrating the critical role of quality control in production.

5.3.2 Uneven density: Optimizing sintering heating rate and holding time

Uneven density is a common quality problem in the production process of tungsten alloy bars. It mainly occurs during the sintering stage and may cause fluctuations in material properties, affecting its functional performance in applications such as aerospace counterweights, medical shielding components, and electronic electrodes. Uneven density is usually caused by improper sintering heating rate or insufficient holding time. Too fast a heating rate may lead to excessive temperature gradients inside the

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billet, resulting in uneven shrinkage and residual porosity; too slow a heating rate may extend the sintering cycle, increase energy consumption, and cause excessive grain growth. Insufficient holding time may limit the full progress of liquid phase sintering, resulting in insufficient density. Solving the problem of uneven density requires optimizing the sintering heating rate and holding time to ensure high material density and uniform performance.

Measures to address density non-uniformity include the following: First, analyze the cause of density non-uniformity. X-ray CT scanning is used to examine the internal porosity distribution of the billet. Combined with sintering parameter records, the heating rate or holding time is identified as a contributing factor. Optimizing the heating rate requires designing a staged heating curve based on the alloy composition and billet size, controlling the rate and ensuring temperature uniformity. The holding time is adjusted based on the target density, typically during the high-temperature phase to promote liquid filling and particle bonding. The process involves using a high-precision sintering furnace, monitoring the temperature distribution within the furnace in real time, and recording shrinkage and density changes. Experimental validation is achieved through small-batch sintering tests, using a densitometer and SEM to analyze density and microstructure. Parameters are then optimized for mass production. Optimization measures include the use of an automated temperature control system to adjust the heating rate and holding time in real time, and the use of thermodynamic simulation software to predict sintering behavior and reduce trial-and-error costs. Environmental friendliness is achieved by optimizing sintering energy consumption and recycling waste gases to minimize environmental impact. Addressing density non-uniformity through optimized sintering heating rate and holding time ensures high density and uniform performance of tungsten alloy bars. This process improvement measure improves the performance stability of the material, supports the reliability of demanding applications such as aerospace counterweights and electronic electrodes, and provides key support for the production of high-quality tungsten alloy bars.

5.3.3 Surface Defects: Improving Grinding and Polishing Processes

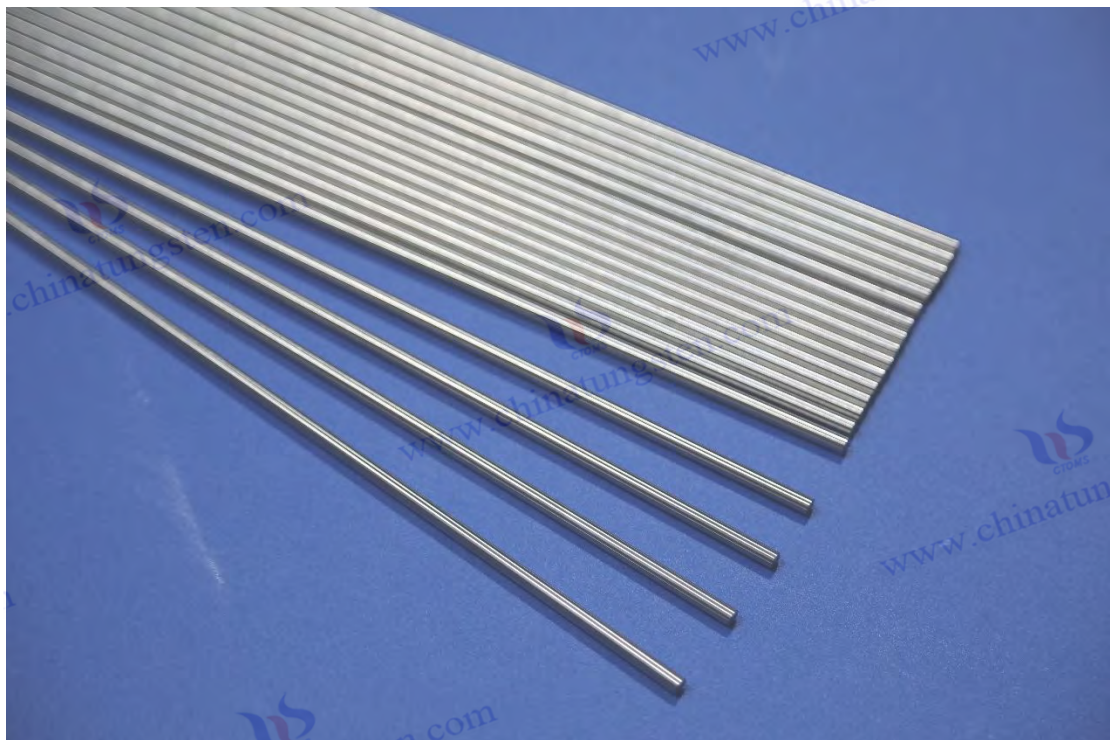
Surface defects are common quality issues during tungsten alloy bar production, primarily occurring during the processing phase. These defects can include scratches, cracks, or excessive roughness, directly impacting the bar's appearance and performance in applications such as aerospace, medical, and electronics. These defects are often caused by improper grinding or polishing processes, such as improper grinding wheel selection, inappropriate grinding parameters, or insufficient polishing fluid concentration. Scratches and cracks can reduce corrosion and wear resistance, while excessive roughness can affect assembly accuracy or electrical conductivity. Addressing surface defects requires improving the grinding and polishing processes to optimize surface finish and quality, ensuring the bar meets the demands of high-precision applications.

Measures to address surface defects include the following steps: First, analyze the cause of the defect, check the surface morphology with an optical microscope or profilometer, and identify problems with the grinding or polishing process in combination with processing parameter records. Improving the grinding process requires optimizing the selection of grinding wheels (such as diamond grinding wheels

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for fine grinding, with a grit size of 200-400 mesh), controlling the grinding speed and feed rate, and reducing surface scratches and thermal damage. The polishing process ensures that the surface roughness meets the standard by selecting a suitable polishing fluid (such as aluminum oxide or diamond suspension) and polishing pad, optimizing the polishing pressure and time. The process includes the use of high-precision grinders and polishing equipment, real-time monitoring of surface quality, and recording of processing parameters. Experimental verification is carried out through small-batch processing tests, using profilometers and microscopes to check surface defects, and optimizing the process for application in mass production.

Optimization measures include the use of automated grinding and polishing equipment, integrated with online inspection systems to improve surface quality control accuracy; regular grinding wheel dressing and polishing pad replacement to ensure process stability. Environmental protection is achieved through the recycling of grinding waste and the optimization of polishing fluid usage to reduce environmental impact. Surface defects are addressed through improved grinding and polishing processes, ensuring the high surface quality and functional performance of tungsten alloy bars. This process improvement improves the material's assembly accuracy and durability, supporting the reliability of high-precision applications such as aerospace counterweights, medical shielding components, and electronic electrodes, providing important support for the production of high-quality tungsten alloy bars.



CTIA GROUP LTD Tungsten Alloy Bar

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Chapter 6 Technological Innovation and Future Trends of Tungsten Alloy Bars

Tungsten alloy rods have broad application prospects in aerospace, medical, electronics, and industrial manufacturing due to their high density, high strength, high temperature resistance, and excellent electrical conductivity. With the continuous advancement of science and technology and the increasing demand of the industry, technological innovation of tungsten alloy rods has become the key to promoting its performance optimization and application expansion. Technological innovation covers the research and development of new alloy compositions, the application of advanced manufacturing technologies, and the introduction of intelligent production processes, aiming to improve the mechanical properties, functional adaptability, and production efficiency of materials, while paying attention to environmental protection and sustainability. By combining new material design and advanced manufacturing processes, tungsten alloy rods can meet high-precision and multi-functional requirements under more demanding working conditions, providing support for the development of high-tech fields. Future trends focus on green manufacturing, intelligent production, and the expansion of cross-domain applications, aiming to promote the competitiveness of tungsten alloy rods in the global industry.

6.1 Technology R&D Direction

The technical research and development direction of tungsten alloy bars focuses on optimizing material properties, innovating production processes, and expanding application scenarios to meet the growing demand for high-performance materials in fields such as aerospace, medical care, electronics, and new energy. Research and development directions include the design of new alloy compositions, the application of advanced manufacturing technologies, and the development of intelligent production processes. New alloy compositions improve the mechanical properties, high-temperature resistance, and functional characteristics of materials by introducing rare earth elements or other functional additives; advanced manufacturing technologies such as 3D printing achieve complex shapes and high-precision manufacturing by breaking through the limitations of traditional processes; and intelligent production improves production efficiency and quality consistency through data-driven and automated technologies. These research and development directions need to be combined with high-precision experimental equipment and simulation analysis technologies to ensure the feasibility and reliability of technological innovations, while focusing on environmental protection, reducing resource consumption and environmental impact by optimizing processes and recycling waste.

6.1.1 Research and Development of New Alloy Components (Rare Earth Doping)

The research and development of novel alloy compositions, particularly rare earth doping, is a core area of technological innovation for tungsten alloy bars. This research aims to significantly enhance the material's mechanical properties, high-temperature resistance, and functional characteristics, meeting the demands of demanding applications such as aerospace counterweights, medical shielding components, and electronic electrodes. Rare earth elements (such as lanthanum, cerium, and yttrium), due to their unique electronic structure and chemical activity, can optimize the microstructure of tungsten alloys, enhance grain boundary strength, improve oxidation resistance and corrosion resistance, and improve

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mechanical properties at high temperatures. Rare earth doping, by introducing trace amounts of rare earth elements into the tungsten matrix, regulates grain size, reduces defects, and enhances the material's toughness and thermal fatigue resistance, opening up new possibilities for the application of tungsten alloy bars in extreme environments.

Implementation of rare earth doping R&D involves the following steps: First, the target performance and application scenarios are determined, and the appropriate rare earth elements and their doping ratios are selected. During the R&D process, a high-precision batching system is used to uniformly mix the rare earth elements with tungsten powder and binder elements such as nickel, iron, and copper to ensure doping uniformity. Powder metallurgy is crucial. By optimizing the sintering temperature and atmosphere (such as vacuum or hydrogen sintering), the rare earth elements are bonded to the tungsten matrix, forming a stable microstructure. During sintering, the distribution of the rare earth elements must be controlled to avoid agglomeration or segregation, ensuring uniform performance. Heat treatment further optimizes the grain structure and enhances the material's strength and toughness. Experimental verification is conducted through small-batch trial production, combined with scanning electron microscopy (SEM) and X-ray diffraction (XRD) microstructural analysis to evaluate the performance enhancements of rare earth doping. Performance testing includes tensile strength, hardness, high-temperature resistance, and oxidation resistance to ensure the material meets application requirements.

Optimization measures include using computational materials science simulations (such as first-principles calculations) to predict the effects of rare earth doping on microstructure and properties, reducing experimental trial-and-error costs; and employing automated batching and sintering equipment to improve doping precision and process consistency. Environmental friendliness is achieved by optimizing sintering energy consumption and recycling waste, reducing rare earth element waste and environmental impact. The development of rare earth doping technology has opened up new avenues for optimizing the performance of tungsten alloy bars. Its enhanced mechanical properties and high-temperature resistance support demanding applications such as high-temperature aerospace components and electronic electrodes. This technological innovation has boosted the potential for tungsten alloy bars to be used in extreme environments, providing important support for material upgrades in high-tech fields and demonstrating the forward-looking nature and application value of the research and development of new alloy compositions.

6.1.2 Application of Advanced Manufacturing Technology (3D Printing)

The application of advanced manufacturing technologies, particularly 3D printing (additive manufacturing), is a key area of technological innovation in tungsten alloy bars. It aims to overcome the limitations of traditional powder metallurgy processes and enable the manufacture of complex, high-precision, and high-performance components. By depositing material layer by layer, 3D printing can directly form tungsten alloy components with complex geometries, reducing material waste and machining steps. This technology is suitable for high-precision applications such as aerospace counterweights, medical shielding components, and electronic electrodes. 3D printing also enables customized production, rapidly responding to diverse needs, while improving environmental friendliness.

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and production efficiency by optimizing material utilization and production processes. 3D printing of tungsten alloy bars requires overcoming the technical challenges presented by tungsten's high melting point and hardness to ensure the density, mechanical properties, and surface quality of the printed parts.

The implementation of 3D printing applications involves the following steps: First, developing a 3D printing process suitable for tungsten alloys, selecting a suitable printing technology, such as selective laser melting (SLM) or electron beam melting (EBM), and optimizing equipment parameters based on the high melting point characteristics of tungsten alloys. Raw material preparation requires the use of a mixed powder of high-purity tungsten powder and binder elements such as nickel, iron, and copper. Spherical powders are produced through aerosolization or plasma spheroidization processes to improve fluidity to meet printing requirements. During the printing process, the laser or electron beam power, scanning speed, and layer thickness must be precisely controlled to ensure uniform material melting and minimize porosity. After printing, hot isostatic pressing (HIP) or heat treatment is used to optimize the microstructure, eliminate residual stress, and improve density and mechanical properties. Surface treatment involves grinding or polishing to optimize the surface finish and ensure that it meets application requirements.

Quality control uses X-ray CT scanning to check for internal defects in printed parts, combined with SEM analysis of the microstructure to verify density and performance consistency. Performance tests include tensile strength, hardness, and high temperature resistance tests to ensure that the printed parts meet the needs of the aerospace and electronics fields. Optimization measures include using digital twin technology to simulate the printing process, predict defects and optimize parameters; and using automated printing equipment to improve production efficiency and consistency. Environmental protection is achieved by recycling unused powder and optimizing energy consumption to reduce resource waste. The application of 3D printing technology provides new possibilities for the complex shape manufacturing and customized production of tungsten alloy bars. Its high precision and high efficiency support high-demand applications such as aerospace counterweights and medical shielding parts. The introduction of this advanced manufacturing technology has promoted the innovation of tungsten alloy bar production methods, provided important support for the rapid development of high-tech fields and green manufacturing, and reflected the future potential of technological innovation.

6.2 Industry Development Trends

The development trend of the tungsten alloy bar industry closely follows the global industrial demand for high performance, sustainability, and cost-effectiveness, focusing on the development of lightweight, cost-effective products and the advancement of green production and recycling technologies. These trends are designed to meet the dual requirements of material performance and environmental friendliness in fields such as aerospace, medical, electronics, and new energy. Lightweight, cost-effective products reduce material density and production costs while maintaining high performance by optimizing alloy composition and manufacturing processes. Green production and recycling technologies reduce energy consumption and environmental impact by improving production processes and waste recycling, in line with the global trend of green manufacturing. Industry development trends also involve intelligent

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production and data-driven quality control, which improve production efficiency and product consistency through the introduction of automated equipment and big data analysis. These development trends require the combination of high-precision experiments, simulation technology, and strict quality control to ensure the feasibility of technological innovation and market competitiveness.

6.2.1 Development of lightweight and cost-effective products

The development of lightweight, cost-effective products is a key development trend in the tungsten alloy bar industry. This trend aims to reduce material density and cost by optimizing material design and production processes, while maintaining high strength, high-temperature resistance, and functional adaptability to meet the demand for efficient and economical materials in fields such as aerospace, electronics, and new energy. The high density of tungsten alloy bar excels in counterweight and shielding applications, but this high density also increases weight and cost, limiting its application in certain lightweight scenarios. Lightweight products reduce density and optimize performance by adjusting alloy composition and manufacturing processes; cost-effectiveness reduces manufacturing costs by simplifying the production process and improving material utilization. This trend not only enhances the market competitiveness of tungsten alloy bar but also supports the lightweight design of aerospace equipment and new energy systems.

The implementation of lightweight product development involves the following steps: First, alloy composition optimization is performed by adjusting the ratio of tungsten to binder elements such as nickel, iron, and copper, and introducing lightweight elements to reduce density while maintaining strength and toughness. For example, increasing the nickel or copper ratio can improve toughness, while reducing the tungsten content can reduce density. Production process optimization utilizes powder metallurgy techniques, precisely controlling the mixing and pressing processes to ensure powder uniformity and billet density. Sintering processes, through optimized temperature and atmosphere (such as vacuum sintering), reduce porosity and improve material properties while reducing energy consumption for cost-effectiveness. Advanced manufacturing technologies, such as 3D printing or isostatic pressing, enable lightweight designs with complex shapes and reduce material waste. Experimental verification involves small-batch trial production, combined with density and mechanical property testing, to assess whether the properties of lightweight alloys meet application requirements, such as the weight balance of aerospace counterweights or the conductivity of electronic electrodes.

The development of cost-effective products focuses on process optimization and cost control. Automated production equipment and online monitoring systems can improve production efficiency, reduce manual intervention and scrap rates, and process simulation software (such as finite element analysis) predicts material behavior and optimizes parameters to reduce trial-and-error costs. Quality control ensures the stable performance of lightweight products through hardness, tensile strength, and microstructure analysis (such as SEM). Environmental protection is achieved through waste recycling and energy optimization, meeting green manufacturing requirements. The development of lightweight, cost-effective products, through scientific design and process improvements, provides new opportunities for the application of tungsten alloy bars in aerospace and new energy fields. This trend promotes the balance

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between material performance and cost, supports the lightweight design and market promotion of high-performance equipment, and demonstrates the competitiveness of tungsten alloy bars in modern industry.

6.2.2 Green production and recycling technology

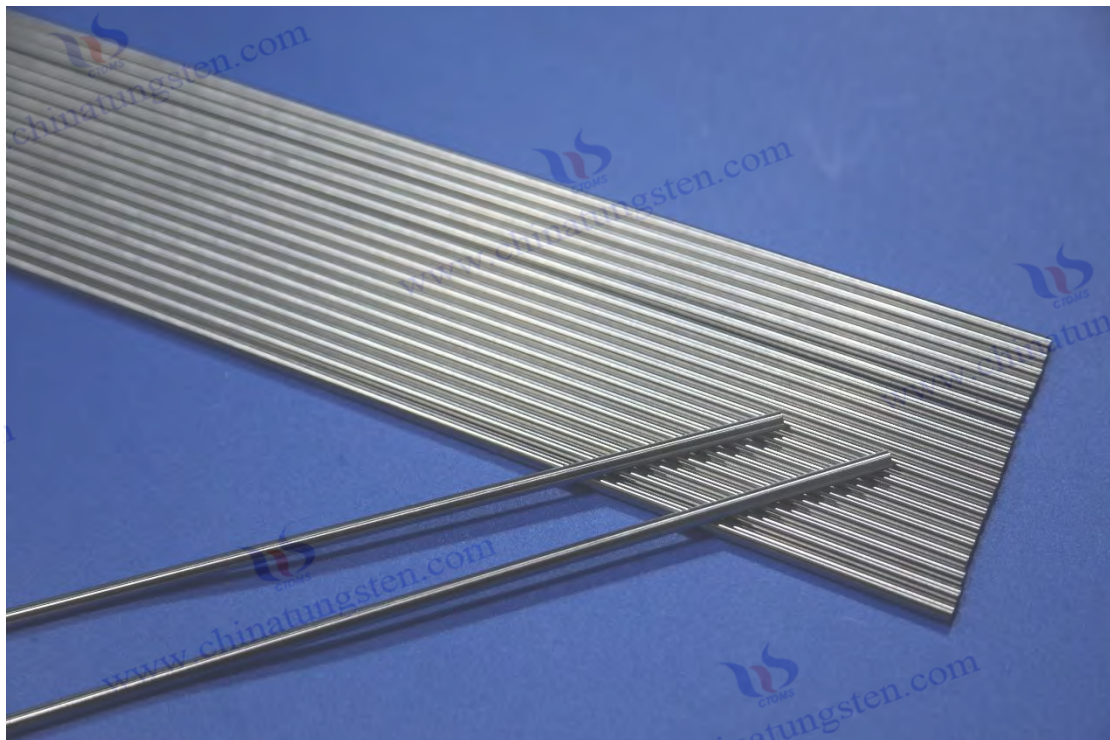
Green production and recycling technologies are key development trends in the tungsten alloy bar industry. These technologies aim to reduce environmental impact and meet global sustainable development requirements by optimizing production processes, reducing energy consumption, and increasing waste recovery rates. Tungsten alloy bar production involves energy-intensive processes such as powder metallurgy, sintering, and processing. Traditional processes can generate waste, exhaust gas, and waste liquids, placing a burden on the environment. Green production technologies reduce energy consumption and emissions by improving processes and equipment; recycling technologies maximize resource utilization by efficiently recovering tungsten powder, processing waste, and chemical reagents. These technologies not only reduce production costs but also enhance the applicability of tungsten alloy bars in the aerospace, medical, and electronics sectors, where environmental requirements are stringent, driving the industry's transition to green manufacturing.

The implementation of green production technologies involves the following steps: First, optimizing the powder metallurgy process, employing efficient mixing equipment and low-energy pressing technology, to reduce powder waste and energy consumption. The sintering process reduces energy consumption and exhaust emissions by using high-precision sintering furnaces and optimizing heating profiles (e.g., staged heating). A vacuum or hydrogen sintering environment can reduce oxide formation, improving material purity and performance stability. High-precision cutting and grinding are used in the machining process to reduce waste, while surface treatment uses environmentally friendly polishing fluids and coating processes to reduce the use of harmful chemicals. Intelligent production systems monitor energy consumption and emissions in real time and dynamically adjust process parameters to further improve energy efficiency. Experimental verification evaluates the effectiveness of green production processes through energy consumption analysis and emission testing to ensure compliance with environmental standards.

The implementation of recycling technology includes the following steps: First, establish a waste recycling system to collect sintering waste, cutting chips and polishing waste, and recover tungsten powder and other metal elements through physical separation and chemical purification. The recycling process requires the use of high-efficiency separation equipment, such as magnetic separators or flotation machines, to ensure the purity of the recycled materials. The recovery of chemical reagents uses filtration and distillation technology to reduce waste liquid emissions. The composition of recycled materials must be verified through spectral analysis (such as XRF) and reused in production to reduce raw material costs. Quality control is carried out through density, mechanical properties and microstructure tests to ensure that the recycled materials meet production requirements. Environmental protection is achieved by optimizing the recycling process and reducing secondary pollution, in line with green manufacturing standards. Green production and recycling technologies support the sustainable development of tungsten alloy rods through scientific processes and efficient recycling. This trend reduces the environmental

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impact of the production process, improves resource utilization, and supports the green development of demanding applications such as aerospace counterweights, medical shielding components, and electronic electrodes. Advances in green production technologies are driving the environmental transformation of the tungsten alloy rod industry, making a significant contribution to the sustainable development of the global industry and embodying the deep integration of technological innovation and environmental awareness.



CTIA GROUP LTD Tungsten Alloy Bar

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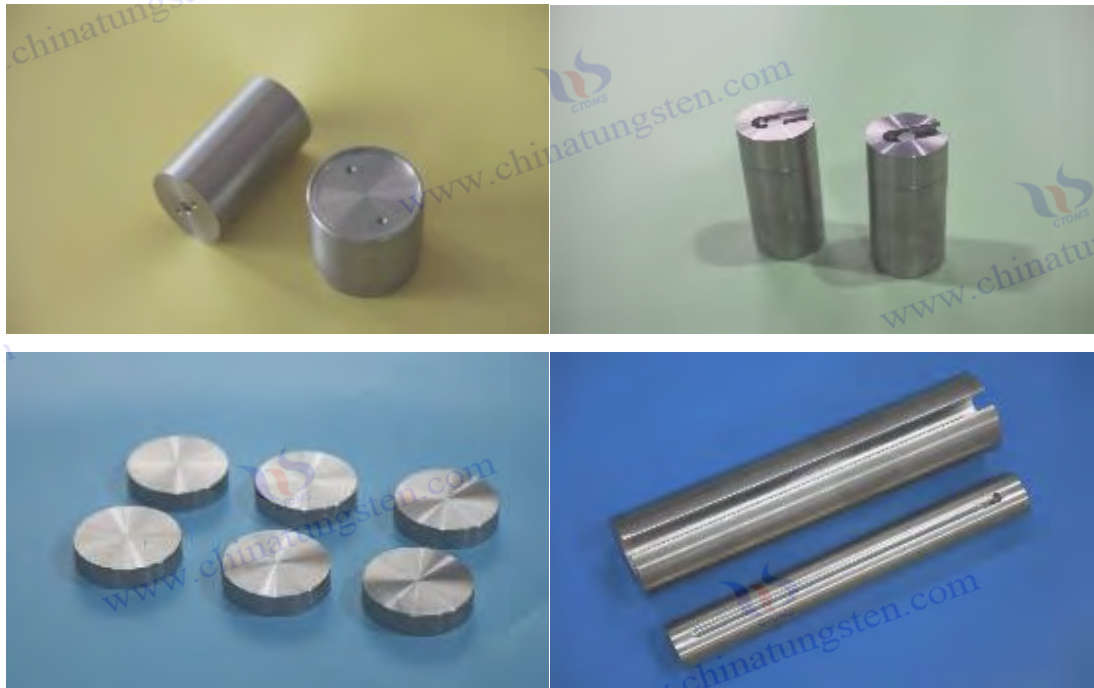
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Chapter 7: Selection and Application of Tungsten Alloy Bars

Tungsten alloy rods have broad application prospects in aerospace, medical, electronics, and industrial manufacturing due to their high density, high strength, high-temperature resistance, and excellent electrical conductivity. Their selection and application require a comprehensive consideration of material properties, processing technology, and the requirements of specific application scenarios to ensure performance matching and reliability. Tungsten alloy rods are manufactured using a powder metallurgy process, combining the high melting point and high density of tungsten with the toughness and functionality of elements such as nickel, iron, and copper to meet the high-precision requirements under complex working conditions. The selection and processing process must strictly adhere to industry standards. Through scientific design and process control, potential problems can be resolved to ensure the material's performance stability in scenarios such as aerospace counterweights, medical shielding components, electronic electrodes, and industrial molds. At the same time, selection and processing must focus on environmental friendliness, reducing resource consumption and environmental impact through process optimization and waste recycling.

7.1 Selection and Processing of Tungsten Alloy Bars

The selection and processing of tungsten alloy bars are key steps in ensuring their optimal performance in specific applications, directly affecting their functional adaptability, reliability, and service life. Selection requires choosing the appropriate alloy composition and specifications based on the performance requirements of the application scenario, such as density, strength, conductivity, or high-temperature resistance; processing requires high-precision processes to ensure dimensional accuracy, surface quality, and performance stability. The high hardness and high density of tungsten alloy bars make them difficult to process, requiring the use of specialized equipment and optimized process parameters to avoid processing defects. The selection and processing process must comprehensively consider material properties, equipment capabilities, and cost-effectiveness, while also focusing on environmental protection and achieving green manufacturing by reducing waste and energy consumption.

7.1.1 Selection Methods for Different Scenarios

The selection method for different scenarios is the basis for the application of tungsten alloy bars, which directly determines its performance matching and reliability in fields such as aerospace, medical, electronics, and industrial manufacturing. The performance of tungsten alloy bars varies depending on the alloy composition, density, and microstructure. The appropriate material type and specification must be selected according to the needs of the specific application scenario. For example, aerospace counterweights require high density and dimensional accuracy, medical shielding parts focus on radiation resistance and non-toxicity, electronic electrodes emphasize conductivity and arc ablation resistance, and industrial molds require high hardness and wear resistance. The selection method must combine performance requirements, process feasibility, and cost-effectiveness, and through scientific analysis and experimental verification, ensure that the material meets the application needs. The implementation of the selection method includes the following steps: First, clarify the performance requirements of the

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application scenario, such as the density and mechanical properties of aerospace counterweights, the lead equivalent of medical shielding components, or the conductivity of electronic electrodes. Select the appropriate alloy composition based on the needs, such as tungsten-nickel-iron alloys suitable for high-strength counterweights, and tungsten-copper alloys suitable for high-conductivity electrodes. Refer to industry standards (such as ASTM B777 or GB/T 3459) to determine density, strength, and size specifications. Processability and cost need to be considered during the selection process. For example, alloys with high copper content are easy to process but have lower density, and performance and cost need to be weighed. Experimental verification is carried out through small-batch trial production to test the density, mechanical properties, and functional characteristics of the material to evaluate whether it meets the application requirements. The selection results must be recorded and formed into a database to support subsequent optimization and quality traceability.

Optimization measures include using material performance simulation software to predict the performance of different alloy compositions, reducing trial and error costs; and collaborating with suppliers to customize tungsten alloy bar specifications to meet specific needs. Environmental protection is achieved by selecting non-toxic alloy components and optimizing the selection process to reduce waste generation. Selection methods for different scenarios are verified through scientific analysis and experiments, ensuring the performance matching of tungsten alloy bars. This precise selection supports the reliability of demanding applications such as aerospace counterweights, medical shielding components, and electronic electrodes, promotes the effective application of materials in multiple fields, and demonstrates the key role of selection in the use of tungsten alloy bars.

7.1.2 Common Problems and Solutions During Processing

Common problems encountered during processing and their solutions are crucial aspects of tungsten alloy bar applications, directly impacting their dimensional accuracy, surface quality, and performance stability. The high hardness and density of tungsten alloy bar make it challenging to process. Common issues include cutting cracks, surface scratches, dimensional deviations, and tool wear, which can lead to performance degradation or component failure. High-precision equipment and optimized process parameters are required during processing to address these issues and ensure that tungsten alloy bar quality requirements are met in applications such as aerospace counterweights, medical shielding components, and electronic electrodes. Solutions require scientific analysis and process improvements, combined with high-precision testing methods, to eliminate processing defects and improve production efficiency and reliability.

Solving machining problems involves the following steps: First, analyze the cause of the problem. Examine the machined surface under a microscope and, in conjunction with machining parameter records, determine the source of cracks, scratches, or deviations. For cutting cracks, it is necessary to optimize cutting parameters, use high-rigidity CNC machine tools and diamond or CBN tools, control cutting speeds and feeds, and reduce thermal stress and mechanical damage. Surface scratches can be addressed by improving the grinding process. Select appropriate grinding wheels (such as diamond grinding wheels with a grit size of 200-400 mesh) and grinding fluids, optimize grinding speeds and pressures, and ensure

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that surface roughness meets standards . Dimensional deviations are controlled within ± 0.01 mm by calibrating the machine tool and fixture and using an online detection system to monitor machining accuracy in real time. Tool wear can be alleviated by regularly dressing the tool and using wear-resistant coated tools (such as TiAlN coatings) to extend tool life.

Experimental verification was conducted through small-batch machining tests, using coordinate measuring machines (CMMs) and profilometers to inspect dimensions and surface quality. After optimizing process parameters, they were applied to mass production. Optimization measures included the use of automated machining equipment and integrated online monitoring systems to improve precision and efficiency; finite element analysis was used to simulate the machining process, predict stress and deformation, and optimize parameters. Environmental friendliness was achieved by recycling cutting waste and optimizing grinding fluid usage, reducing resource waste and environmental impact. Problems solved during machining, through scientific processes and strict control, ensured the high precision and quality of tungsten alloy bars. This process improvement supports the high-reliability application of the material in the aerospace, medical, and electronics fields, providing key support for efficient production and performance optimization, and highlighting the importance of machining control in tungsten alloy bar applications.

7.2 Maintenance and Safety of Tungsten Alloy Bars

The maintenance and safety management of tungsten alloy bars are key to ensuring their long-term stable operation in fields such as aerospace, medical, electronics, and industrial manufacturing, and directly affect the material's service life, performance reliability, and operational safety. Maintenance involves the control of the storage environment and regular inspections to prevent degradation of material performance; safety management covers protective measures during operation and waste disposal regulations to ensure personnel safety and environmental friendliness. The high density and high hardness of tungsten alloy bars require special attention to moisture, corrosion, and mechanical damage during storage and operation. Waste disposal must comply with environmental regulations to avoid pollution from hazardous substances. Maintenance and safety management must be combined with high-precision testing equipment and scientific process design to ensure the stability of material performance and safety of use. At the same time, attention should be paid to environmental protection, and resource waste and environmental impact can be reduced by optimizing management processes and recycling.

7.2.1 Core requirements for storage and maintenance

The core requirements of storage and maintenance are crucial aspects of tungsten alloy bar maintenance and management. Through scientific storage environment control and regular maintenance measures, they aim to prevent material performance degradation, extend service life, and ensure reliability in demanding applications such as aerospace counterweights, medical shielding components, electronic electrodes, and industrial molds. The high density and hardness of tungsten alloy bars make them sensitive to the storage environment. Moisture, corrosive gases, or mechanical impact can cause surface oxidation, corrosion, or damage, affecting their mechanical properties and functional characteristics.

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Maintenance measures, through regular inspection and surface treatment, maintain the material's performance stability and appearance quality. Storage and maintenance must be combined with scientific process design and environmental control to ensure the material's reliability during long-term storage and use.

The core requirements for storage include the following: First, tungsten alloy bars should be stored in a dry, well-ventilated environment to avoid surface oxidation caused by moisture. The storage area should be away from acidic, alkaline or corrosive gases, and sealed packaging (such as vacuum plastic bags or moisture-proof boxes) should be used to protect the material from contact with oxygen and moisture in the air. For long-term storage, shockproof packaging materials (such as foam pads or wooden boxes) should be used to secure the tungsten alloy bars to avoid mechanical collisions that may cause surface scratches or cracks. Maintenance measures include regular inspections, appearance and performance testing every 3-6 months, using an optical microscope to check for signs of oxidation, scratches or corrosion on the surface, and verifying performance stability using a density meter or hardness tester when necessary. Minor surface oxidation can be restored by polishing, and severe damage should be recorded and evaluated for suitability for continued use.

Optimization measures include establishing a digital storage management system to record storage environment parameters (such as temperature and humidity) and inspection data to support quality traceability; using automated monitoring equipment to monitor the storage environment in real time and alert users to abnormal conditions. Environmental protection is achieved by optimizing storage energy consumption and using recyclable packaging materials to reduce resource waste. Core storage and maintenance requirements ensure the performance stability and long-term use of tungsten alloy bars through scientific process design and environmental control. This management approach supports the material's high-reliability applications in aerospace, medical, and electronics fields, providing critical support for extending material life and ensuring performance consistency, and highlighting the importance of maintenance management in tungsten alloy bar applications.

7.2.2 Safety regulations for operation and disposal

Safety regulations for operation and waste disposal are the core of tungsten alloy bar safety management. They aim to ensure operator safety, equipment operation, and environmental friendliness through scientific protective measures and environmentally friendly treatment processes. Tungsten alloy bars may involve cutting, grinding, or high-temperature operations during processing, assembly, and use, posing risks of injury from dust, sharp edges, or high temperatures. Waste disposal requires proper management of waste to avoid environmental pollution. Safety regulations must cover protective requirements during operation, the classified recycling, and compliant disposal of waste, meeting the high safety and environmental requirements of aerospace, medical, and electronics industries. Operation and waste disposal must ensure personnel safety and environmental sustainability through training, equipment protection, and a waste recycling system.

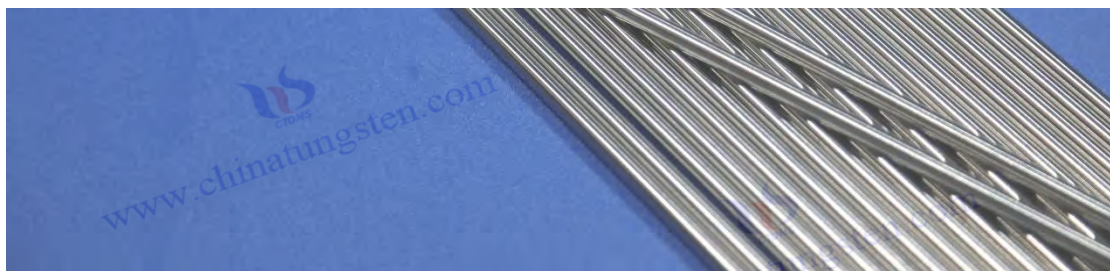
Operational safety regulations include the following measures: During the processing process, operators

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must wear protective equipment such as dust masks, goggles, and wear-resistant gloves to avoid inhaling tungsten alloy dust or being scratched by sharp edges. Processing equipment must be equipped with an efficient dust removal system to collect dust generated by cutting and grinding to prevent the spread of dust and health risks. High-temperature operations (such as welding or heat treatment) require the use of thermal insulation protective clothing and high-temperature equipment to ensure personnel safety. The operating environment must be well ventilated and equipped with air purification devices to reduce the concentration of dust and harmful gases. Before operation, personnel must receive professional training and be familiar with the physical properties of tungsten alloy bars and processing precautions to avoid equipment damage or personal injury due to improper operation. Equipment maintenance requires regular inspections to ensure the stability and safety of the processing equipment.

Waste disposal safety regulations include the following steps: First, tungsten alloy bar waste, such as cuttings, grinding waste, and unqualified finished products, is collected and stored in dedicated sealed containers to prevent scattering and environmental pollution. Waste recycling involves physical separation (such as magnetic separation or screening) and chemical purification to extract elements such as tungsten, nickel, iron, and copper for reuse in production. Environmentally friendly reagents must be used during chemical treatment, and waste liquids must be recovered through filtration and distillation to reduce emissions. Waste disposal must comply with environmental regulations (such as GB/T 30509) and be handled by compliant recycling companies to ensure that waste does not enter the general waste stream. Quality control verifies the composition of recycled materials through spectral analysis (such as XRF) to ensure their suitability for reuse. Waste disposal records must be archived to support environmental audits and quality traceability.

Optimization measures include establishing an automated waste recycling system to improve recycling efficiency and material utilization; using a digital management system to record waste disposal processes and recycling data to ensure regulatory compliance. Environmental protection is achieved by reducing the use of chemical reagents and optimizing waste treatment energy consumption, complying with green manufacturing requirements. Safety regulations for operation and waste disposal ensure the safe use and environmental friendliness of tungsten alloy bars through scientific protective measures and environmentally friendly processes. This management approach supports the high-safety application of the material in the aerospace, medical, and electronics fields, providing key support for personnel protection and sustainable development, and demonstrating the important value of safety management in tungsten alloy bar applications.



CTIA GROUP LTD Tungsten Alloy Bar

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appendix:

Tungsten Alloy Rod Terminology

the term	definition
Tungsten Alloy Bar	A rod-shaped material with tungsten as the main component, made by powder metallurgy process and compounded with binder elements such as nickel, iron, and copper. It has the characteristics of high density, high strength, high temperature resistance and excellent conductivity. It is widely used in aerospace counterweights, medical shielding parts, electronic electrodes and industrial molds.
Powder Metallurgy	A process for preparing metal materials or components by mixing metal powders, pressing and sintering at high temperature. It is used to produce tungsten alloy bars to ensure high density and uniform microstructure.
High density	The main characteristic of tungsten alloy bar is its high mass per unit volume. It is often used in applications that require a high weight-to-volume ratio, such as aerospace counterweights and medical radiation shielding.
sintering	The process of heating the compacted powder billet at high temperature to combine the particles to form a dense material. Tungsten alloy bar sintering is usually carried out in a vacuum or hydrogen environment to improve density and performance stability.
Liquid Phase Sintering	During the sintering process, binder elements (such as nickel and copper) form a liquid phase at high temperature, promoting the bonding of tungsten particles and filling of pores, which is used to improve the density and mechanical properties of tungsten alloy bars.
density	The ratio of the density of tungsten alloy bars to the theoretical density reflects the degree of porosity and defects within the material and is a key indicator for evaluating sintering quality and performance stability.
microstructure	The grain size, phase distribution and defect characteristics inside tungsten alloy bars are usually analyzed by scanning electron microscopy (SEM) or X-ray diffraction (XRD) to evaluate material properties.
tensile strength	The ability of tungsten alloy bars to resist fracture under tensile load is an important indicator for evaluating their mechanical properties and is suitable for high-load

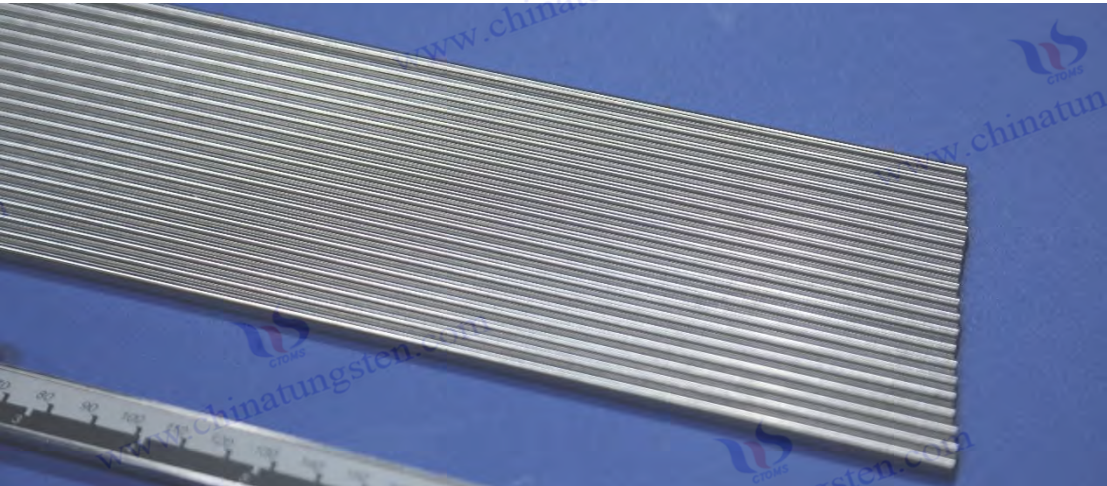
	scenarios such as aerospace structural parts and industrial molds.
hardness	Tungsten alloy bars' ability to resist surface deformation or scratching is usually measured by Vickers hardness (HV) or Rockwell hardness (HRC) testing and is suitable for industrial molds and wear-resistant parts.
toughness	The ability of tungsten alloy bars to absorb energy and resist fracture under impact or high stress is optimized by adding elements such as nickel and iron, making them suitable for dynamic load environments.
Electrical conductivity	The ability of tungsten alloy bars to transmit electric current is usually optimized by adding highly conductive elements such as copper, making them suitable for electronic electrodes and new energy battery connectors.
Arc erosion resistance	Tungsten alloy bars are suitable for electrodes in vacuum switches and plasma equipment due to their ability to resist surface erosion and wear under high voltage arc discharge.
Lead equivalent	Tungsten alloy strips have a thickness equivalent to that of lead in radiation shielding, reflecting its radiation resistance. They are widely used in shielding components of medical radiotherapy and imaging equipment.
Radiation attenuation coefficient	The ability of tungsten alloy strips to reduce the intensity of high-energy radiation (such as X-rays or gamma rays) reflects their shielding properties and is suitable for medical and industrial radiation protection.
Rare earth doping	The technology of adding trace rare earth elements (such as lanthanum, cerium, and yttrium) to tungsten alloy to optimize the microstructure, increase strength and high temperature resistance, and improve material performance.
3D printing	An additive manufacturing technology that produces complex-shaped tungsten alloy components by depositing material layer by layer, enabling high-precision and customized production, suitable for aerospace and medical fields.
Hot isostatic pressing	The technology of densifying tungsten alloy billets under high temperature and high pressure is used to eliminate porosity and defects and improve material density and performance.
Anti-oxidation coating	A protective layer (such as aluminum oxide or silicon nitride) applied to the surface of tungsten alloy bars is used to prevent high-temperature oxidation and corrosion, extending the service life of the material in high-

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sales@chinatungsten.com

	temperature environments.
surface roughness	The smoothness of the tungsten alloy bar surface, usually measured by the Ra value (e.g. Ra 0.2-0.4 μm), affects its corrosion resistance and assembly performance.
Geometric tolerances	The allowable deviations in size, shape and position of tungsten alloy bars reflect their geometric accuracy and are suitable for the assembly requirements of aerospace counterweights and medical shielding parts.
Green Manufacturing	In the production of tungsten alloy bars, by optimizing energy consumption, recycling waste and reducing emissions, we achieve an environmentally friendly and sustainable production method that is in line with modern industrial trends.
Quality traceability	By recording raw materials, process and test data, a traceability system for the entire tungsten alloy bar production process is established to ensure quality consistency and compliance.
Press molding	The process of pressing tungsten alloy powder into billets under high pressure in powder metallurgy to form the initial shape and increase density.
Heat treatment	The process of heating and cooling tungsten alloy bars to optimize the microstructure, eliminate internal stresses, and increase strength and toughness.
Recycling	Waste materials (such as cutting chips and grinding waste) from tungsten alloy bar production are collected, separated and purified, and reused in production to reduce costs and environmental impact.



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sales@chinatungsten.com