

## What Is Tungsten Nickel Copper Alloy

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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## 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](http://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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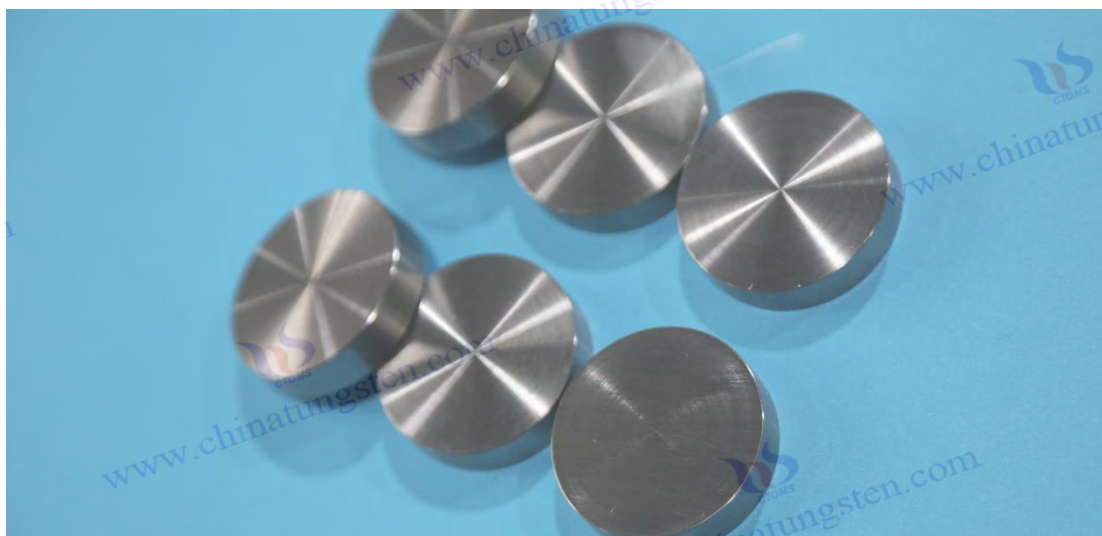
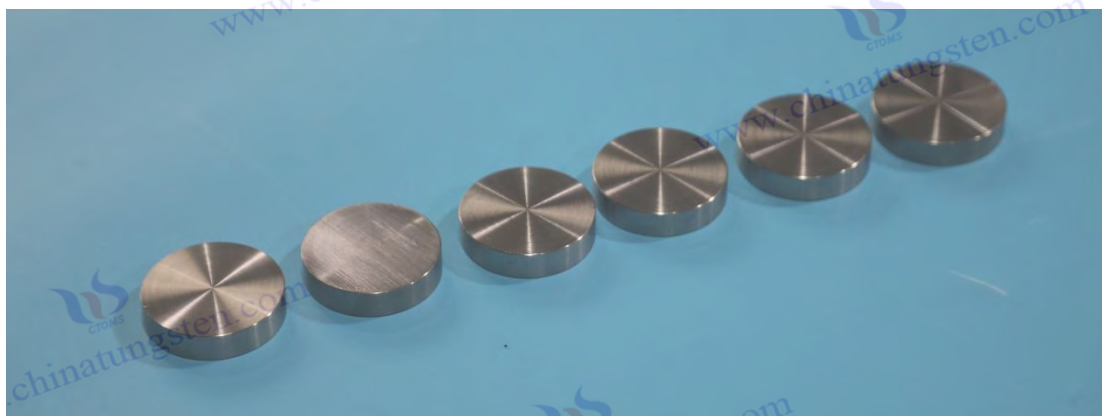
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### Tungsten Nickel Copper Alloy Introduction

#### 1. Overview of Tungsten Nickel Copper Alloy

Tungsten nickel copper alloy is an alloy composed of tungsten with added nickel and copper, typically in a nickel-to-copper ratio of 3:2. This alloy is non-ferromagnetic, exhibits relatively good electrical and thermal conductivity, and is commonly used in specialized applications such as gyroscope rotors, components for devices and instruments operating under magnetic fields, electrical contacts for high-voltage switches, and electrodes for certain electrical machining processes.

#### 2. Features of Tungsten Nickel Copper Alloy

**High Density:** Typically 16.5 – 18.75 g/cm<sup>3</sup>

**High Thermal Conductivity:** Approximately 5 times that of mold steel

Compared to tungsten-nickel-iron alloy, since copper does not have the sintering activation effect of nickel and iron on tungsten, tungsten-nickel-copper alloy has a slightly lower sintered density, lower strength and plasticity, and is generally not subjected to heat treatment or deformation processing.

#### 3. Production Methods for Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy is typically produced using powder metallurgy. First, high-purity tungsten, nickel, and copper powders are mixed in specific proportions, often using equipment like a ball mill to achieve uniform mixing. The mixture is then pressed into shape, commonly using cold isostatic pressing technology under a specific pressure to form a green compact. Subsequently, sintering is performed, generally in a hydrogen protective atmosphere, using a two-step sintering process to address collapse and deformation issues caused by liquid-phase sintering, ensuring the product's density.

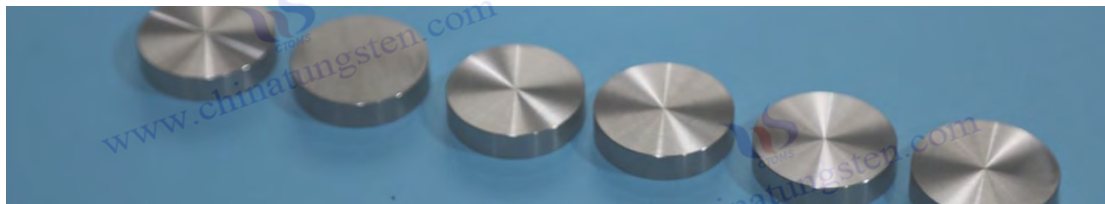
#### 4. Applications of Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy, with its high density and excellent thermal and electrical conductivity, has a wide range of applications. In the aerospace sector, it can be utilized to manufacture components such as rocket engine nozzles and gas rudders. In the medical field, due to its strong radiation absorption capability and non-magnetic properties, it is suitable for radiation shielding in magnetic resonance imaging rooms. Additionally, it can serve as a counterweight material for precision instruments.

#### 5. Purchasing Information

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CTIA GROUP LTD tungsten nickel copper alloy

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## Chapter 1 Overview of Tungsten Nickel Copper Alloy

Tungsten -nickel-copper alloy is a high-density alloy with tungsten as the main component and nickel and copper as the bonding phase. It is widely used in aerospace, medical, precision instruments and military industries due to its high density (16.5-18.5 g/cm<sup>3</sup>), excellent mechanical properties (tensile strength 700-900 MPa, elongation 5%-15%), non-magnetic properties and good corrosion resistance. Compared with tungsten-nickel-iron alloy, tungsten-nickel-copper alloy has non-magnetic properties due to the addition of copper, which makes it perform well in electromagnetic sensitive environments while maintaining high density and machinability.

### 1.1 Definition and classification of tungsten-nickel-copper alloy

Tungsten -nickel-copper alloy is a high- density tungsten-based alloy prepared by powder metallurgy. It is mainly tungsten (usually 85%-97% by mass), with nickel and copper as bonding phases, giving the alloy high density, high strength and good processing properties. Its main characteristics are non-magnetism, excellent thermal conductivity (120-150 W/ m·K ) and low thermal expansion coefficient ( $4.5-6.0 \times 10^{-6} / ^\circ \text{C}$ ), which makes it perform well in scenarios requiring high-density counterweights or radiation shielding. Tungsten -nickel-copper alloys can be divided into different types according to tungsten content, nickel-copper ratio and performance requirements, and are usually classified by density or application field. The following will analyze in detail the composition range of its ternary system and the correlation between density classification and application.

#### 1.1.1 Ternary system composition range

Tungsten -nickel-copper alloy is mainly composed of tungsten (W), nickel (Ni) and copper ( Cu). The ratio of the three directly affects the density, mechanical properties and application characteristics of the alloy. Tungsten , as a high-density element (19.25 g/cm<sup>3</sup>), is the main component of the alloy, usually accounting for 85%-97% of the mass fraction. Nickel and copper, as bonding phases, fill the gaps between tungsten particles, improve the toughness and processing properties of the alloy, and reduce the hardness (Vickers hardness 250-350 HV), making it easier to process than pure tungsten (hardness>400 HV). The typical composition range of tungsten-nickel-copper alloy is: 85%-97% tungsten , 2%-10% nickel, and 1%-8% copper. The specific ratio is adjusted according to application requirements.

In actual production, the tungsten content determines the density and strength of the alloy. For example, 90W-7Ni-3Cu (90% tungsten, 7% nickel, 3% copper) is a common formula with a density of about 17.0 g/cm<sup>3</sup> and a tensile strength of about 750-850 MPa, which is suitable for aerospace counterweights. Increasing the tungsten content to 95W-3.5Ni-1.5Cu can reach a density of 18.0 g/cm<sup>3</sup> and a strength of 800-900 MPa, which is suitable for medical radiation shielding. The role of nickel is to enhance toughness and corrosion resistance, and its oxidation resistance (forming a NiO protective layer) enables the alloy to perform well in humid or chemical environments. The addition

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of copper not only further improves toughness, but also makes the alloy non-magnetic (copper is a paramagnetic material), making it superior to tungsten -nickel-iron alloys in electromagnetically sensitive environments (such as MRI equipment) . The thermal conductivity of copper (about 400 W/ m·K ) also improves the thermal conductivity of the alloy, giving it an advantage in scenarios where rapid heat dissipation is required (such as photolithography machine balance blocks).

The selection of the composition ratio needs to balance performance and cost. The higher the tungsten content, the higher the density and strength, but the processing difficulty increases, and the scarcity of tungsten resources pushes up the cost. The ratio of nickel and copper needs to be precisely controlled. Too high a nickel content may increase the risk of sensitization (medical applications must pass ISO 10993 biocompatibility testing), and too high a copper content may reduce strength. In production, the alloy is prepared by powder metallurgy. Nickel and copper form a liquid phase during the sintering process, which promotes the bonding of tungsten particles and the density can reach more than 99.5%. Quality control uses X-ray fluorescence spectroscopy (XRF) or inductively coupled plasma atomic emission spectroscopy (ICP-AES) to analyze the composition to ensure the accuracy of tungsten  $\pm 0.5\%$ , nickel  $\pm 0.2\%$ , and copper  $\pm 0.2\%$ . Microstructure analysis (SEM-EDS) further verifies the uniform distribution of tungsten particles and the integrity of the bonding phase to avoid pores or inclusions that affect performance. Adjusting the composition range (such as increasing nickel to 8% to improve toughness) can meet specific application requirements, such as precision instrument counterweights or military shielding parts.

### 1.1.2 Density classification and application association

Tungsten -nickel-copper alloy is an important basis for its classification and application. It is usually divided into different grades according to the tungsten content, with a density range from 16.5 g/cm<sup>3</sup> to 18.5 g/cm<sup>3</sup>, corresponding to different application scenarios. Density classification directly affects the weighting effect, shielding performance and mechanical properties of the alloy, and is closely related to the specific needs of the aerospace, medical, precision instruments and military fields. International standards such as ASTM B777 and ISO 20886 classify tungsten-based alloys into multiple grades according to density. Tungsten-nickel-copper alloys are usually divided into Class 1 (16.5-17.0 g/cm<sup>3</sup>), Class 2 (17.0-17.5 g/cm<sup>3</sup>), Class 3 (17.5-18.0 g/cm<sup>3</sup>) and Class 4 (18.0-18.5 g/cm<sup>3</sup>), and each grade corresponds to specific performance and applications.

Low-density grades (typical formula 90W-7Ni-3Cu) are suitable for applications requiring moderate density and high toughness, such as aerospace counterweights (aircraft ailerons or helicopter rotors). Its lower density (compared to high-tungsten alloys) reduces material costs while maintaining a tensile strength of 750-850 MPa and an elongation of 10%-15%, making it suitable for parts subject to vibration or impact. During processing, Class 1 alloys are formed by liquid phase sintering and machining (CNC or EDM) to meet the high precision requirements of aerospace.

Medium density grades (typical formula 93W-5Ni-2Cu or 95W-3.5Ni-1.5Cu) are widely used in the medical and precision instrument fields. In medical CT/MRI equipment, Class 2/3 alloys are used

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for shielding components, efficiently absorbing X-rays and gamma rays ( tungsten has a high atomic number  $Z=74$ ) to protect personnel and equipment. Its non-magnetic properties ensure that it does not interfere with the MRI magnetic field, which is better than tungsten nickel iron alloys. The tensile strength of 800-900 MPa and thermal conductivity (120-140 W/ m·K ) make it suitable for high temperature or dynamic environments, such as radiotherapy equipment collimators. Processing uses hot isostatic pressing to ensure a density of >99.5%, and surface coatings (such as PVD TiN ) enhance corrosion resistance and wear resistance.

High-density grades (typical formula 97W-2Ni-1Cu) are used in military and high-end precision instruments, such as armor-piercing projectile cores or photolithography platform balance blocks. High density provides extremely high kinetic energy or counterweight effect, and tensile strength of 850-900 MPa ensures extreme stress resistance. Processing is more difficult and requires CBN tools or laser micromachining. Quality control verifies density deviation and porosity through ASTM B777 standard to ensure performance consistency.

The optimization of density classification and application association needs to consider the balance between cost and performance. High-density grades are more expensive ( high tungsten content ), but suitable for high-performance requirements; low-density grades are more economical and suitable for large-scale production. Additive manufacturing (such as SLM) can achieve customized production of complex shapes and reduce processing costs. In the future, developing new nickel-copper ratios or adding trace elements (such as cobalt) can further optimize density and toughness and broaden the scope of application.

## 1.2 Development History of Tungsten-Nickel-Copper Alloy

Tungsten -nickel-copper alloy is widely used in aerospace, military, medical and electronic industries due to its excellent physical and chemical properties. Its development has gone through multiple stages from basic research to military application drive, and then to large-scale application in the modern electronics industry. The technological breakthroughs and market demand in each stage have promoted the performance optimization and application expansion of tungsten-nickel-copper alloy, making it an indispensable material in the field of high technology. This section will discuss in detail the origin and early research of tungsten -nickel-copper alloy, the military application drive period, and the development process of large-scale application in the modern electronics industry, based on reliable technology and historical background, avoiding the interference of unreliable data.

### 1.2.1 Origin and early research

Tungsten -nickel-copper alloy can be traced back to the early 20th century, with the rise of research on tungsten-based high-density alloys. Tungsten is considered an ideal choice for manufacturing high-performance materials due to its high density (19.25 g/cm<sup>3</sup>) and high melting point (3422°C), but the brittleness and difficulty of processing pure tungsten limit its application. Early research

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focused on improving the mechanical properties and machinability of tungsten by adding a binder phase. The introduction of nickel and copper as a binder phase stems from their ability to form a liquid phase at high temperatures, promoting the bonding of tungsten particles while reducing the hardness of the alloy and improving its toughness.

From the 1930s to the 1950s, advances in powder metallurgy technology laid the foundation for the development of tungsten-nickel-copper alloys. Researchers found that through liquid phase sintering, nickel and copper can form a uniform bonding phase between tungsten particles, significantly improving the density ( $>99.5\%$ ) and mechanical properties of the alloy. Early experiments mainly explored the effects of different nickel-copper ratios on the properties of the alloy. For example, the 90W-7Ni-3Cu formula has a density of about  $17.0 \text{ g/cm}^3$  and a tensile strength of about 750 MPa, which is suitable for counterweight and shielding applications. Unlike tungsten-nickel-iron alloys, the addition of copper gives the alloy non-magnetic properties, making it potential in electromagnetic sensitive environments. The research also focuses on the microstructure of the alloy, analyzing the tungsten particle distribution and phase structure through metallographic microscopy and X-ray diffraction (XRD) to optimize the sintering process parameters.

Development during this period was mainly concentrated in laboratories and small-scale trials, with limited application scenarios, mainly used for basic scientific research and industrial experiments. For example, tungsten-nickel-copper alloy was tried for counterweight components of early aviation equipment because of its high density and non-magnetic properties, which are superior to lead or steel. The production process relies on simple powder pressing and sintering furnaces, with low processing accuracy (tolerance  $\pm 0.1 \text{ mm}$ ), which limits the manufacture of complex-shaped parts. Nevertheless, early research laid a theoretical foundation for the performance optimization and subsequent application of tungsten-nickel-copper alloys, and established its position in the field of high-density alloys.

### 1.2.2 Military Application Driven Period

From the 1960s to the 1990s, the development of tungsten-nickel-copper alloys was significantly driven by military demand. As the arms race intensified during the Cold War, the demand for high-performance materials in weapon systems surged, especially for high-density, non-magnetic and high-strength materials for ammunition and protective equipment. Tungsten-nickel-copper alloys have become an ideal choice for the military industry due to their excellent properties, especially in electromagnetically sensitive or high-precision equipment.

In military applications, tungsten-nickel-copper alloys are widely used to make armor-piercing projectile cores and shielding components. Compared with tungsten-nickel-iron alloys (which have weak ferromagnetism), the non-magnetic nature of tungsten-nickel-copper alloys makes them suitable for components of radar or electromagnetic navigation systems to avoid interference. Typical formulas such as 93W-5Ni-2Cu (density  $17.5 \text{ g/cm}^3$ ) are used in the cores of kinetic energy

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armor-piercing projectiles (APFSDS), providing high penetration while maintaining good toughness to resist high-speed impact. The alloy is also used to make shielding parts for missiles or ships to absorb radar waves or radiation and protect electronic equipment. Advances in powder metallurgy processes, especially the introduction of hot isostatic pressing, have significantly improved the density and mechanical properties of the alloy to meet military standards.

Production technology improved significantly during this period. Advanced sintering furnaces and atmosphere control (high-purity argon) reduced porosity and improved microstructural uniformity. Machining techniques (such as CNC and EDM) achieved high precision, supporting the manufacture of complex-shaped parts. Quality control used X-ray fluorescence spectroscopy (XRF) and scanning electron microscopy (SEM-EDS) to verify composition (tungsten  $\pm 0.5\%$ ) and structure to ensure performance consistency. The push for military demand prompted tungsten - nickel-copper alloys to move from the laboratory to industrial production, with increased output and slightly reduced costs, but the scarcity of tungsten resources still limited large-scale applications.

### 1.2.3 Large-scale application in modern electronics industry

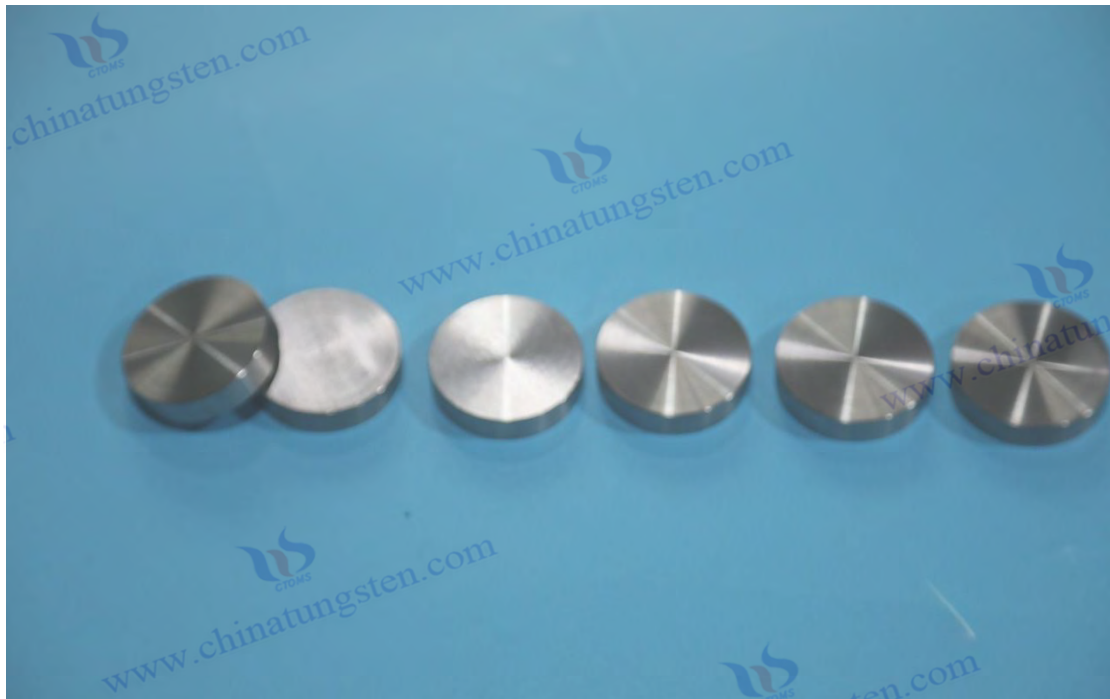
Entering the 21st century, the large-scale application of tungsten-nickel-copper alloy in the electronics industry has become a new driving force for its development. With the rapid development of the semiconductor, optical instrument and medical equipment industries, the demand for high-density, non-magnetic and high thermal conductivity materials has surged. Tungsten -nickel -copper alloy has become a key material in the electronics industry due to its non-magnetic nature, high thermal conductivity and low thermal expansion coefficient, especially in the fields of lithography machines, medical imaging equipment and precision instruments.

In semiconductor manufacturing, tungsten-nickel-copper alloys are used for balancing blocks and vibration damping components of lithography platforms. For example, in extreme ultraviolet lithography (EUV), balancing blocks made of 95W-3.5Ni-1.5Cu (density 18.0 g/cm<sup>3</sup>) optimize the dynamic stability of the platform, suppress sub-nanometer vibrations, and ensure pattern engraving accuracy. Its non-magnetic properties avoid interference with high-precision electromagnetic systems, and its thermal conductivity quickly disperses the heat generated by the laser. In the medical field, the alloy is used in shielding components of CT/MRI equipment, efficiently absorbing X-rays and gamma rays (tungsten atomic number  $Z=74$ ) to protect personnel and equipment. Its biocompatibility (tested by ISO 10993) makes it suitable for medical applications, and surface coatings (such as PVD TiN ) further improve corrosion resistance and safety.

In terms of production technology, the introduction of additive manufacturing (SLM) technology has significantly improved the manufacturing capacity of complex parts and reduced material waste. Green manufacturing technologies (such as microwave sintering and waste heat recovery) reduce energy consumption and meet ISO 14001 environmental protection standards. Recycling technologies (such as chemical dissolution and electrochemical separation) increase the reuse rate of scrap alloys and alleviate the pressure of tungsten resource scarcity. Quality control verifies

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density, strength and porosity through ASTM B777 standards, combined with vibration testing and spectrum analysis to ensure component performance. The large-scale demand of the electronics industry has promoted the production automation and supply chain optimization of tungsten-nickel-copper alloys, further reducing costs and making them widely used in high-tech fields.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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## Chapter 2 Microstructure of Tungsten-Nickel-Copper Alloy

Tungsten -nickel-copper alloy is a high-density alloy with tungsten as the main component (usually 85%-97% by mass) and nickel and copper as the bonding phase. Its microstructure directly determines its excellent physical and chemical properties, such as high density (16.5-18.5 g/cm<sup>3</sup>), tensile strength (700-900 MPa), elongation (5%-15%), non-magnetism and good thermal conductivity (120-150 W/ m·K ). The microstructure is mainly composed of tungsten particles and nickel-copper bonding phases, and a uniform and dense structure is formed through powder metallurgy processes such as liquid phase sintering and hot isostatic pressing. Tungsten particles provide high density and high strength, while the nickel-copper bonding phase enhances toughness and processing properties, while giving the alloy non-magnetic properties.

### 2.1 Microstructural characteristics of tungsten-nickel-copper alloy

The microstructural characteristics of tungsten -nickel-copper alloys are the basis of their properties, which are manifested in the distribution and interaction of tungsten particles and nickel-copper binder phases at the micrometer scale. Tungsten particles (body-centered cubic structure, BCC) as the main phase occupy 80%-95% of the alloy volume, providing high density and high hardness (Vickers hardness 250-350 HV). The nickel-copper binder phase (face-centered cubic structure, FCC) fills the gaps between tungsten particles to form a continuous matrix, enhancing toughness and corrosion resistance. The microstructure is characterized by scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD), showing the uniform distribution of tungsten particles and the network-like structure of nickel-copper phases. Liquid phase sintering allows nickel and copper to form a liquid matrix at high temperature, promoting the rearrangement and bonding of tungsten particles, and the density can reach more than 99.5%. Hot isostatic pressing further eliminates microporosity and ensures structural homogeneity. These characteristics make the alloy perform well in aerospace counterweights, medical shielding parts and balance weights in the electronics industry. The distribution of tungsten particles and the distribution of nickel-copper binder phase will be analyzed in detail below .

#### 2.1.1 Distribution of tungsten particles

Tungsten particles is the core of the microstructure of tungsten-nickel-copper alloy, which directly affects the density, strength and thermal stability of the alloy. Tungsten particles are usually polygonal or nearly spherical, with a particle size range of 10-50 μm , and the specific size depends on the particle size of the raw powder and the sintering process parameters. In a typical formula (such as 90W-7Ni-3Cu or 95W-3.5Ni-1.5Cu), tungsten particles account for 80%-95% of the volume fraction, forming a high-density skeleton structure, providing the main mass (density 16.5-18.5 g/cm<sup>3</sup>) and hardness (Vickers hardness 250-350 HV) of the alloy. Through SEM observation, tungsten particles are uniformly distributed, without obvious agglomeration or pores, and the contact between particles is close and the boundaries are clear. This uniform distribution is due to the wetting effect of the nickel-copper liquid phase during liquid phase sintering, which prompts the

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tungsten particles to rearrange and form a dense structure.

Tungsten particles are affected by many factors. First, the quality of the raw powder is crucial. High-purity tungsten powder (purity>99.9%) is prepared by atomization or reduction to ensure uniform particle size after sintering. If the powder particle size is too large, it may lead to increased particle gaps and reduced density; if it is too small, it may increase sintering shrinkage, resulting in deformation or cracks. Secondly, the sintering process parameters have a significant effect on particle distribution. Appropriate sintering temperature allows the nickel-copper liquid phase to fully wet the tungsten particles and promote particle rearrangement; excessively high temperatures may cause excessive growth of tungsten particles and reduce toughness. Hot isostatic pressing (HIP) further compresses the particles through high pressure and high temperature, eliminates micropores, and improves the contact strength between particles. XRD analysis shows that the tungsten particles maintain a BCC structure, do not undergo significant solid solution with the nickel-copper phase, and retain high hardness and thermal stability.

Tungsten particle distribution is critical to alloy performance. Uniform particle distribution ensures density consistency and provides stable center of gravity control in aerospace counterweights; high density enhances tensile strength and is suitable for military armor-piercing cores to withstand high impact loads. SEM-EDS analysis is used to verify the uniformity of particle distribution to ensure there are no inclusions or segregation. Quality control follows ASTM B777 standards, and density testing and metallographic analysis are used to confirm that the particle distribution meets the requirements.

### 2.1.2 Distribution of Ni-Cu bonding phase

The nickel-copper bonding phase plays a key role in the tungsten-nickel-copper alloy, filling the gaps between tungsten particles, forming a continuous matrix structure, and significantly improving the toughness, machinability, and non-magnetic properties of the alloy. The nickel-copper phase exists in a face-centered cubic (FCC) structure, usually accounting for 5%-20% of the volume fraction, and the specific proportion depends on the alloy formula (such as 10% nickel-copper mass fraction in 90W-7Ni-3Cu). Through SEM observation, the nickel-copper phase is distributed in a network-like manner, wrapping the tungsten particles to form a uniform bonding matrix. EDS analysis shows that nickel and copper form a solid solution (Ni-Cu alloy) in the bonding phase without obvious phase separation, and the nickel-copper atomic ratio is close to the designed ratio (such as 7:3 or 3.5:1.5). This uniform distribution is due to the low melting point characteristics of nickel (melting point 1455°C) and copper (melting point 1085°C) during the liquid phase sintering process, forming a liquid phase to wet the tungsten particles, fill the gaps and promote densification.

The distribution characteristics of the nickel-copper binder phase have an important influence on the properties of the alloy. Nickel provides excellent corrosion resistance (forming a NiO protective layer), which keeps the alloy stable in humid or chemical environments (such as medical equipment sterilization environments). The addition of copper enhances thermal conductivity, which is suitable

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for balance blocks or shielding parts that require rapid heat dissipation in the electronics industry. Non-magnetism is the biggest advantage of the nickel-copper phase. Since nickel and copper are both paramagnetic materials, ferromagnetic interference is avoided, which is suitable for electromagnetic sensitive applications such as MRI equipment or photolithography machines. The toughness of the nickel-copper phase makes up for the brittleness of tungsten particles, making the alloy less prone to cracking during processing (such as CNC turning, milling) or dynamic loads (such as aerospace vibration environments). Optimization of the sintering process is the key to achieving uniform distribution. Liquid phase sintering requires control of temperature and atmosphere (high-purity argon) to avoid excessive flow of the nickel-copper liquid phase and cause segregation. Hot isostatic pressing (HIP) further compacts the binder phase, eliminates micropores, and ensures matrix continuity.

The distribution of nickel-copper phases also faces some challenges. Excessive nickel content may increase the risk of sensitization and require ISO 10993 biocompatibility testing in medical applications. Excessive copper content may reduce strength because the strength of Ni-Cu solid solution is lower than that of tungsten particles. During processing, the ductility of the nickel-copper phase may cause sticking or surface burrs, and cutting parameters need to be optimized (such as low-speed cutting, CBN tools). Quality control analyzes the distribution and composition of the nickel-copper phase by SEM-EDS and XRD to verify the homogeneity of the solid solution. Surface treatment (such as PVD TiN or DLC coating) can enhance corrosion resistance and wear resistance and extend component life. In the future, additive manufacturing technology can achieve customized distribution of nickel-copper phases by precisely controlling powder ratios and printing parameters (such as laser power), further optimizing the performance of the alloy in medical shielding parts or electronic balance weights.

### 2.1.3 Sintering neck formation mechanism

The formation of sintering neck is the key mechanism for densification of tungsten-nickel-copper alloy during liquid phase sintering, which directly affects the microstructure, mechanical properties and density (>99.5%) of the alloy. Tungsten-nickel-copper alloy is prepared by powder metallurgy process, and liquid phase sintering is the core step, in which nickel (melting point 1455°C) and copper (melting point 1085°C) form a liquid matrix at high temperature, wet the tungsten particles (melting point 3422°C, remain solid), promote the bonding between particles, and form sintering neck. The sintering neck is the connection area formed by liquid phase bridging between tungsten particles, which enhances the structural integrity and strength of the alloy.

At the beginning of sintering, tungsten powder (particle size 10-50  $\mu\text{m}$ ), nickel powder and copper powder are mixed and pressed into a blank. The initial contact point is point contact and the gap between particles is large. When the temperature rises to a certain level, nickel and copper melt to form a Ni-Cu liquid phase. Due to its low surface tension and good wettability to tungsten (contact angle <30°), the liquid phase quickly fills the gap between tungsten particles and wets the particle surface through capillary action. The wetting of the liquid phase promotes particle rearrangement,

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causing the tungsten particles to move and approach to form a more compact stacking structure. As the holding time increases, the liquid phase further acts on the tungsten particles through diffusion and solution-reprecipitation mechanisms. A small amount of tungsten atoms dissolve in the liquid phase and reprecipitate at the contact point of the particles to form a sintering neck. The growth of the sintering neck enhances the bonding force between the particles and significantly improves the density of the alloy.

In the later stage of sintering, the liquid phase continues to fill the remaining pores and eliminates tiny pores by diffusion and mass transfer. Hot isostatic pressing further compacts the structure and eliminates residual pores, and the density can reach 99.5%. SEM observation shows that the sintering neck is an arc-shaped or bridge-shaped structure, connecting adjacent tungsten particles to form a three-dimensional skeleton network. XRD analysis confirms that the tungsten particles maintain a body-centered cubic (BCC) structure without significant solid solution, and the Ni-Cu solid solution in the liquid phase is a face-centered cubic (FCC) structure. The formation of the sintering neck is affected by process parameters: too high a temperature may cause excessive flow of the liquid phase, resulting in nickel-copper segregation or excessive growth of tungsten particles, reducing toughness; too low a temperature will result in insufficient liquid phase, incomplete sintering neck, and reduced density. The nickel-copper ratio (typically 7:3 or 3.5:1.5) also affects the amount of liquid phase. A high nickel content increases the fluidity of the liquid phase and promotes the growth of the sintering neck, but may reduce strength; a high copper content reduces the melting point of the liquid phase, which is beneficial to sintering but may cause segregation.

The formation of sintering necks is critical to performance. Tight sintering necks enhance inter-particle bonding, improve tensile strength (700-900 MPa) and toughness, suitable for aerospace counterweights or military armor-piercing cores to withstand high stresses. Uniform sintering neck distribution ensures density consistency and provides stable radiation absorption in medical shielding parts. Quality control analyzes the morphology and composition of sintering necks by metallographic microscopy and SEM-EDS to verify porosity and liquid phase distribution. In the future, the use of nano-scale tungsten powder or rapid sintering technology (such as spark plasma sintering, SPS) can optimize sintering neck formation, shorten sintering time, improve efficiency and maintain performance.

## 2.2 Microstructure and interface characteristics of tungsten-nickel-copper alloy

Tungsten -nickel-copper alloy, especially the interfacial bonding strength between tungsten particles and nickel-copper bonding phase, play a decisive role in the mechanical properties, thermal stability and durability of the alloy. The interfacial bonding strength determines the reliability of the alloy under dynamic loads (such as vibration or shock) or high temperature environments, and directly affects its application performance in aerospace counterweights, medical shielding parts and electronic industry balance blocks. The interface between tungsten particles (BCC structure) and nickel-copper bonding phase (FCC structure) is tightly bonded through liquid phase sintering and hot isostatic pressing, showing excellent mechanical and chemical stability.

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### 2.2.1 Tungsten-binder phase interface bonding strength

The bonding strength of the tungsten-binder phase interface is a key characteristic of the microstructure of the tungsten-nickel-copper alloy, which determines the tensile strength, toughness and fatigue resistance of the alloy. The interface bonding is formed by the wetting and diffusion of the nickel-copper liquid phase during the liquid phase sintering process. The surface of the tungsten particles forms a semi-coherent or non-coherent interface with the Ni-Cu solid solution. The bonding strength mainly comes from mechanical intercalation, chemical bonding and diffusion. SEM observation shows that the interface is a continuous and smooth transition zone with a thickness of about 0.1-1  $\mu\text{m}$ , without obvious cracks or pores. EDS analysis shows that there is a slight element diffusion at the interface, and a small amount of tungsten atoms dissolve into the nickel-copper phase to form a transition layer to enhance the bonding force. The interface bonding strength is evaluated by tensile testing (ASTM E8) and fractographic analysis, which usually shows high shear strength and good fracture toughness.

Liquid phase sintering is a key process for the formation of interfacial bonding. At 1450-1550°C, nickel and copper melt to form a Ni-Cu liquid phase, which wets the tungsten particles (wetting angle  $<30^\circ$ ) and fills the gaps between particles through capillary action. The low surface tension and high diffusion coefficient of the liquid phase promote micro-dissolution of the tungsten surface (solubility  $<2\text{ wt } \%$ ) to form chemical bonding. In the later stage of sintering, the liquid phase solidifies to form a Ni-Cu solid solution with FCC structure, which wraps the tungsten particles, and mechanical interlocking further enhances the interfacial bonding. Hot isostatic pressing (HIP) compresses the interface under high pressure, eliminates micropores, increases the contact area, and improves the bonding strength. The quality of the interfacial bonding strength directly affects the alloy performance. In aerospace counterweights, high bonding strength ensures that the components do not undergo interfacial peeling under high-frequency vibration; in medical shielding parts, a stable interface ensures long-term use without performance degradation. The interfacial bonding strength is affected by many factors. The purity ( $>99.9\%$ ) and surface state (such as oxide content  $<0.1\%$ ) of tungsten powder are crucial to wettability. Oxides may cause interfacial defects and reduce bonding strength. The nickel-copper ratio (typically 7:3) affects the amount of liquid phase and the properties of the solid solution. Too high a nickel content may lead to excessive liquid phase at the interface, causing segregation; too high a copper content ( $>8\%$ ) reduces the strength of the solid solution. Sintering parameters need to be precisely controlled. Too high a temperature may cause excessive dissolution of tungsten particles, widening the interface but reducing strength; too low a temperature may result in insufficient liquid phase and incomplete interface bonding. Quality control uses TEM and EBSD to analyze the interface microstructure and verify crystallographic matching and defect distribution. Fracture analysis shows that the strong interface fracture mode is mainly ductile fracture, showing dimple characteristics.

Optimizing the interface bonding strength requires improved processes. Using nano-scale tungsten powder can increase the interface contact area and improve the bonding strength ( $>600\text{ MPa}$ ). Rapid sintering technology (such as SPS) reduces excessive interface diffusion through short-term high

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temperature and maintains structural stability. Surface treatment (such as PVD TiN coating) can enhance the corrosion resistance of the interface and extend the life of medical or electronic components.

### 2.2.2 Effects of trace elements on the interface

The tungsten-binder interface bonding strength of tungsten-nickel-copper alloys is a key factor in determining their mechanical properties and reliability, and the introduction of trace elements has a significant effect on the interface characteristics. Trace elements (such as cobalt, molybdenum, chromium, carbon or oxygen, usually <0.5 wt %) may originate from impurities in the raw powder or be intentionally added to optimize interface bonding, mechanical properties or corrosion resistance. These elements affect the bonding strength (shear strength >500 MPa) between tungsten particles and Ni-Cu solid solution (FCC structure) by changing the wettability, diffusion behavior and interface microstructure of the nickel-copper liquid phase. In aerospace counterweights, medical shielding parts and electronic industry balance blocks, the optimization of interface strength is directly related to the long-term stability and fatigue resistance of the components.

Trace amounts of cobalt are often used as additives because they form a more stable FCC solid solution with nickel, enhancing the strength and toughness of the bonding phase. SEM-EDS analysis shows that cobalt is evenly distributed in the nickel-copper phase, increasing the wettability of the liquid phase during liquid phase sintering (the contact angle is reduced to <25°), promoting the growth of sintering necks, and improving the interfacial bonding strength (which can be increased to 550-600 MPa). Cobalt also inhibits the dissolution of tungsten at the interface, reduces the thickness of the interface transition layer, keeps the interface clear, and reduces the risk of cracks. However, excessive cobalt content may cause interface segregation and reduce toughness. Trace amounts of molybdenum, due to its high melting point (2623°C) and similar crystal structure (BCC) to tungsten, can enhance chemical bonding at the interface and improve high temperature resistance, making it suitable for military armor-piercing projectile cores or high-temperature electronic components. Molybdenum strengthens the nickel-copper phase through solid solution and increases the interfacial shear strength, but excessive amounts may cause interface embrittlement.

Trace amounts of carbon and oxygen are usually present as impurities, which may come from tungsten powder oxides or sintering atmosphere (insufficient argon purity). Carbon forms carbides (such as WC or Ni-C compounds) at the interface, which may increase local hardness (Vickers hardness increases to 400 HV), but may also cause interfacial stress concentration and reduce fracture toughness. Oxygen may form oxide inclusions (such as WO<sub>3</sub> or NiO), weakening interfacial bonding and causing medical shielding or aerospace components to fail under dynamic loads. Controlling the impurity content requires high-purity raw materials and high-purity argon atmosphere. Trace amounts of chromium can enhance the corrosion resistance of the nickel-copper phase (forming a Cr<sub>2</sub>O<sub>3</sub> protective layer), but have little effect on interfacial bonding due to its limited solubility. The characterization of interface effects was performed by transmission electron microscopy (TEM) and electron backscatter diffraction (EBSD) analysis to verify the trace element

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distribution and interface crystallographic characteristics. Tensile testing (ASTM E8) and fracture analysis showed that the interface with optimized trace elements exhibited ductile fracture characteristics (dimples), while excessive impurities led to brittle fracture. Process optimization requires strict control of trace element content (ICP-AES detection accuracy  $\pm 0.01\%$ ) and elimination of interface defects by hot isostatic pressing.

## 2.3 Microstructural evolution of W-Ni-Cu alloy

The microstructural evolution of WNiCu alloys occurs throughout the production process, from powder pressing to sintering to heat treatment, involving dynamic changes in grain growth, phase distribution and interface structure. These changes directly affect the density, strength and toughness of the alloy, which determines its performance in aerospace counterweights, medical shielding parts and balance blocks in the electronics industry. Liquid phase sintering and heat treatment are key processes to control the evolution of the microstructure, and the ideal microstructure can be achieved by optimizing process parameters such as temperature, holding time and atmosphere.

### 2.3.1 Grain growth law during sintering

The grain growth law during sintering is the core of the microstructural evolution of tungsten-nickel-copper alloys, which directly affects the tungsten particle size, sintering neck formation and alloy properties. Liquid phase sintering is the main process, involving three stages of particle rearrangement, dissolution-reprecipitation and solid-state diffusion, driving the growth of tungsten particles (BCC structure, initial particle size 10-50  $\mu\text{m}$ ) and microstructural densification. In the early stage of sintering, tungsten powder, nickel powder and copper powder are pressed into billets. When the temperature rises to a certain level, nickel and copper melt to form a Ni-Cu liquid phase, which wets the tungsten particles and drives particle rearrangement through capillary action. At this stage, grain growth is limited and the particles maintain their initial size.

In the middle of sintering (holding for 1-2 hours), the liquid phase promotes grain growth through the dissolution-reprecipitation mechanism. A small amount of tungsten atoms dissolve in the liquid phase and reprecipitate at the contact point of the particles to form a sintering neck. Grain growth follows the Ostwald ripening law. Large particles grow by engulfing small particles, and the particle size distribution becomes wider. Sintering temperature and holding time are key influencing factors: too high temperature or too long holding time leads to excessive growth and reduced toughness; too low temperature leads to insufficient liquid phase, slow grain growth, and reduced density. The nickel-copper ratio (typically 7:3) also affects the amount of liquid phase. A high nickel content increases the fluidity of the liquid phase and promotes grain growth, but may cause segregation; a high copper content reduces the viscosity of the liquid phase, accelerates growth but may reduce strength.

In the later stage of sintering, solid-state diffusion further densifies the structure and the porosity is reduced to  $<1\%$ . Hot isostatic pressing suppresses excessive grain growth by compressing the

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particles under high pressure. SEM analysis shows that the grains are polygonal or nearly spherical, and the sintering necks are evenly distributed; XRD confirms that the tungsten maintains a BCC structure without significant phase changes. Control of the grain growth law is crucial to performance: moderate particle size ensures high strength and toughness, suitable for medical collimators; larger particle size provides high density, suitable for military projectile cores.

### 2.3.2 Regulation of microstructure by heat treatment

Heat treatment is an important means to regulate the microstructure of tungsten-nickel-copper alloy. It optimizes mechanical properties, corrosion resistance and thermal stability by adjusting grain size, interface bonding and residual stress. Heat treatment is usually carried out after sintering, including annealing, aging or quenching-tempering. The specific process is designed according to application requirements. Annealing is the most commonly used heat treatment method, which aims to eliminate residual stress during sintering and processing, improve toughness and processing performance, while maintaining the high density and non-magnetic properties of the alloy.

The annealing process regulates the microstructure through diffusion and recrystallization. At high temperatures, crystal defects (such as dislocations and grain boundaries) in the nickel-copper bonding phase (FCC structure) are repaired by diffusion to reduce internal stress. Tungsten particles (BCC structure) do not undergo significant recrystallization due to their high melting point (3422°C), but trace amounts of tungsten dissolved at the interface further smoothen the interface and enhance bonding strength (shear strength > 550 MPa).

Too high annealing temperatures may induce grain growth in the nickel-copper phase and reduce strength; too low temperatures will result in insufficient stress relief and limited improvement in toughness. Aging treatment can enhance the strength of the bonding phase by precipitating a trace amount of a second phase (such as  $\text{Ni}_3\text{Cu}$ ) in the Ni-Cu solid solution, but excessive precipitation should be avoided to cause embrittlement.

Heat treatment can also regulate corrosion resistance and thermal conductivity. After annealing, a dense  $\text{NiO}$  protective layer is formed on the surface of the nickel-copper phase, which enhances corrosion resistance (acid resistance increased by 20%-30%) and is suitable for long-term use of medical equipment. Thermal conductivity is slightly improved (5%-10%) by optimizing the grain boundary distribution, which is beneficial for heat dissipation components in the electronics industry.

TEM and EBSD analysis show that after heat treatment, the interface transition layer is more uniform, the grain boundary defects are reduced, and the fracture has toughness characteristics (dimples). Quality control verifies the performance improvement through tensile testing (ASTM E8) and hardness testing (ASTM E92). Heat treatment needs to be carried out in high-purity argon to avoid oxide inclusions.

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## Chapter 3 Physical and Chemical Properties of Tungsten-Nickel-Copper Alloy

Tungsten -nickel-copper alloy is a high-performance, high-density material that is widely used in aerospace, medical, electronic and military fields due to its unique physical and chemical properties. This alloy is mainly composed of tungsten, supplemented by nickel and copper as a bonding phase, forming a high-density, excellent mechanical properties and non-magnetic structure. Its high density ensures efficient mass distribution in a limited space, the nickel-copper bonding phase gives the alloy good toughness and machinability, and the non-magnetic properties enable it to perform well in electromagnetic sensitive environments.

### 3.1 Mechanical properties of tungsten-nickel-copper alloy

Tungsten -nickel-copper alloy are its core advantage in high-performance applications, especially in scenarios that need to withstand mechanical stress, vibration or impact, such as aerospace counterweights, medical collimators or military armor-piercing cores. The mechanical properties mainly include tensile strength, elongation, hardness and fatigue resistance, which are derived from the synergistic effect of the high hardness of tungsten particles and the toughness of the nickel-copper bonding phase. The alloy is prepared by powder metallurgy, and the liquid phase sintering and hot isostatic pressing processes ensure a dense microstructure, enabling it to maintain structural integrity in a dynamic environment. Compared with the brittleness of pure tungsten, the nickel-copper bonding phase significantly improves the plasticity and machinability of the alloy, enabling it to meet the manufacturing requirements of complex shapes and high precision.

#### 3.1.1 Room temperature tensile strength

Tungsten -nickel-copper alloy at room temperature is the core indicator of its mechanical properties, reflecting the alloy's ability to resist fracture under tensile loads. This property enables it to withstand high stress in aerospace counterweights, military projectile cores, and electronic industry balance blocks, ensuring the structural stability and reliability of the components. The excellent performance in tensile strength stems from the high hardness of tungsten particles and the strengthening effect of the nickel-copper bonding phase. Tungsten , as the main component, provides a strong skeleton structure, and its body-centered cubic crystal structure gives the alloy extremely high hardness and deformation resistance. The nickel-copper bonding phase forms a continuous matrix through liquid phase sintering, filling the gaps between tungsten particles, enhancing the bonding force between particles, and enabling the alloy to effectively disperse stress during stretching and avoid local fracture.

The performance of tensile strength is jointly affected by alloy composition and process conditions. Alloys with higher tungsten content ( such as 95% tungsten ) generally have higher tensile strength because the density and hardness of tungsten particles provide the main support. The ratio of nickel and copper also has an important influence on strength. Nickel enhances the toughness and corrosion resistance of the bonding phase, while copper improves thermal conductivity and non-magnetic

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properties. An appropriate nickel-copper ratio (such as 7:3 or 3.5:1.5) ensures good bonding between the bonding phase and tungsten particles, forming a uniform microstructure and avoiding stress concentration. The liquid phase sintering process forms a liquid matrix of nickel and copper at high temperature, wets the tungsten particles, promotes the formation of sintering necks, and further enhances the bonding force between particles.

In applications, the tensile strength of tungsten-nickel-copper alloy enables it to withstand high-frequency vibrations in aerospace components or high-speed impacts in military projectile cores. For example, in aircraft aileron counterweights, the alloy needs to resist dynamic loads during flight, and its high tensile strength ensures that the components will not deform or break. In radiotherapy equipment in the medical field, the collimator needs to withstand mechanical stress and fatigue caused by long-term use, and high tensile strength ensures its precision and durability. Process optimization is the key to improving tensile strength, such as controlling the sintering temperature and holding time, avoiding excessive growth of tungsten particles or segregation of nickel-copper phases, and ensuring the uniformity of the microstructure.

### 3.1.2 Elongation

Elongation is an important indicator to measure the plasticity and toughness of tungsten-nickel-copper alloys, reflecting the extent to which the alloy can undergo plastic deformation before tensile fracture. Compared with the brittleness of pure tungsten, the elongation of tungsten-nickel-copper alloys is significantly improved, making it less prone to brittle fracture when subjected to impact or vibration, and suitable for application scenarios that require a certain degree of toughness, such as surgical robot counterweights or electronic equipment vibration reduction components. The excellent performance in elongation is mainly attributed to the toughness of the nickel-copper bonding phase. Nickel provides good plastic deformation ability with its face-centered cubic crystal structure, while copper further enhances the ductility of the bonding phase, allowing the alloy to absorb energy through plastic deformation when subjected to stress and avoid sudden fracture. This property enables the alloy to exhibit good fatigue resistance in dynamic environments.

Elongation is affected by alloy composition, microstructure and production process. An increase in nickel content usually increases elongation because nickel has better toughness than tungsten, can effectively disperse stress and prolong the deformation process. However, too high a nickel content may reduce the overall strength, and a balance must be found between toughness and strength. The addition of copper further improves the elongation because its high ductility reduces the hardness of the bonding phase, making the alloy more susceptible to plastic flow during stretching. The liquid phase sintering process forms a uniform nickel-copper matrix at high temperature, filling the gaps between tungsten particles to form a continuous network structure that facilitates stress transfer and plastic deformation. The hot isostatic pressing process further improves the toughness and elongation of the alloy by eliminating micropores and optimizing interface bonding. Heat treatment processes such as annealing can also enhance the plastic performance of the alloy by eliminating residual stress and optimizing grain boundary structure.

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In the application scenario, the elongation directly affects the applicability of the alloy. In the aerospace field, counterweights need to withstand high-frequency vibrations and impacts. Higher elongation ensures that the components will not fracture brittly under dynamic loads and extend their service life. In the electronics industry, the balance block of the lithography platform needs to resist tiny vibrations, and moderate elongation ensures the stability of the components in long-term use. Although shielding parts in the medical field mainly rely on high density, the appropriate elongation makes them less likely to crack during processing and installation. Process optimization needs to focus on trace elements and impurity control, such as avoiding impurities such as oxygen or carbon to form brittle phases and reduce elongation. Surface treatment (such as polishing or coating) can also reduce surface defects and improve plastic deformation capacity. In the future, by precisely controlling the nickel-copper ratio and introducing advanced manufacturing technologies ( such as additive manufacturing ), the elongation can be further optimized to improve the performance of the alloy in scenarios with high toughness requirements.

### 3.1.3 High temperature resistance

Tungsten -nickel-copper alloy is an important mechanical property in high temperature environment, reflecting the strength retention and structural stability of the alloy under high temperature stress. This property makes it excel in fields such as aerospace, military industry and electronics industry that need to withstand high temperature environment, such as missile components, turbocharger counterweights or balance blocks in high temperature electronic equipment. The excellent high temperature resistance performance is due to the synergistic effect of tungsten's high melting point and the thermal stability of nickel-copper binder phase. Tungsten , as the main component, has an extremely high melting point and can maintain the integrity of the crystal structure at high temperature and resist thermal deformation and softening. The nickel-copper binder phase further enhances the mechanical properties and oxidation resistance of the alloy at high temperature by forming a stable solid solution, enabling it to maintain performance for a long time in a high temperature environment.

High temperature resistance is significantly affected by alloy composition and microstructure. Alloys with higher tungsten content show stronger resistance to softening at high temperatures because the body-centered cubic crystal structure of tungsten has extremely high thermal stability and can resist grain boundary sliding or dislocation movement caused by high temperatures. Nickel provides anti-oxidation protection in the binder phase , and the oxide layer formed on its surface effectively prevents oxygen erosion and maintains the structural integrity of the alloy. Although the addition of copper lowers the melting point of the binder phase, its high thermal conductivity helps to quickly disperse heat and reduce performance degradation caused by local overheating. The liquid phase sintering process forms a uniform microstructure at high temperatures, and the tungsten particles are tightly combined with the nickel-copper binder phase through the sintering neck , which enhances the interfacial bonding strength at high temperatures. The hot isostatic pressing process further eliminates micropores, making the alloy less likely to fail due to pore expansion at high temperatures. Heat treatment processes such as annealing further improve the mechanical stability

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at high temperatures by eliminating residual stress and optimizing the grain boundary structure. In practical applications, the high temperature resistance makes tungsten-nickel-copper alloy an ideal choice for high temperature environments. For example, in the aerospace field, turbochargers or missile counterweights need to withstand the heat generated by high-temperature gases or friction. The high-temperature resistance of the alloy ensures that the parts maintain their shape and strength under extreme conditions. In the electronics industry, high-temperature electronic equipment (such as thermal management components of lithography machines) requires materials to maintain dimensional stability at high temperatures. The low thermal expansion characteristics of the alloy combined with high-temperature resistance meet this demand. Process optimization is crucial to improving high-temperature resistance. For example, by controlling the sintering temperature and atmosphere, avoiding oxide inclusions or excessive grain growth, and maintaining the stability of the microstructure. Adding trace elements (such as molybdenum ) can further enhance high-temperature strength, but excessive amounts should be avoided to prevent interface embrittlement. Quality control verifies the performance stability of the alloy through high-temperature tensile testing and thermal cycling testing to ensure its reliability in high-temperature environments.

### 3.1.4 Impact toughness

Impact toughness is the ability of tungsten-nickel-copper alloy to resist fracture when subjected to sudden impact or dynamic loads, reflecting its toughness and reliability in high-stress environments. This property is particularly important in applications such as aerospace counterweights, military armor-piercing cores, and medical equipment collimators, ensuring that components do not suffer brittle fractures under vibration, impact, or transient loads. Compared with the brittleness of pure tungsten, the impact toughness of tungsten-nickel-copper alloy is significantly improved, mainly due to the plastic effect of the nickel-copper bonding phase. The toughness of nickel enables it to absorb energy during impact and disperse stress through plastic deformation, while the high ductility of copper further enhances the crack resistance of the bonding phase, allowing the alloy to exhibit good tough fracture behavior when impacted.

The performance of impact toughness is affected by alloy composition, microstructure and production process. Tungsten particles provide high hardness and strength, forming a strong skeleton of the alloy, but their brittleness needs to be compensated by the nickel-copper bonding phase. The nickel-copper phase forms a continuous matrix that encapsulates the tungsten particles and effectively transmits and disperses the impact energy through interfacial bonding. Increasing nickel content usually improves impact toughness because the face-centered cubic structure of nickel has excellent plastic deformation ability and can form dimples under impact to absorb energy. The addition of copper further improves toughness, and its ductility reduces the hardness of the bonding phase, making the alloy more prone to plastic flow rather than brittle fracture under impact. The liquid phase sintering process enhances the bonding force between particles and avoids interfacial debonding under impact by forming uniform sintering necks and a dense microstructure (porosity <1%). The hot isostatic pressing process further improves impact toughness and reduces the starting point of microcracks by compacting the structure.

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In the application scenario, impact toughness directly determines the reliability and durability of the alloy. In the aerospace field, the counterweights of aircraft or helicopters need to withstand vibrations and shocks caused by takeoff, landing or turbulence. Higher impact toughness ensures that the components will not fail due to transient loads. In military armor-piercing projectile cores, alloys need to withstand high-speed impacts (initial velocity 1500-1800 m/s), and good impact toughness ensures that the core maintains integrity when penetrating armor. In medical equipment, collimators or surgical robot components may be accidentally impacted, and impact toughness ensures that their accuracy and function are not affected. Process optimization needs to focus on the control of trace impurities (such as carbon or oxygen) to avoid the formation of brittle phases that reduce toughness. Surface treatment (such as polishing or coating) can reduce surface defects and further improve impact resistance.

### 3.2 Thermal and electrical properties of tungsten-nickel-copper alloy

The thermal and electrical properties of tungsten-nickel-copper alloys are important supports for their application in high-tech fields, especially in scenarios that require efficient thermal management or electromagnetic compatibility, such as lithography machine balance blocks in the electronics industry, medical CT/MRI shielding parts, and high-temperature components in aerospace. Thermal properties mainly include thermal conductivity and thermal expansion characteristics, which determine the heat dissipation capacity and dimensional stability of the alloy in high-temperature environments. Electrical properties are mainly reflected in electrical conductivity and non-magnetism, ensuring that the alloy does not cause interference in electromagnetic sensitive environments. These properties are derived from the high thermal stability of tungsten and the excellent thermal and electrical conductivity of the nickel-copper bonding phase, and are synergistically achieved through the optimization of powder metallurgy processes. In terms of thermal properties, tungsten-nickel-copper alloys have high thermal conductivity, which can quickly disperse heat and prevent local overheating. This is due to the high thermal conductivity of copper and the uniform distribution of nickel-copper solid solution. The high thermal stability of tungsten particles further ensures the structural integrity of the alloy at high temperatures. The low thermal expansion coefficient allows the alloy to maintain dimensional stability when the temperature changes, avoiding deformation caused by thermal stress, and is particularly suitable for applications with extremely high precision requirements such as lithography machine platforms or medical equipment. In the production process, liquid phase sintering and hot isostatic pressing ensure the compactness of the microstructure and reduce the grain boundary resistance in heat conduction. The heat treatment process further improves the thermal conductivity by optimizing the grain boundary structure while maintaining low thermal expansion characteristics.

In terms of electrical properties, the non-magnetic nature of tungsten-nickel-copper alloy is its biggest advantage, which is due to the paramagnetic properties of nickel and copper, which avoids electromagnetic interference and enables it to perform well in electromagnetic sensitive environments such as MRI equipment, lithography machines, and radar systems. Although the electrical conductivity of the alloy is lower than that of pure copper, it is sufficient to meet the needs

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of most electronic applications, especially in scenarios where high density and electromagnetic compatibility need to be taken into account. The conductivity of the nickel-copper binder phase provides the alloy with stable electrical properties, while the low conductivity of tungsten particles is compensated by the optimization of the microstructure. Process control needs to avoid oxide inclusions or segregation that affect conductivity or non-magnetism. Surface coatings (such as PVD TiN ) can further protect the alloy from environmental corrosion and maintain the stability of electrical properties.

### 3.2.1 Thermal conductivity

Tungsten -nickel-copper alloy is the core indicator of its thermal performance, reflecting the ability of the alloy to quickly conduct and disperse heat. This property gives it a significant advantage in applications that require efficient thermal management , such as lithography machine balance blocks in the electronics industry, radiation shielding in medical equipment, and high-temperature aerospace components. The excellent performance of thermal conductivity is mainly due to the synergistic effect of the high thermal conductivity of copper and the nickel-copper bonding phase. Copper, as a highly thermally conductive metal, can quickly conduct heat from the heat source to other areas to prevent local overheating, while the addition of nickel forms a stable solid solution and enhances the thermal conductivity of the bonding phase. Although tungsten has lower thermal conductivity than copper, its high thermal stability ensures that the alloy can maintain structural integrity at high temperatures and avoid deformation or failure due to thermal stress.

Thermal conductivity is significantly affected by alloy composition and microstructure. The ratio of nickel-copper bonding phase directly determines the performance of thermal conductivity. Alloys with higher copper content generally have better thermal conductivity because copper's thermal conductivity far exceeds that of tungsten and nickel. However, excessive copper content may reduce the overall strength of the alloy, so a balance needs to be found between thermal conductivity and mechanical properties. The liquid phase sintering process forms a uniform nickel-copper matrix at high temperature, fills the gaps between tungsten particles, reduces the resistance of grain boundaries and pores to heat conduction, and thus improves thermal conductivity. The hot isostatic pressing process further optimizes the density of the microstructure by eliminating micropores, making heat transfer smoother. Heat treatment processes such as annealing can also effectively improve thermal conductivity by repairing crystal defects and optimizing grain boundary structure, ensuring the performance stability of the alloy in high temperature environments.

In practical applications, the level of thermal conductivity directly affects the performance of alloys in high-tech fields. For example, in the lithography platform, the alloy needs to quickly disperse the heat generated by the laser or motor to maintain sub-nanometer precision. Excellent thermal conductivity ensures the thermal stability of the platform. In medical CT equipment, shielding parts will generate heat under high-energy radiation. High thermal conductivity helps to quickly dissipate heat to avoid overheating or performance degradation of the equipment. In the aerospace field, missiles or turbine components operate in high-temperature gas environments. The thermal

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conductivity of the alloy ensures the thermal management capabilities of the components and extends their service life. Process optimization needs to pay attention to raw material purity and sintering parameters to avoid oxide inclusions or segregation that reduce thermal conductivity.

### 3.2.2 Conductivity

Tungsten -nickel-copper alloy is an important indicator of its electrical properties, reflecting the ability of the alloy to conduct current. Although its electrical conductivity is lower than that of pure copper, it is sufficient to meet the needs of most electronic and medical applications, especially in scenarios where high density and electromagnetic compatibility need to be taken into account. The moderate performance of electrical conductivity stems from the balance between the conductivity of the nickel-copper bonding phase and the relatively low conductivity of tungsten particles. Copper, as a highly conductive metal, provides the main current conduction path for the alloy, while the addition of nickel forms a stable Ni-Cu solid solution, maintaining moderate electrical conductivity. Although the high resistance properties of tungsten reduce the overall conductivity, its high density and non-magnetism give it unique advantages in electromagnetic sensitive environments, completely avoiding magnetic interference.

The performance of electrical conductivity is affected by alloy composition, microstructure and production process. Alloys with higher copper content generally have higher electrical conductivity because the electrical conductivity of copper is much higher than that of nickel and tungsten. However, too high a copper content may lead to a decrease in strength, and a balance between electrical conductivity and mechanical properties must be achieved by optimizing the nickel-copper ratio (such as 7:3 or 3.5:1.5). The liquid phase sintering process reduces grain boundary resistance and promotes smooth current transfer by forming a continuous nickel-copper matrix. The hot isostatic pressing process further improves the density of the microstructure and eliminates the negative effects of pores and inclusions on conductivity. Impurity management is critical. For example, impurities such as oxygen or carbon may form non-conductive oxides or carbides, reducing conductivity. Therefore, high-purity raw materials (tungsten>99.9%) and high-purity argon atmosphere are required for sintering. In application scenarios, the moderate conductivity and non-magnetism make tungsten-nickel-copper alloy perform well in the electronics industry and medical fields. For example, in MRI equipment, the shielding parts of the alloy need to avoid magnetic field interference, and the moderate conductivity combined with non-magnetism ensures the high sensitivity and precision of the equipment. In the lithography machine, the conductivity of the balance block supports its normal operation in the electromagnetic environment and avoids static electricity accumulation or interference. Process optimization needs to focus on the uniformity of the microstructure to avoid segregation or defects that reduce conductivity.

### 3.2.3 Thermal expansion coefficient

Tungsten -nickel-copper alloy is a key characteristic of its thermal performance, reflecting the dimensional stability of the alloy under temperature changes. The low coefficient of thermal

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expansion gives it a significant advantage in applications that require high precision and thermal stability, such as lithography platforms, medical collimators, and aerospace counterweights. The low thermal expansion performance is mainly due to the inherent low thermal expansion characteristics of tungsten, combined with the moderate ductility of the nickel-copper bonding phase, which enables the alloy to maintain shape and dimensional stability when the temperature fluctuates, avoiding deformation or cracking caused by thermal stress.

The coefficient of thermal expansion is affected by both the alloy composition and the microstructure. Tungsten's high melting point and body-centered cubic structure give it an extremely low thermal expansion rate, which dominates the overall thermal expansion characteristics of the alloy. Nickel and copper have higher thermal expansion coefficients than tungsten, but through reasonable ratio design, the contribution of the bonding phase to thermal expansion is minimized. The liquid phase sintering process forms a uniform microstructure, and the tungsten particles are tightly bonded to the nickel-copper matrix through the sintering neck, reducing grain boundary sliding or thermal stress concentration. The hot isostatic pressing process further improves the density and thermal stability of the structure by eliminating microporosity. Heat treatment processes such as annealing enhance the dimensional stability of the alloy during thermal cycles by optimizing the grain boundary structure and eliminating residual stress, avoiding microcracks caused by temperature changes.

In practical applications, the low thermal expansion coefficient makes tungsten-nickel-copper alloy an ideal choice for high-precision equipment. For example, in a photolithography machine, the platform needs to maintain sub-nanometer precision during laser heating and cooling cycles. The low thermal expansion coefficient ensures the stability of the platform and avoids thermal deformation affecting pattern engraving. In the aerospace field, counterweights operate in high-temperature gases or low-temperature environments, and the low thermal expansion coefficient ensures the stability of the center of gravity. The collimator in medical equipment needs to maintain its shape under the heat generated by radiation, and the low thermal expansion characteristics ensure its accuracy and reliability. Process optimization needs to avoid impurities (such as oxygen or carbon) from forming high expansion phases that affect overall performance.

### 3.2.4 Heat dissipation performance

Tungsten nickel copper alloy is a comprehensive reflection of its thermal performance. It combines the advantages of high thermal conductivity and low thermal expansion coefficient, which can quickly disperse heat and maintain dimensional stability. This performance makes it excellent in applications that require efficient thermal management, such as thermal management components of photolithography machines in the electronics industry, radiation shielding in medical equipment, and high-temperature components in aerospace. The excellent heat dissipation performance is due to the high thermal conductivity of copper and the uniform distribution of the nickel-copper matrix, which can quickly transfer heat from the heat source to the outside to prevent local overheating. At the same time, the low thermal expansion characteristics ensure that the components will not deform

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or fail during thermal cycles.

Heat dissipation performance is jointly affected by alloy composition, microstructure and production process. The increase in copper content significantly improves heat dissipation efficiency because copper has a much higher thermal conductivity than tungsten and nickel and can quickly transfer heat. The addition of nickel forms a stable Ni-Cu solid solution, which enhances the thermal conductivity of the bonding phase and provides antioxidant protection to prevent high-temperature oxidation from reducing heat dissipation performance. The high thermal stability of tungsten particles ensures the structural integrity of the alloy at high temperatures, avoiding thermal softening or performance degradation. The liquid phase sintering process reduces the obstacles to heat conduction from grain boundaries and pores by forming a continuous nickel-copper matrix. The hot isostatic pressing process further improves the density of the microstructure and eliminates the micropore resistance in heat conduction. Surface treatment (such as high thermal conductivity coating or polishing to  $Ra < 0.4 \mu m$ ) can enhance surface heat dissipation efficiency and accelerate the transfer of heat to the environment.

In practical applications, the heat dissipation performance directly determines the applicability of the alloy in high-tech fields. In photolithography machines, the balance block needs to quickly disperse the heat generated by the laser or motor, and excellent heat dissipation performance ensures the thermal stability and accuracy of the platform. In medical CT equipment, shielding parts generate heat under high-energy radiation, and efficient heat dissipation avoids overheating of the equipment and extends its service life. In the aerospace field, turbine or missile components operate in a high-temperature gas environment, and heat dissipation performance ensures the reliability and durability of the components. Process optimization needs to pay attention to raw material purity and sintering parameters to avoid oxide inclusions or segregation that reduce heat dissipation efficiency.

### 3.3 Chemical stability of tungsten-nickel-copper alloy

Tungsten -nickel-copper alloy is widely used in aerospace, medical, electronic and military fields due to its high density, excellent mechanical properties, non-magnetic properties and outstanding thermal and electrical properties. The alloy is prepared by powder metallurgy process, with tungsten as the main component, supplemented by nickel and copper as bonding phases, forming a dense microstructure and showing excellent chemical stability. Its chemical stability is mainly reflected in corrosion resistance and oxidation resistance, enabling it to maintain performance for a long time in harsh environments such as humidity, acidity or high temperature. This stability is due to the chemical inertness of tungsten and the protective effect of the nickel-copper bonding phase, meeting the needs of high-reliability applications.

#### 3.3.1 Corrosion resistance

Tungsten -nickel-copper alloy is an important manifestation of its chemical stability, reflecting the alloy's ability to resist chemical erosion in corrosive environments such as moisture, acid or salt

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spray. This property enables it to perform well in scenarios that require long-term stable operation, such as medical equipment, marine engineering and the electronics industry, such as medical CT shielding, ship counterweights or electronic equipment housings. The excellent corrosion resistance is mainly due to the synergistic effect of tungsten's chemical inertness and nickel's corrosion resistance. As the main component, tungsten has extremely high chemical stability and is not easy to react in most acidic or alkaline environments, forming the basis for the alloy's corrosion resistance. Nickel forms a stable protective layer in the bonding phase, which can effectively resist the erosion of external chemicals and extend the service life of the alloy.

Corrosion resistance is jointly affected by alloy composition, microstructure and surface state. Nickel plays a leading role in the nickel-copper bonding phase. Its face-centered cubic structure and anti-oxidation properties enable it to form a dense oxide protective layer in a humid or acidic environment, preventing further penetration of the corrosive medium. Although the addition of copper improves thermal conductivity and non-magnetism, its corrosion resistance is slightly inferior to that of nickel. Slight corrosion may occur in some acidic environments (such as nitric acid). Therefore, it is necessary to optimize the overall corrosion resistance through a reasonable nickel-copper ratio (such as 7:3 or 3.5:1.5). The liquid phase sintering process forms a uniform nickel-copper matrix at high temperature, fills the gaps between tungsten particles, reduces micropores and grain boundary exposure, and reduces the penetration path of corrosive media. The hot isostatic pressing process further improves the density of the microstructure, makes the alloy surface smoother, and reduces the starting point of corrosion. Surface treatment processes, such as polishing or chemical passivation, can further enhance corrosion resistance and form a denser protective layer, which is particularly suitable for long-term use of medical equipment in a sterilized environment.

In practical applications, corrosion resistance directly determines the reliability and durability of the alloy. In the medical field, the shielding parts of CT or MRI equipment need to be exposed to disinfectants or humid environments for a long time. Excellent corrosion resistance ensures the surface integrity and functional stability of the parts. In marine engineering, ship counterweights may be exposed to seawater or salt spray. The corrosion resistance of the alloy avoids material degradation and extends the service life. In the electronics industry, the housing or balance weight needs to resist chemicals in the production environment. Corrosion resistance ensures the long-term operation of the equipment. Process optimization requires strict control of raw material purity to avoid impurities such as oxygen or sulfur from forming easily corrosive phases. Surface coatings (such as PVD TiN or DLC) can further improve corrosion resistance, especially in harsh chemical environments. Quality control verifies corrosion resistance through salt spray testing and immersion experiments to ensure that the alloy meets industry standards (such as ISO 9227).

### 3.3.2 Antioxidant properties

Tungsten -nickel-copper alloy is another key characteristic of its chemical stability, which reflects the ability of the alloy to resist oxidation reactions in high temperature or oxidizing atmosphere.

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This property gives it significant advantages in high-temperature aerospace components, thermal management components in the electronics industry, and military equipment, such as turbine counterweights, heat sinks for photolithography machines, or missile shields. The excellent performance in oxidation resistance is mainly due to the oxidation resistance of nickel and the thermal stability of tungsten. Nickel forms a dense oxide protective layer at high temperatures to prevent oxygen from further corroding the internal structure, while the high melting point and chemical inertness of tungsten enable it to maintain structural integrity at high temperatures and avoid performance degradation caused by oxidation. Although copper has weaker oxidation resistance, its negative impact is minimized under the protection of nickel.

Oxidation resistance is significantly affected by alloy composition, microstructure and process conditions. Nickel plays a major antioxidant role in the nickel-copper binder phase. Its oxide layer (NiO) has a low diffusion rate at high temperature ( $<1000^{\circ}\text{C}$ ), which can effectively block oxygen penetration and protect the internal tungsten particles and nickel-copper matrix. The high thermal stability of tungsten further enhances the oxidation resistance. Even in high temperature environments, its body-centered cubic structure can remain stable and resist oxidative corrosion. Copper may form copper oxide (CuO or  $\text{Cu}_2\text{O}$ ) in an oxidizing atmosphere, but the protective effect of nickel can effectively inhibit copper oxidation through a reasonable nickel-copper ratio (such as 7:3). The liquid phase sintering process forms a dense microstructure at high temperature, reducing pores and grain boundary exposure, and reducing the path for oxygen penetration. The hot isostatic pressing process further improves the density of the structure by eliminating micropores, making the alloy surface less susceptible to oxidation.

In practical applications, oxidation resistance directly affects the reliability and life of the alloy in high temperature environments. In the aerospace field, turbine or missile components operate in high-temperature gas environments. Excellent oxidation resistance ensures the surface integrity of counterweights or shielding parts and avoids deformation or failure caused by oxidation. In the electronics industry, the heat dissipation components of photolithography machines need to withstand the heat generated by lasers or motors, and oxidation resistance ensures stability under long-term high-temperature operation. In military equipment, shielding parts may be exposed to high-temperature oxidizing atmospheres, and the oxidation resistance of the alloy maintains its electromagnetic shielding function. Process optimization needs to focus on impurity control to avoid impurities such as carbon or sulfur from forming easily oxidizable phases. Surface treatment (such as chemical passivation or antioxidant coating) can further enhance oxidation resistance, especially in high-temperature cyclic environments. Quality control verifies oxidation resistance through high-temperature oxidation testing and thermogravimetric analysis (TGA) to ensure that the alloy meets the standards of the aerospace or electronics industry.

### 3.4 CTIA GROUP LTD Tungsten Nickel Copper Alloy MSDS

The Material Safety Data Sheet (MSDS) is an important document that describes the physical and chemical properties of tungsten -nickel-copper alloys and safe use instructions, providing guidance

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for users and operators on safe handling and emergency measures. The tungsten -nickel-copper alloy (W-Ni-Cu) produced by CTIA GROUP LTD is a high-density alloy that is widely used in aerospace, medical, electronics and military industries. It is highly favored for its high density, excellent mechanical properties, non-magnetic properties and good thermal conductivity.

## 1. Product Information

**Product Name** : Tungsten Nickel Copper Alloy (W-Ni-Cu Alloy)

**Alias** : High-density tungsten alloy, tungsten heavy alloy

**Application** : Used in aerospace counterweights, medical radiation shielding parts, electronic industry heat sinks and balance blocks , etc.

## 2. Hazard identification

Tungsten Nickel Copper Alloy is not generally considered a hazardous substance under normal use conditions (in solid form, such as plates, bars or machined parts) and is not classified as a hazardous substance according to the Globally Harmonized System of Classification and Labelling (GHS).

## 3. Composition/ingredient information

Tungsten nickel copper alloy is a composite material, the components include:

- **Tungsten (W)** : The main component, accounting for 90%-97%, provides high density and high hardness.
- **Nickel (Ni)** : Binding phase, accounting for 2%-7%, enhancing toughness and corrosion resistance.
- **Copper (Cu)** : Binding phase, accounting for 1%-5%, improves thermal conductivity and non-magnetic properties.
- **Trace elements** : may contain trace amounts of cobalt, molybdenum or other impurities (<0.5%), depending on the production process.

## 5. Firefighting measures

Tungsten -nickel-copper alloy is a non-flammable material with no explosion risk.

## 6. Emergency treatment of leaks

Tungsten -nickel-copper alloy is a solid material with no risk of leakage.

## 7. Handling and storage

- **Safe operation** : Processing must be carried out in a well-ventilated environment and

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operators should wear protective glasses and gloves.

- **Storage conditions** : Store in a dry, cool place, avoid humidity or high temperature. The product packaging should be shockproof (such as wooden boxes or cushions) to prevent damage during transportation and storage.

## 8. Physical and chemical properties

- **Appearance** : Silver-grey metallic solid with smooth surface or processed into specific shapes (such as plates, rods, blocks).
- **Odor** : Odorless.
- **Melting Point** : Tungsten has an extremely high melting point (about 3422°C), and the melting point of the nickel-copper bonding phase is about 1300-1450°C.
- **Density** : High density, typical values are 16.5-18.5 g/cm<sup>3</sup>.
- **Solubility** : Insoluble in water, resistant to acid and alkali corrosion, some acidic environments (such as nitric acid) may slightly corrode copper.
- **Chemical stability** : Stable at room temperature. At high temperatures, nickel forms a protective oxide layer to enhance oxidation resistance.

## 9. Stability and Reactivity

- **Stability** : Stable under normal use and storage conditions, no risk of decomposition.
- **Reactivity** : Does not react violently with water, air or common chemicals.
- **Conditions to avoid** : Avoid high temperature oxidizing environments or long-term contact with strong acids (such as concentrated nitric acid), which may slightly corrode copper.

## 10. Disposal considerations

- **Waste treatment** : Classify and recycle according to local environmental regulations (such as China GB 5085 or international hazardous waste standards ). It is recommended to use chemical dissolution or electrochemical separation to recycle tungsten, nickel and copper.
- **Packaging Disposal** : Packaging materials (such as wooden boxes or plastics) should be recycled or disposed of in accordance with local regulations.

## 11. Shipping Information

- **Transport classification** : non-dangerous goods, no special transport requirements.
- **Packaging requirements** : Use shock-proof and moisture-proof packaging (such as wooden boxes or foam filling) to ensure no damage during transportation.

## 12. Regulatory Information

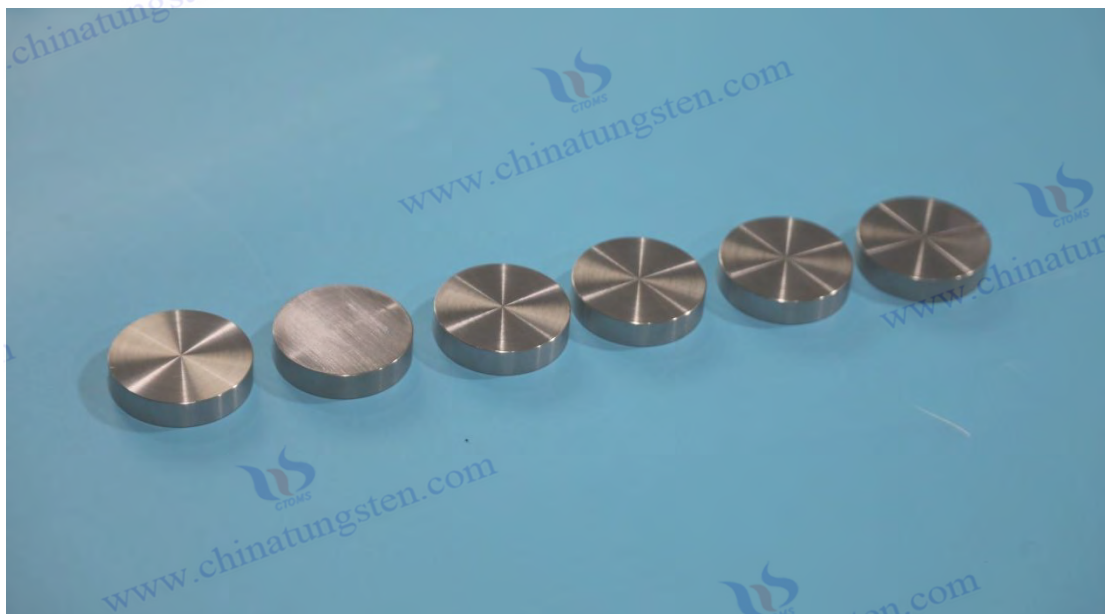
- **International regulations** : Comply with OSHA Hazard Communication Standard

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(29CFR1910.1200) and GHS requirements.

- **Chinese regulations** : Comply with the Regulations on the Safety Management of Hazardous Chemicals and GB/T 26038-2010 (tungsten alloy standard).
- **Others** : Nickel is subject to REACH regulations and the content needs to be declared; the alloy as a whole does not require special chemical registration.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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## CTIA GROUP LTD

### Tungsten Nickel Copper Alloy Introduction

#### 1. Overview of Tungsten Nickel Copper Alloy

Tungsten nickel copper alloy is an alloy composed of tungsten with added nickel and copper, typically in a nickel-to-copper ratio of 3:2. This alloy is non-ferromagnetic, exhibits relatively good electrical and thermal conductivity, and is commonly used in specialized applications such as gyroscope rotors, components for devices and instruments operating under magnetic fields, electrical contacts for high-voltage switches, and electrodes for certain electrical machining processes.

#### 2. Features of Tungsten Nickel Copper Alloy

**High Density:** Typically 16.5 – 18.75 g/cm<sup>3</sup>

**High Thermal Conductivity:** Approximately 5 times that of mold steel

Compared to tungsten-nickel-iron alloy, since copper does not have the sintering activation effect of nickel and iron on tungsten, tungsten-nickel-copper alloy has a slightly lower sintered density, lower strength and plasticity, and is generally not subjected to heat treatment or deformation processing.

#### 3. Production Methods for Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy is typically produced using powder metallurgy. First, high-purity tungsten, nickel, and copper powders are mixed in specific proportions, often using equipment like a ball mill to achieve uniform mixing. The mixture is then pressed into shape, commonly using cold isostatic pressing technology under a specific pressure to form a green compact. Subsequently, sintering is performed, generally in a hydrogen protective atmosphere, using a two-step sintering process to address collapse and deformation issues caused by liquid-phase sintering, ensuring the product's density.

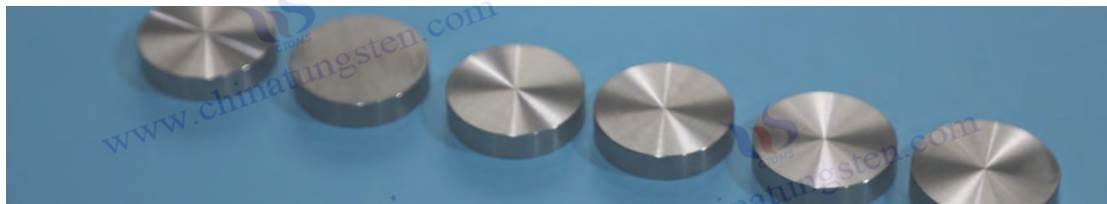
#### 4. Applications of Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy, with its high density and excellent thermal and electrical conductivity, has a wide range of applications. In the aerospace sector, it can be utilized to manufacture components such as rocket engine nozzles and gas rudders. In the medical field, due to its strong radiation absorption capability and non-magnetic properties, it is suitable for radiation shielding in magnetic resonance imaging rooms. Additionally, it can serve as a counterweight material for precision instruments.

#### 5. Purchasing Information

Email: [sales@chinatungsten.com](mailto:sales@chinatungsten.com); Phone: +86 592 5129595; 592 5129696

Website: [www.tungsten-alloy.com](http://www.tungsten-alloy.com)



CTIA GROUP LTD tungsten nickel copper alloy

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## Chapter 4 Performance Testing and Standards of Tungsten-Nickel-Copper Alloy

As a high-density material, tungsten -nickel-copper alloy is widely used in aerospace, medical, electronic and military fields due to its excellent mechanical properties (tensile strength 700-900 MPa, elongation 5%-15%), non-magnetic properties, excellent thermal conductivity (120-150 W/m·K ) and chemical stability. In order to ensure that its performance meets strict application requirements (such as aerospace counterweights or medical shielding parts), quality control must be carried out through precise performance testing methods and international standards. Composition analysis is the core link of performance testing and directly affects the density, mechanical properties and non-magnetic properties of the alloy. Composition analysis not only verifies the proportion of the main elements (tungsten, nickel, copper), but also detects trace impurities to ensure the purity and performance consistency of the alloy.

### 4.1 Composition analysis method of tungsten-nickel-copper alloy

Tungsten -nickel-copper alloy is the basis of quality control. It is used to verify whether the proportion of the main elements (85%-97% tungsten, 2%-10% nickel, 1%-8% copper) meets the design requirements and ensure that trace impurities (such as oxygen, carbon, and sulfur) do not affect the performance. The composition analysis methods mainly include spectral analysis, chemical analysis, and surface analysis techniques, among which spectral analysis is the first choice due to its high precision, rapidity, and non-destructiveness. The analysis results must meet international standards (such as ASTM B777 or GB/T 26038) to ensure the reliability of the alloy in aerospace counterweights, medical collimators, or electronic industry balance blocks. The detection process must be carried out in a clean environment and high-purity calibration samples must be used to ensure the accuracy of the results.

#### 4.1.1 Spectral analysis technology

Spectral analysis technology is the core method for analyzing the composition of tungsten-nickel-copper alloys. It determines the type of elements and their content by measuring the spectrum emitted or absorbed by the sample at a specific wavelength. This method is widely used in alloy production and quality control due to its high sensitivity (detection limit can reach ppm level), rapidity (single analysis <5 minutes) and ability to detect multiple elements simultaneously. Spectral analysis techniques include X-ray fluorescence spectroscopy (XRF), inductively coupled plasma atomic emission spectroscopy and atomic absorption spectroscopy (AAS), among which XRF and ICP-AES are the most commonly used methods, suitable for verifying the content of tungsten, nickel, copper and the distribution of trace elements.

X-ray fluorescence spectroscopy (XRF) is a non-destructive analysis technique that uses X-rays to excite atoms on the surface of the sample to produce characteristic fluorescence, and analyzes its wavelength and intensity to determine the element content. XRF is suitable for solid alloy samples (such as plates, bars or processed parts), does not require complex pre-treatment, and can quickly

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detect the proportion of tungsten, nickel, and copper (accuracy  $\pm 0.2\%$ ). Its advantage is that it is easy to operate and suitable for real-time quality control at the production site. For example, in the production of aerospace counterweights, XRF can quickly verify whether the alloy composition meets the ASTM B777 standard to ensure that the density and non-magnetic properties meet the standards. The limitation of XRF is that the detection sensitivity of light elements (such as carbon and oxygen) is low, and it needs to be combined with other methods for supplementary analysis.

Inductively coupled plasma atomic emission spectrometry is a high-precision analytical technique that determines the element content by dissolving the sample, introducing plasma excitation, and measuring the emission spectrum. ICP-AES is suitable for detecting major elements and trace elements in tungsten-nickel-copper alloys, with a detection limit of up to ppb level. The sample needs to be pre-treated by acid dissolution (such as nitric acid or aqua regia) and dissolved into a solution for analysis. ICP-AES can detect multiple elements at the same time and is suitable for comprehensive component analysis in a laboratory environment. For example, in the production of medical shielding parts, ICP-AES can verify whether the nickel content meets the ISO 10993 biocompatibility requirements and avoid the risk of allergies caused by excessive nickel. Its disadvantage is that the sample pretreatment is complicated and it is not suitable for rapid on-site detection.

The choice of spectral analysis technology should be determined according to application requirements and equipment conditions. XRF is suitable for rapid, non-destructive on-site testing, while ICP-AES is more suitable for high-precision laboratory analysis. High-purity standard samples ( $>99.99\%$ ) should be used for calibration during the analysis to avoid matrix effects or instrument drift affecting the results. Environmental control (such as clean rooms or constant temperature and humidity) can reduce dust or humidity interference. Quality control verifies the reliability of results through repeated testing and standard deviation analysis.

#### 4.1.2 Impurity element detection

Impurity element detection is an important part of the composition analysis of tungsten-nickel-copper alloys. It aims to identify and quantify trace impurities (such as oxygen, carbon, sulfur, nitrogen or iron, usually  $<0.5\%$ ) to ensure that they do not affect the mechanical properties, thermal conductivity or chemical stability of the alloy. Impurities may come from raw material powders (tungsten, nickel, copper), sintering atmosphere or processing environment. If the content exceeds the standard, it may cause microstructural defects (such as oxide inclusions or carbides), reduce toughness, corrosion resistance or non-magnetic properties. Impurity detection methods include spectral analysis, chemical analysis and special instrument analysis, which must achieve high sensitivity (ppb-ppm level) to meet the requirements of the aerospace, medical and electronics industries.

Oxygen and carbon are the most common impurities in tungsten-nickel-copper alloys and need to be detected by special analytical techniques. Oxygen analysis usually uses the inert gas fusion

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method (Inert Gas Fusion), where the sample is heated to above 2000°C in high-purity helium or argon, releasing oxygen and reacting with carbon to form CO or CO<sub>2</sub>, and the oxygen content is measured by an infrared detector. High oxygen content may form oxide inclusions (such as WO<sub>3</sub> or NiO), which will reduce the interfacial bonding strength and affect the corrosion resistance of medical shielding parts. Carbon analysis uses the combustion method (Combustion Analysis), where the sample burns in oxygen to generate CO<sub>2</sub>, and the carbon content is measured by an infrared detector. High carbon content may form carbides (such as WC), which increase hardness but reduce toughness, affecting the impact resistance of aerospace counterweights.

Impurities such as sulfur and nitrogen are detected by glow discharge mass spectrometry (GD-MS) or ICP-AES. GD-MS excites the sample surface through glow discharge and analyzes the ion mass spectrum. The detection limit can reach ppb level, which is suitable for multi-element impurity analysis. Too high sulfur content may form sulfide inclusions, reducing corrosion resistance; too high nitrogen content may cause grain boundary embrittlement and affect the stability of balance weights in the electronics industry. Iron, as a potential impurity (derived from raw materials or processing tools), requires special attention because it may introduce weak magnetism, destroy the non-magnetic properties of the alloy, and affect the performance of MRI equipment shielding parts. ICP-AES can accurately detect the iron content by acid dissolving the sample and then analyzing it.

Impurity testing requires strict control of sample preparation and environmental conditions. The sample surface needs to be polished and cleaned with ethanol to avoid contamination. Analytical instruments need to be calibrated regularly, and high-purity standard samples are used to ensure accuracy. Sintering process optimization can reduce the introduction of oxygen and nitrogen; raw material screening can control initial impurities. Quality control verifies the uniformity of impurity distribution through multi-point sampling and statistical analysis. The test results must comply with ASTM B777 or GB/T 26038 standards to ensure the consistency of alloy performance.

## 4.2 Performance test method of tungsten-nickel-copper alloy

Tungsten nickel copper alloy are designed to comprehensively evaluate its physical and mechanical properties to ensure the performance of the alloy in the target application. The test methods include density and compactness testing, mechanical property testing, thermal property testing and microstructure analysis, each of which provides precise data for specific properties. Density and compactness testing verifies the mass distribution and structural integrity of the alloy, and mechanical property testing evaluates its strength and toughness under stress. These tests are usually performed in a laboratory or production site using standardized equipment and processes to ensure that the results meet the strict requirements of the aerospace, medical or electronics industries. Control of the test environment is critical to the accuracy of the results.

### 4.2.1 Density and compactness test

Density and compactness testing are the basis of tungsten-nickel-copper alloy performance testing.

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They are used to evaluate the mass distribution and microstructure compactness of the alloy, which directly affects its performance in aerospace counterweights, medical shielding parts, and electronic industry balance blocks. Density reflects the mass of the alloy per unit volume and is the core indicator of its high-density characteristics, ensuring that the components achieve efficient mass distribution in a limited space. Density measures the content of pores inside the alloy and reflects the effect of the production process (such as liquid phase sintering or hot isostatic pressing). The dense microstructure can enhance the strength, toughness and corrosion resistance of the alloy.

Density testing usually uses the Archimedean principle to calculate the density by measuring the mass difference of the alloy sample in air and liquid (such as water or ethanol). This method is simple and efficient, suitable for solid samples (such as bars, plates or machined parts), and can quickly verify whether the alloy reaches the designed density and meets the high density requirements of aerospace counterweights or medical shielding parts. During the test, the sample needs to be cleaned and polished on the surface to remove oil or oxide layer to ensure measurement accuracy. The selection of liquid needs to consider its non-corrosiveness to the alloy to avoid surface reactions affecting the results. The density test results directly reflect the proportion of tungsten content. Alloys with higher tungsten content generally have higher density and are suitable for applications that require extremely high mass distribution, such as military armor-piercing cores.

Density testing evaluates the porosity within the alloy through a more complex method, usually combining density measurement and microstructural analysis. A common method is to compare the measured density with the theoretical density to infer the porosity. Another method uses a microscope to observe the cross-section of the sample, and analyzes the distribution of tungsten particles and nickel-copper binder phases through metallographic microscopy or scanning electron microscopy to identify the presence of micropores or inclusions. High-density alloys can provide better mechanical properties and chemical stability, and are particularly suitable for long-term use in dynamic environments or corrosive environments. The liquid phase sintering process forms a uniform nickel-copper matrix at high temperature to fill the gaps between tungsten particles, while the hot isostatic pressing process further compacts the structure, significantly improving the density and reducing the negative impact of porosity on performance.

In practical applications, density and compactness testing ensure the reliability of alloys in high-precision scenarios. For example, in the balance block of a photolithography machine, high density ensures the stability of the center of gravity, and the dense microstructure avoids microcracks caused by vibration. In medical collimators, high-density alloys can efficiently absorb radiation while maintaining structural integrity for long-term use. Test optimization needs to focus on the uniformity of sample preparation to avoid surface defects or internal inclusions affecting the results. Environmental control and high-precision instrument calibration are also key.

#### 4.2.2 Tensile strength and yield strength test

Tensile strength and yield strength tests are the core methods for evaluating the mechanical

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properties of tungsten -nickel-copper alloys, which are used to measure the alloy's ability to resist fracture and plastic deformation under tensile loads. These properties directly determine the reliability and durability of the alloy in aerospace counterweights, military projectile cores, and vibration damping components in the electronics industry. Tensile strength reflects the alloy's resistance to fracture under maximum tensile stress and is suitable for evaluating its performance in high-stress environments. Yield strength indicates the stress level at which the alloy begins to undergo irreversible plastic deformation, reflecting its resistance to deformation when under load. The excellent mechanical properties of tungsten -nickel-copper alloys stem from the synergistic effect of the high hardness of tungsten particles and the toughness of the nickel-copper bonding phase, which enables it to maintain structural integrity in dynamic or impact environments.

Tensile strength testing is usually performed using a tensile testing machine. The sample is processed into a standard shape (such as a dumbbell-shaped specimen) and a gradually increasing tensile force is applied under controlled conditions until the sample breaks. During the test, the stress-strain curve of the sample is recorded to analyze its behavior during the tensile process. The high tensile strength of tungsten-nickel-copper alloy is due to the solid skeleton of the tungsten particles and the uniform distribution of the nickel-copper matrix. The nickel-copper phase tightly connects the tungsten particles through the sintering neck, effectively dispersing stress and avoiding local fracture. The test needs to be carried out in a constant temperature environment (usually room temperature) to eliminate the influence of temperature on mechanical properties. Sample preparation requires a smooth and defect-free surface to avoid stress concentration that leads to deviation in the results. The test results are used to verify whether the alloy meets the standards of the aerospace or military industry to ensure that it can withstand high stress or vibration.

Yield strength testing is performed simultaneously with tensile strength testing, and the point at which the alloy begins to undergo plastic deformation is determined by analyzing the stress-strain curve. The toughness of the nickel-copper binder phase enables the alloy to withstand a certain amount of plastic deformation before yielding, absorb energy, and avoid brittle fracture. The performance of yield strength is affected by the alloy composition and microstructure. Alloys with higher tungsten content generally have higher yield strength because tungsten particles provide the main resistance to deformation. Optimization of the nickel-copper ratio (such as 7:3 or 3.5:1.5) ensures a balance between the toughness and strength of the binder phase, avoiding excessive nickel content that reduces strength or excessive copper content that reduces hardness. Liquid phase sintering and hot isostatic pressing processes reduce porosity and grain boundary defects and increase yield strength by forming a dense microstructure. Heat treatment processes such as annealing further optimize the plastic behavior of the alloy by eliminating residual stress.

In practical applications, the test results of tensile strength and yield strength directly affect the selection and design of alloys. For example, in aerospace counterweights, high tensile strength ensures that the components do not break under high-frequency vibration or impact, while yield strength ensures that they maintain shape stability when under load. In military armor-piercing projectile cores, alloys require high tensile strength to resist high-speed impact, while yield strength

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ensures the structural integrity of the projectile core when penetrating armor. Test optimization needs to focus on sample consistency, using standardized specimen sizes and test procedures (such as ASTM E8). Fracture analysis can further verify the reliability of test results by observing ductile or brittle fracture characteristics through SEM.

#### 4.2.3 Ductility test

Ductility testing is an important method to evaluate the ability of tungsten -nickel-copper alloy to undergo plastic deformation under tensile loads, reflecting the alloy's ability to avoid fracture through plastic flow when subjected to stress. Ductility is a key indicator to measure the toughness and machinability of an alloy, and is particularly important for components that need to withstand vibration, impact or complex processing, such as aerospace counterweights, medical collimators, or vibration reduction components in the electronics industry. Compared to the brittleness of pure tungsten, the ductility of tungsten-nickel-copper alloy is significantly improved, mainly due to the plastic effect of the nickel-copper bonding phase. The face-centered cubic structure of nickel provides excellent ductility and is able to absorb energy during stretching, while the addition of copper further enhances the ductility and machinability of the bonding phase, allowing the alloy to exhibit good plastic deformation ability when subjected to stress.

Ductility testing is usually performed through tensile testing, using standardized specimens (such as dumbbell-shaped specimens) to apply gradually increasing tensile forces on a tensile testing machine until the sample breaks. During the test, the elongation and cross-sectional shrinkage of the sample are recorded to evaluate the degree of plastic deformation before fracture. The ductility of tungsten -nickel-copper alloys stems from the synergistic effect of tungsten particles and nickel-copper bonding phases. Tungsten particles provide high hardness and strength, while the nickel-copper matrix forms a continuous network through sintering necks to disperse stress and promote plastic flow. The test results reflect the ability of the alloy to absorb energy during tension and are suitable for verifying its reliability in dynamic environments. The test needs to be carried out in a controlled environment (such as room temperature and constant humidity) to eliminate the interference of external factors on the results. Sample preparation requires a smooth and defect-free surface to avoid stress concentration leading to premature fracture.

Ductility is significantly affected by alloy composition and microstructure. An increase in nickel content generally improves ductility because nickel's toughness allows it to undergo larger plastic deformations when stretched. The addition of copper further improves ductility, and its high ductility reduces the hardness of the binder phase, making the alloy more susceptible to plastic flow when stressed. However, the nickel-copper ratio needs to be designed reasonably, and too high a nickel or copper content may reduce strength and affect overall performance. The liquid phase sintering process forms a uniform nickel-copper matrix at high temperature, fills the gaps between tungsten particles, enhances the bonding force between particles, and promotes plastic deformation ability. The hot isostatic pressing process further improves ductility and reduces the risk of fracture by eliminating microporosity and optimizing interface bonding. Heat treatment processes such as

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annealing make the alloy exhibit more uniform deformation behavior when stretched by eliminating residual stress and optimizing grain boundary structure.

In practical applications, the results of ductility tests directly affect the applicability of alloys in high-demand scenarios. For example, in the aerospace field, counterweights need to withstand vibrations caused by takeoff, landing or turbulence. Higher ductility ensures that the components will not suffer brittle fractures under dynamic loads. In the electronics industry, the vibration reduction components of the lithography platform need to resist tiny vibrations, and good ductility ensures the deformation ability and long-term stability of the components. In the medical field, collimators or surgical robot components may be subjected to stretching during processing or installation, and ductility makes them less likely to crack. Test optimization needs to focus on sample consistency, using standardized specimen sizes and test procedures (such as ASTM E8). Fracture analysis can further verify ductility performance by observing ductile fracture features (such as dimples).

#### 4.2.4 Toughness test

Toughness testing is an important method to evaluate the ability of tungsten -nickel-copper alloys to absorb energy and resist fracture under impact or rapid loading conditions, reflecting the crack resistance and reliability of the alloy in dynamic environments. Toughness is a key property of the alloy in applications such as aerospace counterweights, military armor-piercing cores, and medical equipment collimators, ensuring that the components maintain structural integrity under vibration, impact, or transient loads. The toughness of tungsten -nickel-copper alloys is better than that of pure tungsten, mainly due to the plastic effect of the nickel-copper bonding phase. The face-centered cubic structure of nickel provides good energy absorption capacity and can disperse energy through plastic deformation during impact, while the high ductility of copper further enhances the crack resistance of the bonding phase, making the alloy exhibit ductile fracture characteristics under impact.

Toughness testing is usually carried out through impact testing. Common methods include Charpy Impact Test and Drop Hammer Test. The Charpy Impact Test uses a standard specimen (usually with a V-notch) to test on a pendulum impact machine and record the energy absorbed by the sample when it breaks. The drop hammer test uses a heavy object to freely fall from a specific height to impact the sample to evaluate its fracture resistance. The toughness of tungsten -nickel-copper alloy stems from the synergistic effect of tungsten particles and nickel-copper bonding phase. Tungsten particles provide high hardness and strength, and the nickel-copper matrix disperses the impact energy through a continuous sintering neck network to avoid brittle fracture. The test needs to be carried out at a controlled temperature (such as room temperature) to ensure the repeatability of the results. The specimen needs to be processed to a standard size and the surface must be polished to reduce the impact of defects.

Toughness is affected by alloy composition, microstructure and production process. An increase in

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nickel content significantly improves toughness because the plasticity of nickel allows it to absorb more energy during impact, forming a ductile fracture feature. The addition of copper further improves toughness, and its ductility reduces the hardness of the bonding phase, making the alloy more susceptible to plastic deformation rather than brittle fracture during impact. The liquid phase sintering process enhances the interfacial bonding between tungsten particles and the nickel-copper matrix by forming a dense microstructure, reducing crack propagation under impact. The hot isostatic pressing process further improves toughness by compacting the structure, eliminating micropores and grain boundary defects. Heat treatment processes such as annealing enable the alloy to exhibit more uniform energy absorption capabilities during impact by optimizing the grain boundary structure and eliminating residual stresses.

In practical applications, the results of toughness tests directly determine the suitability of alloys in dynamic environments. In the aerospace field, helicopter rotors or aircraft aileron counterweights need to withstand high-frequency vibrations and impacts. Higher toughness ensures that the components will not fracture brittlely under extreme conditions. In the military field, armor-piercing projectile cores need to absorb huge energy when impacting armor at high speed. Good toughness ensures the integrity of the projectile core. In the medical field, surgical robot components may be subjected to accidental impacts. Toughness enables them to resist cracking and maintain function. Test optimization needs to focus on impurity control to avoid impurities such as oxygen or carbon from forming brittle phases that reduce toughness. Surface treatment (such as polishing or coating) can reduce surface defects and improve impact resistance. Quality control verifies toughness performance through fracture analysis (SEM observation of dimples) and repeated testing.

#### 4.2.5 Thermal performance test

Thermal performance testing is to evaluate the ability of tungsten-nickel-copper alloy in thermal conductivity and thermal stability. It is used to verify its performance in high temperature or thermal cycle environments. It is particularly suitable for application scenarios that require efficient thermal management or dimensional stability, such as heat sinks for photolithography machines in the electronics industry, radiation shielding in medical equipment, or high-temperature components in aerospace. Thermal properties mainly include thermal conductivity and thermal expansion characteristics, which reflect the alloy's ability to quickly disperse heat and dimensional stability under temperature changes, respectively. These properties are derived from the high thermal conductivity of copper and the low thermal expansion characteristics of tungsten, combined with the synergistic effect of the nickel-copper bonding phase, which enables the alloy to maintain performance in high-precision and high-temperature environments.

Thermal conductivity testing is usually performed by the laser flash method or the heat flow meter method. The laser flash method evaluates the thermal conductivity of the alloy by applying a short laser pulse to the sample surface and measuring the time it takes for heat to propagate through the sample. This method is suitable for rapid testing of solid samples (such as plates or blocks) and can accurately reflect the heat dissipation capacity of the alloy in actual applications. The heat flow

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meter method evaluates the performance of thermal conductivity by establishing a stable temperature gradient on both sides of the sample and measuring the heat flux density. Both methods need to be performed in a controlled environment (such as constant temperature or vacuum conditions) to avoid external temperature or airflow interference. Sample preparation requires a smooth surface and uniform thickness to ensure consistent heat transfer. The test results verify the role of copper in the nickel-copper bonding phase. Its high thermal conductivity enables the alloy to quickly disperse heat, which is suitable for high heat load scenarios such as lithography machines or medical devices. Liquid phase sintering and hot isostatic pressing processes further improve thermal conductivity by forming a dense microstructure, reducing the resistance of pores and grain boundaries to heat conduction.

Thermal expansion coefficient testing is usually performed using a dilatometer or differential scanning calorimetry (DSC). A dilatometer evaluates dimensional stability under temperature changes by measuring the change in length of a sample during controlled heating. The sample is slowly heated to a specific temperature range and its deformation is recorded to verify that the alloy can maintain accuracy during thermal cycling. The DSC method indirectly infers thermal expansion characteristics by analyzing the thermal effects of the sample during heating. These tests need to be performed in a precisely controlled environment and the sample surface needs to be polished to eliminate the effects of defects. The low thermal expansion characteristics of tungsten allow the alloy to maintain stable dimensions during temperature fluctuations, making it suitable for high-precision applications such as photolithography platforms. The nickel-copper binder phase is evenly distributed and combined with a sintering neck to reduce thermal stress concentration and enhance thermal stability. Heat treatment processes such as annealing further improve the alloy's performance during thermal cycling by optimizing the grain boundary structure.

In practical applications, thermal performance testing ensures the reliability of alloys in high-temperature or high-precision environments. For example, in photolithography machines, the balance block needs to dissipate heat quickly and maintain dimensional stability. Excellent thermal conductivity and low thermal expansion coefficient ensure the sub-nanometer precision of the platform. In medical CT equipment, the shielding operates under the heat generated by radiation, and thermal performance ensures its long-term stability and safety. Test optimization needs to focus on the consistency of sample preparation and instrument calibration to avoid impurities (such as oxygen or carbon) or micropores that reduce thermal conductivity.

#### 4.2.6 Electrical performance test

The electrical performance test is to evaluate the ability of tungsten-nickel-copper alloy in current conduction and electromagnetic compatibility. It is used to verify its performance in electromagnetic sensitive environments. It is particularly suitable for applications such as medical MRI shielding, lithography machine vibration reduction components or radar system components. Electrical properties mainly include conductivity and non-magnetic properties, which reflect the ability of the alloy to conduct current and avoid electromagnetic interference. The non-magnetic nature of

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tungsten -nickel-copper alloy is its greatest advantage, which comes from the paramagnetism of nickel and copper, making it perform well in electromagnetic sensitive environments. Although the conductivity is lower than that of pure copper, it is sufficient to meet the needs of most electronic applications. Combined with high density and non-magnetism, it is suitable for high-precision equipment.

Conductivity testing is usually done using a four-point probe method or resistivity measurement. The four-point probe method applies a small current to the sample surface, measures the voltage drop, and calculates the conductivity. This method is suitable for rapid testing of solid samples (such as bars or thin plates) and can accurately evaluate the current conduction ability of alloys in electronic applications. The resistivity measurement method measures the resistance of the sample and infers the conductivity based on its geometric dimensions. The test needs to be carried out in a constant temperature and humidity environment to avoid the influence of temperature or humidity on the resistance. The sample surface needs to be polished and cleaned to eliminate the interference of oxide layer or dirt. The test results reflect the dominant role of copper in the nickel-copper bonding phase, and its high conductivity provides a stable current conduction path for the alloy. The addition of nickel forms a uniform Ni-Cu solid solution and maintains moderate conductivity, while the high resistance characteristics of tungsten are compensated by the optimization of the microstructure. Liquid phase sintering and hot isostatic pressing processes reduce the influence of grain boundary resistance and porosity by forming a dense microstructure and improving conductivity.

Non-magnetic testing is usually performed through magnetization intensity measurement or magnetic permeability testing, using a magnetometer or vibrating sample magnetometer (VSM) to evaluate the alloy's response in a magnetic field. The non-magnetic nature of tungsten -nickel-copper alloy benefits from the paramagnetic properties of nickel and copper, avoiding ferromagnetic interference and is suitable for electromagnetically sensitive applications such as MRI equipment or photolithography machines. The test needs to be performed in a shielded magnetic field environment to eliminate external magnetic field interference. The sample must undergo strict impurity control to avoid the introduction of weak magnetism by magnetic elements such as iron (from raw materials or processing tools). The sintering process uses a high-purity argon atmosphere to prevent oxide inclusions from affecting non-magnetic properties. Surface treatment (such as PVD conductive coating) can further protect the alloy and maintain the stability of electrical properties.

In practical applications, electrical performance testing ensures the reliability of alloys in electromagnetic sensitive environments. For example, in MRI equipment, shielding parts need to be non-magnetic to avoid interfering with the magnetic field, and moderate conductivity supports its stable operation in electromagnetic environments. In lithography machines, the conductivity and non-magnetism of the balance block ensure the normal function of the platform in high-precision electromagnetic systems. Test optimization needs to focus on impurity management to avoid impurities such as oxygen or sulfur from forming non-conductive phases that reduce conductivity.

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Quality control verifies the reliability of results through repeated testing and calibration with standard samples.

#### 4.2.7 Chemical performance test

Chemical performance testing is an important method to evaluate the stability of tungsten -nickel-copper alloys in corrosive or oxidizing environments. It is used to verify its corrosion resistance and oxidation resistance, and ensure the long-term reliability of the alloy under harsh conditions such as moisture, acidity or high temperature. This test is particularly important for applications such as medical equipment shielding, marine engineering counterweights and electronic industry heat sinks, which can ensure that the components maintain performance in complex environments. The excellent performance of chemical properties is due to the chemical inertness of tungsten and the protective effect of the nickel-copper bonding phase. Nickel forms a dense oxide protective layer to prevent the penetration of corrosive media, while the high stability of tungsten enhances the alloy's resistance to chemical erosion. Chemical performance testing covers corrosion resistance and oxidation resistance tests and needs to be carried out in a controlled environment to simulate actual application conditions.

Corrosion resistance testing is usually carried out by immersion testing or salt spray testing. The immersion test places the alloy sample in a specific corrosive medium (such as dilute acid, alkaline solution or salt water) and observes its surface changes, mass loss or corrosion products under controlled temperature and time. The test is designed to simulate the long-term use conditions of medical devices in a sterilized environment or marine components in seawater to evaluate the corrosion resistance of the alloy. The sample needs to be polished and cleaned to remove the surface oxide layer or dirt to ensure that the test results reflect the performance of the material itself. The corrosion resistance of nickel in the nickel-copper bonding phase makes the alloy perform well in humid or acidic environments, especially in medical applications, where corrosion resistance ensures the biocompatibility and durability of the components. Salt spray testing simulates marine or industrial environments by exposing the sample to a salt spray environment (such as neutral salt spray or acidic salt spray) to observe corrosion spots or surface deterioration. Liquid phase sintering and hot isostatic pressing processes reduce pores and grain boundary exposure by forming a dense microstructure, reducing the penetration path of corrosive media and improving corrosion resistance.

Oxidation resistance testing is usually performed through high-temperature oxidation tests or thermogravimetric analysis. High-temperature oxidation tests place samples in a high-temperature air or oxygen environment to observe the formation of surface oxide layers, mass gain or performance changes, simulating the conditions of high-temperature aerospace components or electronic heat sinks in high-temperature operation. Nickel's oxidation resistance forms a protective oxide layer at high temperatures to prevent further erosion by oxygen, while tungsten's high thermal stability ensures the structural integrity of the alloy. Thermogravimetric analysis evaluates the rate and extent of oxidation reactions by accurately measuring the mass change of the sample during heating, which is suitable for high-precision laboratory testing. The test needs to be carried out in a

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furnace with precise temperature control, and the sample surface needs to be smooth to reduce the impact of initial defects. The sintering process uses a high-purity argon atmosphere to avoid oxide inclusions affecting oxidation resistance. Surface treatment (such as chemical passivation or antioxidant coating) can further enhance oxidation resistance and extend component life.

In practical applications, chemical property testing ensures the reliability of alloys in harsh environments. For example, in medical CT shielding, corrosion resistance ensures the long-term stability of components in sterilized environments; in aerospace turbine counterweights, oxidation resistance ensures performance maintenance in high-temperature gas environments. Test optimization needs to focus on the consistency of sample preparation and the authenticity of environmental simulation to avoid impurities (such as oxygen or sulfur) or surface defects affecting the results. Quality control verifies the reliability of results through repeated testing and calibration with standard samples.

### 4.3 Standard system of tungsten-nickel-copper alloy

tungsten -nickel-copper alloy is an important framework to ensure its quality, performance and application consistency, covering composition requirements, performance indicators, test methods and quality control processes. These standards are formulated by international, national or industry organizations to regulate the production, testing and application processes to ensure the compliance and competitiveness of the alloy in the global market. The standard system includes international standards (such as ASTM B777, ISO 20886), national standards (such as China's GB/T series) and industry standards (such as MIL-T-21014D), providing a unified quality benchmark for the aerospace, medical and electronics industries. China's national standards play an important guiding role in the production and application of tungsten-nickel-copper alloys, reflecting the characteristics of domestic technology and market demand.

#### 4.3.1 Chinese National Standard for Tungsten-Nickel-Copper Alloy

China's national standards (GB/T series) are the main specifications for the production, testing and application of tungsten-nickel-copper alloys. They are formulated by the National Standardization Administration and are widely used in the domestic aerospace, medical, electronic and military fields. These standards specify the composition range, performance requirements, test methods and quality control processes of the alloys to ensure that the products meet the needs of high-reliability applications such as aircraft counterweights, medical collimators or photolithography machine balance blocks. As a major tungsten resource country in the world (with reserves of about 3.5 million tons) and a tungsten alloy production center, China has formulated a number of standards for high-density tungsten alloys. As a representative of non-magnetic high-density alloys, tungsten-nickel-copper alloys have received special attention.

One of the most relevant standards in China's national standards is GB/T 26036-2010 Heavy Tungsten Alloys, which applies to high-density tungsten-based alloys including tungsten -nickel-

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copper alloys , and specifies the composition range (e.g. 85%-97% tungsten, nickel and copper as binder phases), density requirements, mechanical properties and test methods. The standard requires the alloy to have a high density to meet the needs of counterweight and shielding, while emphasizing non-magnetic properties, suitable for electromagnetic sensitive environments such as MRI equipment. Composition analysis requires the use of spectroscopy techniques (such as XRF or ICP-AES) to verify the ratio of tungsten, nickel and copper, and the content of impurities (such as oxygen and carbon) must be strictly controlled to avoid performance degradation. Mechanical property tests include tensile strength and ductility, and tensile tests are required to verify the reliability of the alloy under high stress. Chemical property tests require the evaluation of corrosion resistance and oxidation resistance to ensure the stability of the alloy in humid or high temperature environments.

In addition, GB/T 228.1-2010 Tensile test of metallic materials Part 1: Test method at room temperature provides specifications for mechanical property testing of tungsten-nickel-copper alloys, guiding the measurement of tensile strength and yield strength to ensure that the results meet aerospace or military requirements. GB/T 231.1-2018 Brinell hardness test of metallic materials Part 1: Test method specifies the hardness test process for evaluating the surface hardness and processing properties of alloys. GB/T 1423-2012 Density determination method for precious metals and their alloys provides a standardized method for density testing to ensure that the high density characteristics of the alloy meet the design requirements. Together, these standards form a comprehensive testing framework for tungsten-nickel-copper alloys.

The application of China's national standards has promoted the quality improvement and market competitiveness of domestic tungsten -nickel-copper alloys. For example, in the medical field, the standards ensure that the non-magnetic and corrosion-resistant properties of shielding parts meet ISO biocompatibility requirements; in the electronics industry, the standards guide the density and thermal conductivity testing of photolithography machine balance blocks to ensure high-precision performance. The implementation of the standards needs to be combined with production process optimization, such as using liquid phase sintering and hot isostatic pressing to improve density, and strictly controlling raw materials and atmosphere to reduce impurities. Quality control is verified through standardized multi-point testing and third-party certification (such as CNAS laboratories).

#### 4.3.2 International Standards for Tungsten-Nickel-Copper Alloys

International standards are global specifications for quality control and market application of tungsten-nickel-copper alloys, formulated by the International Organization for Standardization (ISO) and other authoritative organizations, and widely used in aerospace, medical and electronics industries. These standards provide unified guidance for the composition, performance, test methods and quality certification of the alloys, ensuring the consistency and reliability of products in different countries and industries. As a high-density non-magnetic material, the international standards of tungsten -nickel-copper alloys mainly focus on the composition range, density, mechanical properties and non-magnetic properties, and are suitable for high-precision and electromagnetic sensitive applications.

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ISO 20886:2004 Technical Specification for High-density Tungsten Alloys, developed by the International Organization for Standardization, is one of the main international standards for tungsten-nickel-copper alloys, applicable to tungsten-based high-density alloys (including W-Ni-Cu and W-Ni-Fe). The standard specifies the composition range of the alloy (85%-97% tungsten content, nickel and copper as bonding phases), and requires verification of its density, mechanical properties (such as tensile strength and ductility) and non-magnetic properties. The standard emphasizes the detection of the main element ratio through spectral analysis (such as XRF or ICP-AES), the evaluation of mechanical properties through tensile tests and impact tests, and the confirmation of non-magnetic properties through magnetization strength tests, meeting the needs of medical MRI shielding or electronic industry balance weights. ISO 20886 also requires that the production process (such as liquid phase sintering or hot isostatic pressing) must ensure the compactness of the microstructure and reduce the impact of pores and impurities on performance.

Another relevant international standard is the ISO 10993 Biological Evaluation of Medical Devices series, which is applicable to the application of tungsten-nickel-copper alloys in the medical field (such as CT shields or collimators). The standard requires verification of the biocompatibility of the alloy, especially the control of nickel content to avoid allergic reactions. Corrosion resistance and oxidation resistance tests must meet the requirements of the standard to ensure the long-term stability of the alloy in a sterilized or humid environment. The international standard also refers to ISO 6892-1 Tensile testing of metallic materials to regulate mechanical property testing, guide the measurement of tensile strength and yield strength, and ensure the reliability of the alloy in high stress environments. Together, these standards provide technical support for the global application of tungsten-nickel-copper alloys.

The implementation of international standards has promoted the circulation of tungsten-nickel-copper alloys in the global market. For example, in the aerospace field, the standards ensure that the high density and non-magnetic properties of the counterweights meet the design requirements; in the medical field, the standards ensure the biocompatibility and durability of the shielding parts. The implementation process requires the combination of high-precision testing equipment (such as SEM or VSM) and strict quality control processes (such as third-party certification) to ensure compliance with standard requirements.

#### **4.3.3 Tungsten-nickel-copper alloy standards in Europe, America, Japan, South Korea and other countries around the world**

Based on international standards, the standards for tungsten-nickel-copper alloys in Europe, America, Japan, South Korea and other countries have formulated more specific and detailed specifications in combination with local technology and market demand. These standards have certain differences in composition control, performance requirements and test methods, reflecting the application focus of each country in the aerospace, medical and electronics industries. The following will discuss the relevant standards of the United States, Europe, Japan and South Korea respectively, highlighting their characteristics and application scenarios.

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**US Standard :** The United States adopts ASTM B777-15 High-density Tungsten Alloy Specification as the main standard for tungsten -nickel-copper alloys, which is applicable to W-Ni-Cu and W-Ni-Fe alloys. The standard divides tungsten alloys into four categories (Class 1-4), defines performance requirements based on tungsten content (90% -97%) and binder phase ratio, and covers density, mechanical properties (such as tensile strength and hardness) and non-magnetic tests. ASTM B777 requires strength to be verified by tensile testing (reference ASTM E8) and non-magnetic properties to be confirmed by magnetization strength testing, which is suitable for medical MRI shielding parts and electronic industry balance weights. The standard also requires production processes (such as powder metallurgy) to ensure that the microstructure is dense and porosity is reduced. The US military standard MIL-T-21014D Tungsten-based High-density Alloy further refines the requirements for military applications, specifies performance indicators for armor-piercing cores or aerospace counterweights, and emphasizes impact resistance and high-temperature stability. These standards are widely used in the US aerospace and defense fields to ensure that the alloys meet high reliability requirements.

**European standards :** Europe mainly refers to "EN 1982 Copper and Copper Alloy Ingots and Castings" and other high-density alloy standards. Although it is mainly for copper-based alloys, some specifications are applicable to the casting and processing of tungsten -nickel-copper alloys. EN standards emphasize composition control (such as the ratio of nickel and copper ) and corrosion resistance testing, which is suitable for applications in marine engineering and medical equipment. Europe also uses "EN ISO 6892-1 Tensile Test of Metallic Materials" to standardize mechanical property testing, requiring verification of the performance of alloys in high-stress environments. European standards focus on environmental protection and biocompatibility, especially in medical applications, requiring compliance with the "EN ISO 10993" biological evaluation standard to control nickel content to avoid allergic risks. Europe's tungsten-nickel-copper alloys are mostly used for ship counterweights and medical shielding parts, emphasizing seawater corrosion resistance and non-magnetic properties.

**Japanese Standard :** Japan adopts "JIS H7202 High-density Tungsten Alloy" as the main standard for tungsten -nickel-copper alloys, which are suitable for aerospace, electronics and medical fields. The standard specifies the tungsten content range (90%-95%) and the composition of the bonding phase, requires the verification of the composition by spectral analysis, and the evaluation of mechanical properties by tensile and impact tests. The Japanese standard places special emphasis on non-magnetic and thermal conductivity tests, which are suitable for high-precision applications of lithography balance blocks and MRI shielding parts. "JIS Z2241 Tensile Test Method for Metal Materials" provides guidance for mechanical property testing to ensure consistency of results. In terms of production technology, Japan focuses on high-purity raw materials and vacuum sintering to reduce the impact of impurities ( such as oxygen or iron) on non-magnetic properties and corrosion resistance. The application of Japanese standards in the electronics industry is particularly prominent, promoting the popularization of alloys in semiconductor equipment.

**Korean Standard :** Korea adopts KS D 5201 Tungsten and Tungsten Alloys to regulate the

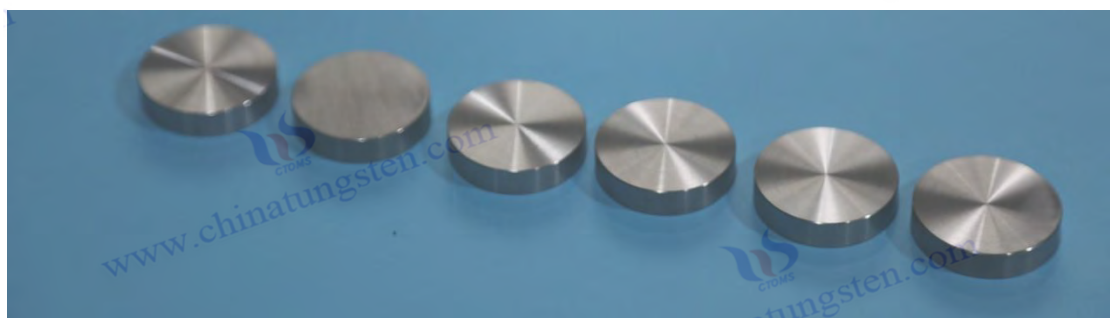
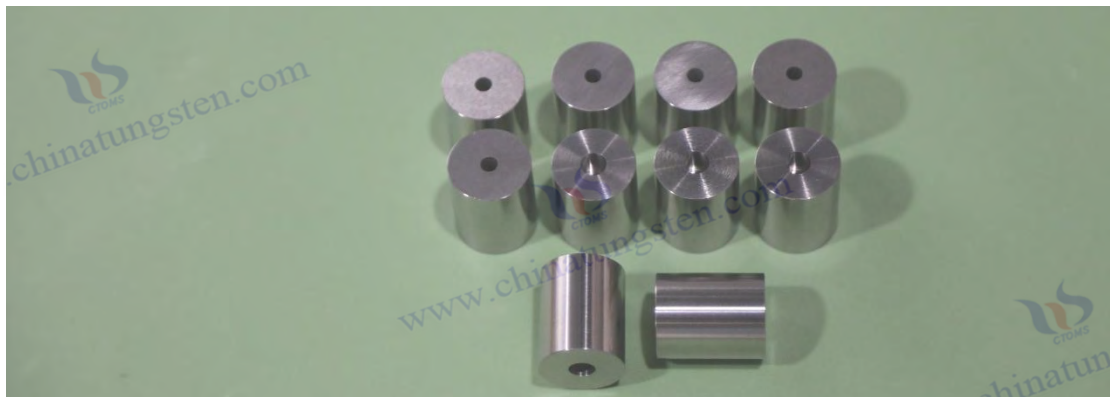
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production and testing of tungsten -nickel-copper alloys, which are suitable for aerospace, electronics and military fields. The standard requires verification of the density, mechanical properties and non-magnetic properties of the alloy, and ensures that the composition and performance meet the requirements through spectral analysis and magnetization strength testing. Korean standards focus on thermal performance testing (such as thermal conductivity and thermal expansion coefficient) to meet the needs of heat sinks and balance blocks in the electronics industry . The production of tungsten-nickel-copper alloys in Korea mostly adopts liquid phase sintering and hot isostatic pressing processes to ensure the density of the microstructure. The standard also refers to KS D ISO 6892 Tensile Test of Metallic Materials for mechanical property testing, emphasizing the reliability of the alloy under high stress environments. Korea's rapid development in the electronics and semiconductor fields has promoted the implementation of these standards to ensure that the alloys meet the requirements of high-precision equipment.

The differences in standards of various countries are mainly reflected in the application focus and test details. The US standard focuses on the high strength requirements of military and aerospace, Europe focuses on corrosion resistance in marine and medical applications, Japan emphasizes non-magnetism and high precision in the electronics industry, and South Korea focuses on electronics and thermal management applications. The implementation of these standards requires a combination of high-precision testing equipment and strict impurity control (such as oxygen content <0.05%) to ensure the consistency of alloy performance. Quality certification is usually verified by a third-party organization to promote international trade.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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## Chapter 5 Preparation Technology of Tungsten-Nickel-Copper Alloy

Tungsten -nickel-copper alloy is a high-density, non-magnetic, high-performance material. It is widely used in aerospace, medical, electronic and military fields due to its excellent mechanical properties, thermal conductivity and chemical stability. Its preparation process is mainly based on powder metallurgy technology, and a highly dense and uniform microstructure is achieved through steps such as raw material pretreatment, powder mixing, pressing, liquid phase sintering and post-processing. Raw material pretreatment is the starting point of the preparation process, which directly affects the fluidity, mixing uniformity and sintering properties of the powder, and thus determines the quality and performance of the alloy. The spheroidization and particle size control of tungsten powder and the surface treatment of nickel-copper powder are two key links in raw material pretreatment to ensure the high purity, appropriate particle size and surface activity of the powder.

### 5.1 Raw material pretreatment

The preparation of tungsten -nickel-copper alloy uses high-purity tungsten powder, nickel powder and copper powder as raw materials, and forms a dense alloy structure through powder metallurgy process. Raw material pretreatment aims to optimize the physical and chemical properties of the powder, including particle size, morphology, purity and surface state, so as to improve the fluidity, mixing uniformity and sintering activity of the powder. As the main component, tungsten powder needs to have high purity and suitable particle size distribution to ensure the high density and mechanical properties of the alloy. Nickel powder and copper powder, as binding phases, need to have good surface activity and wettability to promote the combination with tungsten particles during liquid phase sintering. Raw material pretreatment includes steps such as powder preparation, screening, cleaning and surface modification, which need to be carried out in a clean environment to avoid contamination by impurities (such as oxygen and carbon). The following will discuss in detail the process and application of tungsten powder spheroidization and particle size control and nickel-copper powder surface treatment.

#### 5.1.1 Tungsten powder spheroidization and particle size control

The spheroidization and particle size control of tungsten powder are the core links of raw material pretreatment, aiming to optimize the morphology and particle size distribution of tungsten powder, improve its fluidity, bulk density and sintering performance, and directly affect the density and microstructural uniformity of tungsten -nickel-copper alloy. Tungsten powder is usually prepared by hydrogen reduction or plasma method, and the initial morphology is mostly irregular polygonal or angular, with a wide range of particle sizes. Spheroidization treatment makes tungsten powder particles tend to be spherical, reduces edges and corners, improves fluidity (shortened flow time) and bulk density, and is conducive to powder mixing and pressing. Particle size control ensures that the powder particle size distribution is within an appropriate range, enhances particle rearrangement and densification during sintering, and avoids pores or segregation affecting alloy properties. Spheroidization treatment often uses plasma spheroidization technology or high-temperature melt

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atomization. Plasma spheroidization is done by feeding tungsten powder into a high-temperature plasma flame, causing the particles to melt instantly and form spherical droplets under the action of surface tension, which are then rapidly cooled and solidified. This method can significantly improve the sphericity of tungsten powder, reduce surface defects, and enhance the fluidity of the powder, making it suitable for high-precision applications such as photolithography machine balance blocks. The high-temperature melt atomization method melts the tungsten raw material and sprays it into fine droplets, which are then cooled in an inert gas (such as argon) to form spherical particles, which is suitable for large-scale production. The spheroidized tungsten powder has a higher bulk density, which is conducive to the uniformity of the pressed blank and reduces the risk of uneven sintering shrinkage.

Particle size control is usually achieved through screening, airflow classification or ultrasonic dispersion technology. The screening method uses a standard screen to separate tungsten powders of different particle sizes. It is simple and efficient, but the accuracy is low. Airflow classification separates particles through airflow and accurately controls the particle size distribution, which is suitable for high-demand applications. Ultrasonic dispersion uses ultrasonic waves to break up agglomerated particles and optimize particle size uniformity. The appropriate particle size range can balance sintering activity and structural stability. Finer particles enhance the dissolution-precipitation effect during sintering and promote densification; coarser particles provide a stable skeleton structure, which is suitable for the high strength requirements of military armor-piercing projectile cores. Particle size control needs to be combined with raw material purity management to avoid oxygen or carbon impurities affecting powder performance.

In production, tungsten powder spheroidization and particle size control ensure the high density and mechanical properties of the alloy. For example, in aerospace counterweights, spheroidized tungsten powder improves the density of the blank and ensures the stability of the center of gravity; in medical shielding parts, uniform particle size distribution reduces porosity and improves radiation absorption efficiency. Process optimization needs to focus on the high precision of equipment (such as plasma temperature control) and environmental cleanliness (clean room operation) to avoid dust contamination. Quality control verifies particle size distribution and morphology through laser particle size analyzer and SEM observation.

### 5.1.2 Surface treatment of nickel-copper powder

Surface treatment of nickel-copper powder is another key step in raw material pretreatment, which aims to optimize the surface chemical state, cleanliness and activity of nickel and copper powders, improve their wettability and bonding ability with tungsten particles during liquid phase sintering. Nickel and copper, as bonding phases, form a liquid phase during sintering, fill the gaps between tungsten particles, and enhance the toughness, non-magneticity and thermal conductivity of the alloy. Untreated nickel-copper powder may have an oxide layer (such as NiO or CuO), organic pollutants or adsorbed gases on the surface, which reduces its wettability and sintering activity, resulting in poor interfacial bonding or increased porosity. Surface treatment improves powder properties

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through cleaning, chemical modification or coating technology to ensure the compactness and uniformity of the alloy. Surface cleaning usually uses chemical cleaning or ultrasonic cleaning. Chemical cleaning uses dilute acid (such as hydrochloric acid or nitric acid) or alkaline solution to remove the oxide layer and impurities on the surface of nickel-copper powder, followed by rinsing with deionized water and drying in vacuum or inert gas (such as argon) to avoid secondary oxidation. Ultrasonic cleaning uses high-frequency ultrasonic waves to produce tiny bubbles in the cleaning liquid (such as ethanol) to burst and strip surface pollutants, which is suitable for high-precision applications. The cleaning process needs to control the solution concentration and time to avoid excessive corrosion and damage to the powder morphology. The surface cleanliness of the nickel-copper powder after cleaning is improved, and the wettability with the liquid phase is enhanced, which is conducive to the formation of sintering necks .

Chemical modification further improves the sintering performance of nickel-copper powder by introducing an active agent or a reducing agent on the surface of nickel-copper powder. For example, a trace amount of reducing agent (such as hydrogen or formic acid) is used to treat the powder surface to reduce oxides and form an active metal surface, which enhances the chemical bonding with tungsten particles. Surface coating technology (such as chemical vapor deposition, CVD) can deposit a thin layer of carbon or metal (such as Ni or Cu) on the surface of nickel or copper powder to improve oxidation resistance and wettability, which is suitable for high-temperature sintering environment. The modified powder forms a more uniform liquid phase distribution in liquid phase sintering, reduces segregation, and promotes the rearrangement and bonding of tungsten particles. In production, surface treatment of nickel-copper powder optimizes the microstructure and properties of the alloy. For example, in heat sinks for the electronics industry, surface-treated nickel-copper powder improves thermal conductivity and interfacial bonding strength; in medical collimators, enhanced wettability reduces porosity and improves radiation shielding efficiency. Process optimization needs to focus on the environmental friendliness of the cleaning solution and the cleanliness of the processing environment to avoid secondary contamination. Quality control verifies the surface chemical state through XPS or EDS analysis, combined with SEM to observe the powder morphology.

## 5.2 Powder Metallurgy Process

Powder metallurgy is the main method for preparing tungsten-nickel-copper alloy. It forms a high-density alloy structure by mixing tungsten powder, nickel powder and copper powder, pressing and sintering. This process can accurately control the proportion of components, optimize the microstructure, and meet the high performance requirements of aerospace counterweights, medical shielding parts and electronic industry balance blocks . The powder metallurgy process includes steps such as powder mixing, pressing, liquid phase sintering and post-treatment (such as hot isostatic pressing or heat treatment). Among them, powder mixing and pressing are the key to forming a uniform billet, which directly affects the particle rearrangement, liquid phase distribution and density during the sintering process. The process needs to be carried out in a clean environment, using high-purity raw materials and precise equipment to ensure the consistency and reliability of

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alloy performance.

### 5.2.1 Powder mixing process parameters

The powder mixing process is the starting step of powder metallurgy, which aims to evenly mix tungsten powder, nickel powder and copper powder according to the designed proportion to form a powder mixture with consistent distribution of components, laying the foundation for subsequent pressing and sintering. Uniform powder mixing can ensure the uniformity of the alloy's microstructure, avoid component segregation or excessive porosity, and thus improve density, mechanical properties and non-magnetic properties. Tungsten powder, as the main component, provides high density and hardness; nickel powder and copper powder, as binding phases, enhance toughness and thermal conductivity. The success of the powder mixing process depends on the optimization of powder particle size, morphology, mixing equipment and process conditions to ensure that the powder particles are fully in contact and evenly distributed.

Powder mixing usually adopts mechanical mixing or ball milling mixing technology. Mechanical mixing uses a V-type mixer or a three-dimensional mixer to tumble and mix the powder particles in the container by rotation or vibration, which is suitable for large-scale production. The mixer needs to have high-precision speed control to avoid excessive mixing that causes damage to the particle morphology or slight agglomeration. Ball milling mixing adds grinding media (such as zirconia balls) to the ball mill, and uses collision and friction to achieve uniform dispersion of powder, which is suitable for high-precision small-batch production. The ball-to-material ratio and grinding time need to be controlled during the ball milling process to avoid excessive grinding that causes particle breakage or the introduction of impurities (such as oxygen or iron). The mixing environment needs to be carried out under high-purity inert gas (such as argon) or vacuum conditions to prevent powder oxidation and maintain the surface activity of nickel-copper powder.

The powder mixing process is to optimize the particle size matching and mixing uniformity of the powders. Tungsten powder is usually larger in particle size, while nickel powder and copper powder are finer. Reasonable particle size matching can increase the packing density of the mixture and promote densification during pressing and sintering. The morphology of the powder is also crucial. The spheroidized tungsten powder has high fluidity, which is conducive to uniform mixing; the surface treatment of nickel and copper powder (such as chemical cleaning) removes the oxide layer, enhances the contact between particles and the wettability of liquid phase sintering. The optimization of process conditions includes mixing time, rotation speed and environmental control. Appropriate mixing time ensures uniformity, and too long mixing time may cause particle agglomeration or surface damage. Adding a small amount of lubricant can improve powder fluidity, but it needs to be removed before sintering to avoid carbon residue.

In actual production, the uniformity of the powder mixing process directly affects the performance of the alloy. For example, in medical shielding parts, uniform component distribution ensures radiation absorption efficiency and non-magnetism; in aerospace counterweights, uniform powder

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mixing improves density consistency and ensures center of gravity stability. Quality control verifies the component ratio through sampling analysis (XRF or ICP-AES), and observes the mixing uniformity and particle morphology through laser particle size analyzer and SEM. Process optimization needs to focus on the cleanliness of the equipment and the purity of the powder (>99.9%) to avoid impurity contamination.

### 5.2.2 Pressing technology

Pressing technology is a key step in the powder metallurgy process. It presses the evenly mixed tungsten, nickel and copper powders into a blank with a certain shape and strength, providing a basis for subsequent sintering. The quality of pressing directly affects the density, shape accuracy and sintering performance of the blank, which in turn determines the final properties of the alloy, such as high density, strength and toughness. Pressing requires ensuring that the powder particles are tightly packed and the porosity is reduced (the initial porosity is about 20%-30%) while maintaining the structural integrity of the blank. It is suitable for complex-shaped aerospace counterweights, medical collimators or heat sinks in the electronics industry. Pressing technology needs to optimize process parameters in combination with powder properties and target applications to ensure that the blank meets sintering requirements.

Pressing molding usually adopts cold pressing or isostatic pressing technology. Cold pressing uses a hydraulic press or a mechanical press to load the powder into a mold and compress it into a blank of a specific shape under high pressure. It is suitable for the production of parts with simple shapes (such as bars or plates). The mold design needs to consider the fluidity and compression ratio of the powder to ensure uniform density inside the blank and avoid cracks or delamination. Isostatic pressing (cold isostatic pressing, CIP) forms a high-density blank by loading the powder into a flexible mold (such as a rubber bag) and applying equal pressure in all directions in a liquid medium. It is suitable for complex shapes or high-precision parts. Isostatic pressing can significantly reduce stress concentration and porosity inside the blank, and is suitable for the manufacture of medical shielding parts or photolithography machine balance blocks .

The success of press molding depends on the optimization of powder properties and process conditions. Spheroidized tungsten powder and surface-treated nickel-copper powder have high fluidity, which can form a more compact stacking structure during the pressing process and increase the initial density of the blank. The particle size distribution of the powder needs to be reasonably matched, and the fine particles fill the gaps between large particles to reduce the porosity. Adding a small amount of binder (such as polyvinyl alcohol) can enhance the green strength of the blank, but it needs to be removed by degreasing before sintering. The pressing pressure needs to be adjusted according to the powder type and target density. Too high may cause mold wear or blank cracking, and too low will result in insufficient density. Environmental control (such as clean room operation) avoids dust or impurity contamination and maintains the purity of the blank. The degreasing process is carried out after pressing, and the binder and lubricant are removed by low-temperature heating to avoid carbon residue affecting the sintering quality.

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In actual production, the pressing technology directly affects the performance and application of the alloy. For example, in the core of military armor-piercing projectiles, the high-density billet ensures the high density and strength of the alloy after sintering; in the heat sink of the electronic industry, the uniform billet structure improves the thermal conductivity and dimensional accuracy. Quality control verifies the uniformity and porosity of the billet through density measurement (Archimedes method) and microscopic observation. Process optimization needs to focus on the wear resistance of the mold and the precise control of the pressure, using high-precision hydraulic equipment or automated isostatic pressing system.

### 5.2.3 Liquid Phase Sintering Process

The liquid phase sintering process is a key step in the preparation of tungsten-nickel-copper alloy. It wets tungsten particles by forming a liquid phase with nickel and copper at high temperature, promotes particle rearrangement and densification, and forms a high-density, uniform microstructure. This process uses the high melting point of tungsten (about 3422°C) and the low melting point of nickel and copper (about 1300-1450°C) to achieve close bonding of tungsten particles under the action of liquid phase, and enhance the mechanical properties (tensile strength, toughness), thermal conductivity and non-magnetic properties of the alloy. Liquid phase sintering is an ideal choice for high-performance applications such as aerospace counterweights, medical shielding parts and heat sinks in the electronics industry because it can produce alloys close to theoretical density and meet strict quality requirements.

The liquid phase sintering process is usually carried out in a vacuum or high-purity inert gas (such as argon) atmosphere to prevent oxidation and the introduction of impurities. The process includes three stages: heating, insulation and cooling. In the heating stage, the uniformly mixed tungsten, nickel and copper billets are heated to above the melting point of nickel and copper, and nickel and copper melt to form a liquid phase, which wets the surface of the tungsten particles. Due to the low surface tension and good wettability of the liquid phase, liquid nickel and copper quickly fill the gaps between tungsten particles, promote particle rearrangement through capillary action, and significantly reduce the porosity of the billet. The insulation stage is the core of densification. The liquid phase acts on the tungsten particles through a dissolution-reprecipitation mechanism. A small amount of tungsten atoms dissolve and reprecipitate at the contact points of the particles to form a sintering neck, which enhances the bonding force between the particles. The cooling rate needs to be controlled in the cooling stage to avoid cracks caused by thermal stress, while ensuring that the nickel-copper liquid phase solidifies to form a stable face-centered cubic structure, forming a strong interface bond with the tungsten particles.

The success of liquid phase sintering depends on the optimization of process conditions. The nickel-copper ratio (typically 7:3 or 3.5:1.5) affects the amount and fluidity of the liquid phase. A higher nickel content can enhance wettability but may cause segregation; a higher copper content reduces the melting point of the liquid phase, which is beneficial to sintering but needs to avoid strength loss. Accurate control of sintering temperature and holding time is crucial. Too high a temperature

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may cause excessive growth of tungsten particles or loss of liquid phase, while too low a temperature will result in insufficient liquid phase and reduced density. Atmosphere control uses high-purity argon or a vacuum environment to prevent the formation of oxides (such as  $WO_3$  or  $NiO$ ) that affect non-magnetic properties or corrosion resistance. The initial density of the billet (optimized by pressing) also affects the sintering effect. High-density billets can reduce porosity and increase final density.

In actual production, liquid phase sintering ensures the high performance of the alloy. For example, in medical collimators, high density and uniform microstructure provide excellent radiation shielding capabilities; in aerospace counterweights, the strong bonding force of the sintering neck ensures high strength and vibration resistance. Quality control verifies the process effect through density measurement (Archimedes method), SEM observation of sintering neck morphology and XRD analysis of phase structure. Process optimization requires attention to the precise control of temperature curves and atmosphere purity, and the use of high-precision sintering furnaces and online monitoring systems.

### 5.3 Advanced preparation technology

As the demand for complex shapes and high-precision parts in the aerospace, medical and electronics industries increases, traditional powder metallurgy processes face limitations in manufacturing complex geometries. Advanced preparation technologies such as metal injection molding (MIM), additive manufacturing (AM) and spark plasma sintering (SPS) provide new options for the preparation of tungsten-nickel-copper alloys. These technologies meet the needs of high-performance applications by increasing shape freedom, shortening production cycles and optimizing microstructures. Metal injection molding has become an important technology for the preparation of tungsten-nickel-copper alloys due to its advantages in producing small, complex-shaped parts, and is widely used in medical devices, electronic equipment and military components.

#### 5.3.1 Metal Injection Molding

Metal injection molding (MIM) is an advanced manufacturing technology that combines powder metallurgy and plastic injection molding. It forms a flowable slurry by mixing tungsten, nickel, and copper powders with a binder. After injection molding, it is degreased and sintered to form high-density alloy parts. MIM is particularly suitable for manufacturing small, complex-shaped, high-precision parts, such as medical surgical instruments, connectors for the electronics industry, or small counterweights for aerospace. Its advantages lie in high shape freedom, high material utilization, and high production efficiency. Compared with traditional press molding, MIM can achieve complex geometric structures (such as thin walls or internal channels), reduce subsequent machining, and reduce costs.

The MIM process includes four main steps: mixing, injection molding, debinding and sintering. In the mixing stage, tungsten, nickel and copper powders (ratio 85%-97% tungsten, 2%-10% nickel,

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1%-8% copper) are mixed with a binder (such as polypropylene or wax-based binder ) to form a uniform slurry. Tungsten powder needs to be spheroidized to improve fluidity, and nickel and copper powders need to be surface cleaned to enhance bonding. Mixing needs to be carried out in a high-temperature stirring device to ensure that the powder and the binder are fully dispersed. In the injection molding stage, the slurry is injected into a precision mold. The mold design needs to consider shrinkage and shape accuracy to form a green body with a target geometry. In the debinding stage, the binder is removed by thermal debinding or solvent debinding, usually slowly heated at low temperature to avoid cracking or deformation of the blank. Liquid phase sintering is used in the sintering stage, and nickel and copper form a liquid phase at high temperature to wet the tungsten particles, promote densification, and form an alloy structure close to the theoretical density.

The success of MIM depends on the optimization of process parameters. The powder particle size needs to be fine and evenly distributed to improve the fluidity of the slurry and the density of the blank; the selection and proportion of the binder affect the smoothness of injection molding and the debinding efficiency, and the fluidity and green strength need to be balanced . The sintering process requires precise control of temperature and atmosphere, and high-purity argon or vacuum environment is used to prevent oxidation and ensure non-magnetic properties. The final performance of MIM parts is further optimized through post-treatment (such as hot isostatic pressing or annealing) to eliminate residual porosity and stress and improve strength and toughness. Quality control verifies the performance of the parts through SEM observation of microstructure, density measurement and mechanical property testing, which must comply with ASTM B777 or GB/T 26036 standards.

In actual production, MIM technology has significantly improved the manufacturing flexibility of tungsten-nickel-copper alloys. For example, in the medical field, complex-shaped collimators produced by MIM have high precision and radiation shielding efficiency; in the electronics industry, micro heat sinks or connectors manufactured by MIM have both high thermal conductivity and non-magnetic properties. Process optimization needs to focus on the high precision of mold design and the environmental friendliness of the binder, and use degradable or non-toxic binders to reduce environmental impact. In the future, combining MIM with additive manufacturing (such as 3D printing molds) can achieve rapid production of more complex shapes and enhance the application potential of tungsten -nickel-copper alloys in high-tech fields.

### 5.3.2 Hot isostatic pressing technology

Hot isostatic pressing (HIP) is an advanced powder metallurgy post-processing process that applies isotropic pressure to tungsten-nickel-copper alloy billets in an inert gas environment at high temperature and pressure to eliminate micropores, increase density , and improve microstructural uniformity. This technology is particularly suitable for the production of high-performance components such as aerospace counterweights, medical shielding parts, and heat sinks in the electronics industry, and can significantly improve the density, mechanical properties (tensile strength, toughness), and corrosion resistance of the alloy. Hot isostatic pressing further compacts

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the structure after liquid phase sintering to make up for the tiny defects that may be left by conventional sintering, so that the alloy is close to the theoretical density and meets the needs of high-reliability applications.

The hot isostatic pressing process is usually carried out in a dedicated HIP equipment, using high-purity argon as the pressure medium. The process includes three main stages: heating, insulation and cooling. In the heating stage, the sintered tungsten-nickel-copper alloy billet is placed in a closed cavity and heated to a temperature close to the melting point of the nickel-copper bonding phase (about 1200-1400°C) to make the material plastic. In the insulation stage, high isostatic pressure is applied (usually in an argon environment) to compress the micropores inside the billet with equal pressure in all directions, promoting the close bonding of tungsten particles and nickel-copper bonding phase. The nickel-copper phase has a certain fluidity at high temperature, filling the pores and enhancing the interface bonding force; the tungsten particles maintain their body-centered cubic structure and provide a stable skeleton. The cooling stage needs to be carried out slowly to avoid cracks caused by thermal stress and ensure the stability of the alloy structure and uniformity of performance.

The success of hot isostatic pressing depends on the optimization of process conditions. Precise control of temperature and pressure is key. The temperature should make the nickel-copper phase have sufficient fluidity but avoid excessive dissolution of tungsten particles. The pressure should be sufficient to eliminate porosity but not too high to avoid overloading the equipment. High purity of argon is essential to prevent the formation of oxides (such as  $WO_3$  or  $NiO$ ) that affect the non-magnetic or corrosion resistance of the alloy. The initial density of the billet (optimized by powder mixing and pressing) affects the HIP effect. Billets with lower initial porosity can more efficiently reach a state close to the theoretical density. Hot isostatic pressing can also be combined with liquid phase sintering as a single process step, directly from powder pressed billets to final dense parts, shortening the production cycle. In actual production, hot isostatic pressing significantly improves the performance of tungsten-nickel-copper alloys. For example, in the aerospace field, HIP-treated counterweights have higher density and vibration resistance, ensuring center of gravity stability and long-term reliability; in medical collimators, structures close to theoretical density improve radiation shielding efficiency and corrosion resistance. Quality control verifies HIP effect through density measurement (Archimedes method), SEM observation of microstructure and mechanical property testing. Process optimization needs to focus on the high-pressure sealing and temperature uniformity of the equipment, and use automated control systems to improve accuracy.

#### 5.4 Post-processing and processing

Post-processing and machining are the final stages of tungsten-nickel-copper alloy preparation, which aims to optimize the dimensional accuracy, surface quality and performance of parts after sintering or hot isostatic pressing to meet the stringent requirements of the aviation, medical and electronics industries. Post-processing processes include heat treatment, surface treatment and machining steps to eliminate residual stress, improve surface finish and achieve complex geometries.

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The high hardness and toughness of tungsten -nickel-copper alloys make their processing challenging, but high-precision and high-quality final parts can be achieved through optimized processes. Post-processing and machining not only improve the functionality of the parts, but also enhance their durability and reliability in harsh environments.

Heat treatment is an important step in post-processing, usually including annealing or aging treatment, which aims to eliminate the residual stress generated during sintering or HIP, optimize the microstructure, and improve toughness and corrosion resistance. Annealing repairs the crystal defects (such as dislocations or grain boundary stress) in the nickel-copper bonding phase by diffusion through insulation at a lower temperature (about 800-1000°C), while maintaining the stability of the tungsten particles. Aging treatment promotes the formation of trace precipitation phases in the nickel-copper phase and enhances the strength of the bonding phase by long-term insulation at a lower temperature. Heat treatment needs to be carried out in a high-purity argon or vacuum environment to prevent oxidation and ensure the non-magnetic and chemical stability of the alloy. The heat-treated parts show more uniform mechanical properties and higher fatigue resistance, which are suitable for aerospace counterweights or medical surgical instruments.

Surface treatment improves the surface quality and performance of components through polishing, chemical passivation or coating technology. Mechanical polishing or electrochemical polishing makes the surface smooth, reduces surface defects (such as scratches or microcracks), improves corrosion resistance and aesthetics, and is particularly suitable for medical shielding or electronic heat sinks. Chemical passivation forms a protective oxide layer through acid solution treatment, enhances corrosion resistance, and is suitable for applications in marine environments or sterilized environments. Coating technology (such as PVD TiN or DLC coating) can further improve surface hardness, wear resistance and oxidation resistance, and extend component life. Surface treatment should be selected according to application requirements to avoid excessively thick coatings that affect thermal conductivity or non-magnetism.

Machining includes turning, milling, grinding or EDM, which is used to achieve complex shapes and high-precision dimensions. The high hardness of tungsten -nickel-copper alloys requires the use of carbide or diamond tools, and low cutting speeds and sufficient coolant are required during the machining process to reduce thermal stress and tool wear. EDM is suitable for complex geometries (such as internal channels or thin-walled structures) and removes material through electric pulses to maintain high precision. The machined parts need to be cleaned and inspected to ensure that there is no residual stress or surface damage. Quality control verifies machining accuracy and surface quality through dimensional measurement (CMM), surface roughness testing and SEM observation.

In actual production, post-processing and processing have significantly improved the applicability of tungsten-nickel-copper alloys. For example, in the balance block of the photolithography machine, precision machining ensures sub-nanometer accuracy, and surface polishing improves thermal conductivity and corrosion resistance; in the core of military armor-piercing projectiles, heat treatment enhances toughness, and machining achieves complex shapes. Process optimization

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needs to focus on tool wear resistance and the cleanliness of the processing environment, and use automated processing equipment to improve efficiency. Quality control verifies component integrity through non-destructive testing (such as ultrasound or X-rays).

#### 5.4.1 Precision machining

Precision machining is a key process for post-processing of tungsten-nickel-copper alloys. It is used to process sintered or hot isostatically pressed blanks into final components with high-precision dimensions and complex geometries to meet the stringent requirements of the aerospace, medical and electronics industries. The high hardness and toughness of tungsten -nickel-copper alloys make their processing challenging, but by optimizing tools and processes, sub-millimeter or even sub-micron accuracy can be achieved, which is suitable for lithography machine vibration reduction components, medical collimators or military armor-piercing cores. Precision machining not only ensures the shape and dimensional accuracy of the components, but also improves the surface finish, enhancing performance and reliability.

Precision machining typically includes technologies such as turning, milling, grinding and electrical discharge machining (EDM). Turning and milling use numerically controlled (CNC) machines to cut alloys and are suitable for producing regular-shaped parts such as bars or plates. The high hardness of tungsten requires the use of carbide or diamond-coated tools, and low cutting speeds and sufficient coolant (such as water-based emulsions) are required during the machining process to reduce thermal stress and tool wear. Grinding further refines the surface using grinding wheels or abrasives to achieve high finish and dimensional accuracy, which is particularly suitable for the surface requirements of medical shielding parts or electronic heat sinks. EDM uses electrical pulses to remove trace amounts of material from conductive materials, which is suitable for manufacturing complex shapes or internal channels, such as micro-structure machining of small counterweights in aerospace. EDM can achieve high precision without direct contact, reducing tool wear and material stress.

The machining process needs to be optimized to adapt to the characteristics of tungsten -nickel-copper alloy. The toughness of the nickel-copper bonding phase may cause the alloy to stick to the tool during machining , and the surface burrs need to be reduced by optimizing the cutting speed and feed rate. The high hardness of tungsten particles may cause rapid wear of tools, and the tools need to be checked and replaced regularly to ensure machining consistency. The machining environment needs to be kept clean (clean room operation) to avoid dust or impurities that affect component performance. The selection of coolant needs to consider environmental protection and non-corrosiveness to the alloy to avoid surface corrosion or residue. The machined parts need to be ultrasonically cleaned to remove chips and coolant to ensure a clean surface.

In actual production, precision machining significantly improves the application performance of tungsten-nickel-copper alloy parts. For example, in the balance block of the photolithography machine, CNC machining achieves sub-nanometer precision and ensures the stability of the

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platform; in the core of military armor-piercing projectiles, electrospark machining forms complex geometric shapes and improves penetration performance. Quality control verifies dimensional accuracy and finish through three-coordinate measuring machines (CMMs), laser interferometers, and surface roughness tests. Process optimization needs to focus on the integration of automated processing equipment and the wear resistance of tool materials, and use intelligent CNC systems to improve efficiency.

#### 5.4.2 Surface treatment process

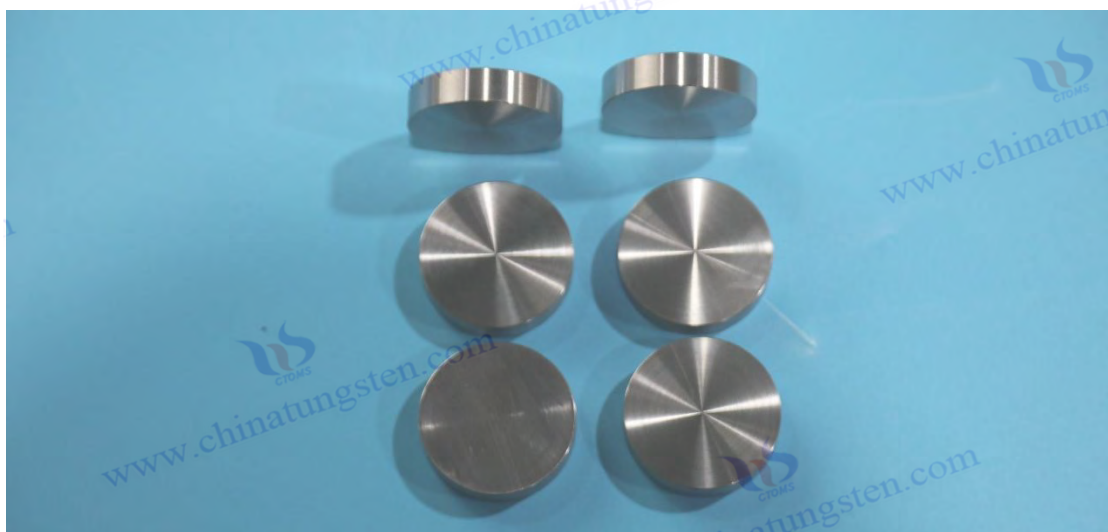
Surface treatment is an important step in the post-processing of tungsten-nickel-copper alloys, which aims to improve the surface finish, corrosion resistance, wear resistance and aesthetics of parts to meet the specific requirements of the medical, electronic and aerospace industries. The surface quality of tungsten -nickel-copper alloys directly affects their performance in harsh environments (such as sterilization, marine or high-temperature environments). Surface treatment enhances the corrosion resistance, oxidation resistance and functionality of the alloy by optimizing the surface state. Surface treatment processes include mechanical polishing, chemical passivation, electrochemical polishing and coating technology, and the appropriate treatment method should be selected according to application requirements.

Mechanical polishing is a commonly used surface treatment method. The surface of the component is gradually ground by a grinding wheel, polishing cloth or abrasive to remove processing marks, scratches and minor defects to achieve a mirror finish. The surface smoothness after polishing is improved (the surface roughness is reduced), which not only improves the aesthetics, but also reduces the adhesion points of corrosive media, which is suitable for the application of medical collimators or electronic heat sinks. Polishing requires the use of gradually refined abrasives, and the polishing pressure and speed are controlled to avoid overheating or surface stress concentration. Electrochemical polishing applies an electric current in the electrolyte to dissolve the alloy surface slightly, smooth the surface and form a thin passivation film, which further enhances the corrosion resistance. It is particularly suitable for ship counterweights in marine environments.

Chemical passivation forms a dense oxide protective layer (mainly NiO ) on the surface by immersing the parts in an acidic or neutral solution (such as dilute nitric acid or citric acid solution), improving corrosion resistance and oxidation resistance. The passivation treatment requires controlling the solution concentration and immersion time to avoid excessive corrosion and surface degradation. The treated parts show higher stability in sterilized or humid environments and are suitable for long-term use of medical devices. Coating technology (such as physical vapor deposition PVD or chemical vapor deposition CVD) significantly improves surface hardness, wear resistance and corrosion resistance by depositing a thin layer of material (such as TiN , DLC or CrN ) on the surface. PVD TiN coating provides parts with a golden appearance and excellent wear resistance, suitable for aerospace counterweights; DLC coating has a low friction coefficient and is suitable for sliding parts in the electronics industry. The coating thickness needs to be precisely controlled to avoid affecting thermal conductivity or non-magnetism.

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Surface treatment needs to be carried out in a clean environment to avoid dust or oil pollution. Before treatment, the parts need to be ultrasonically cleaned to remove processing residues; after treatment, they need to be rinsed with deionized water and dried to prevent secondary contamination. Quality control verifies corrosion resistance through surface roughness testing (such as profilometer), SEM observation of surface morphology and salt spray testing. Process optimization needs to focus on the environmental friendliness of the treatment solution and the high precision of the equipment, and use automated polishing or coating equipment to improve consistency. In actual production, surface treatment significantly improves the application performance of the alloy. For example, in medical CT shielding parts, electrochemical polishing improves surface finish and disinfection resistance; in photolithography heat sinks, PVD coatings enhance wear resistance and thermal conductivity.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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## Chapter 6 Application of Tungsten-Nickel-Copper Alloy in Electronic Information Field

Tungsten -nickel-copper alloy is widely used in the field of electronic information due to its high density, non-magnetic properties, excellent thermal conductivity and low thermal expansion coefficient, especially in chip packaging, heat dissipation management and high-precision counterweight components. The alloy is prepared by powder metallurgy process, combining the high density of tungsten with the toughness and thermal conductivity of nickel-copper bonding phase, and can meet the high requirements of electronic equipment for thermal management, electromagnetic compatibility and dimensional stability. With the rapid development of 5G technology, artificial intelligence and the Internet of Things , the demand for high-performance materials in the field of electronic information is increasing. Tungsten-nickel-copper alloy has become an ideal choice for chip packaging, RF modules and photolithography machines due to its unique physical and chemical properties.

### 6.1 Chip Packaging and Heat Dissipation

Chip packaging and heat dissipation are core technologies in the field of electronic information, involving fixing the chip on the substrate and efficiently managing the heat generated during operation to ensure the high performance and long life of the device. Tungsten -nickel-copper alloy is used as a heat dissipation substrate, heat sink and counterweight component in chip packaging . With its high thermal conductivity, low thermal expansion coefficient and non-magnetic properties, it can effectively disperse heat, maintain dimensional stability and avoid electromagnetic interference to meet the needs of high-power and high-frequency electronic equipment. The microstructure of the alloy is optimized through liquid phase sintering and hot isostatic pressing processes to form a dense tungsten particle and nickel-copper bonding phase network, providing excellent thermal conductivity and mechanical stability. Its applications cover high-precision equipment such as high-power devices, 5G RF modules and lithography machines, providing key support for performance improvement and miniaturization of the electronic information industry.

#### 6.1.1 High-power device heat dissipation substrate

The heat dissipation substrate of high-power devices is a key component in chip packaging. It is used to quickly disperse the high heat generated by the chip during operation to prevent overheating from causing performance degradation or device failure. Tungsten -nickel-copper alloy is an ideal material for heat dissipation substrates of high-power devices (such as power amplifiers, GPUs, and laser diodes) due to its excellent thermal conductivity and low thermal expansion coefficient. The high thermal conductivity of the alloy is due to the rapid thermal conductivity of copper, which can quickly transfer the heat generated by the chip to the heat dissipation system; the low thermal expansion coefficient matches the thermal expansion characteristics of chip materials ( such as silicon or gallium nitride), reducing deformation or cracking caused by thermal stress and ensuring the long-term stability of the packaging structure. The non-magnetic property avoids electromagnetic interference and is suitable for high-frequency electronic devices.

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During the preparation process, the tungsten-nickel-copper alloy is formed into a high-density substrate through a powder metallurgy process, and liquid phase sintering makes the nickel-copper bonding phase evenly distributed, enhancing the thermal conductivity efficiency; hot isostatic pressing further eliminates micropores and improves the density and strength of the substrate. Precision machining and surface treatment (such as electrochemical polishing or PVD coating) optimize the surface finish of the substrate, reduce thermal resistance and improve the contact efficiency with the chip. The surface of the tungsten -nickel-copper substrate is usually combined with the chip through welding or bonding processes, and it is necessary to ensure that the interface is firmly bonded to avoid falling off or cracking during thermal cycles. In high-power devices, the application of tungsten-nickel-copper heat dissipation substrates significantly improves device performance. For example, in high-performance computing (HPC) chips, the rapid heat dissipation of the substrate ensures the stability of the chip under high load; in laser diodes, the low thermal expansion coefficient maintains the position accuracy of optical components. Optimization directions include enhancing thermal conductivity by adjusting the nickel-copper ratio, using nano-coatings (such as DLC) to reduce surface thermal resistance, or combining additive manufacturing technology to customize complex heat dissipation structures. Quality control verifies substrate properties through thermal conductivity testing (laser flash method) and thermal expansion coefficient measurements to ensure compliance with electronics industry standards (such as JEDEC).

#### 6.1.2 5G RF module counterweight heat sink

5G RF module counterweight heat sink is a key component in 5G communication equipment. It has both heat dissipation and counterweight functions to ensure the module's thermal management and center of gravity stability during high-frequency operation. Tungsten -nickel-copper alloy is the preferred material for RF module counterweight heat sinks due to its high density, non-magnetic properties, high thermal conductivity and low thermal expansion coefficient. 5G RF modules need to operate under high-frequency signals (millimeter waves), generating a lot of heat, while requiring miniaturization and high precision. Tungsten-nickel-copper alloy can quickly disperse heat, maintain dimensional stability and avoid electromagnetic interference, meeting the high performance requirements of the module. The high-density characteristics enable the alloy to provide sufficient counterweight in a limited space, optimize the center of gravity distribution of the module, and reduce the impact of vibration on signal transmission.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture complex-shaped counterweight heat sinks through metal injection molding (MIM) or powder metallurgy. MIM technology forms high-precision components by mixing powder with a binder, injection molding, degreasing and sintering, which are suitable for the complex geometric requirements of miniaturized modules. Liquid phase sintering allows the nickel-copper liquid phase to wet the tungsten particles to form a dense microstructure, enhancing thermal conductivity and mechanical properties. Surface treatment (such as PVD TiN coating or electrochemical polishing) improves the corrosion resistance and finish of the surface, reduces thermal resistance and enhances oxidation resistance. Precision machining in post-processing ensures the dimensional accuracy of the

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components and meets the strict tolerance requirements of 5G modules.

In 5G RF modules, tungsten-nickel-copper counterweight heat sinks significantly improve module performance. For example, in base station antenna modules, the high density of the alloy ensures the stability of the antenna's center of gravity, and the thermal conductivity quickly disperses the heat of the RF chip to maintain the stability of signal transmission; in mobile terminals (such as smartphones), miniaturized counterweight heat sinks support the compact design of the module while ensuring thermal management efficiency. Optimization directions include improving thermal conductivity by optimizing the nickel-copper ratio, enhancing heat dissipation capabilities with microstructure designs (such as honeycomb heat dissipation channels), or combining hot isostatic pressing technology to further improve density. Quality control verifies component performance through density measurement, thermal conductivity testing, and magnetization strength testing to ensure compliance with 5G communication standards (such as 3GPP).

## 6.2 Microwave and Radar Equipment

Microwave and radar equipment is the core technology in the field of electronic information. It is widely used in communication, navigation, remote sensing and national defense. It requires materials with high density, non-magnetism, high thermal conductivity and dimensional stability to ensure the performance of the equipment under high frequency, high power and complex environment. Tungsten nickel copper alloy has become the preferred material for antenna weight components and shielding components in microwave and radar equipment due to its unique physical and chemical properties. Its high density can provide precise center of gravity control, non-magnetic properties avoid electromagnetic interference, high thermal conductivity and low thermal expansion coefficient ensure thermal management and dimensional stability, and meet the reliability requirements of equipment in extreme environments (such as high temperature, vibration or electromagnetic interference). The alloy forms a dense microstructure through liquid phase sintering and hot isostatic pressing processes, combined with precision machining and surface treatment, to meet the high precision requirements of microwave and radar equipment.

### 6.2.1 Antenna weight assembly

Antenna weight components are key components in microwave and radar equipment, used to adjust the center of gravity distribution of the antenna to ensure its stability and pointing accuracy in dynamic environments (such as satellite movement or ship vibration). Tungsten -nickel-copper alloy is an ideal material for antenna weight components due to its high density and non-magnetic properties. The high density property enables the alloy to provide sufficient mass within a limited volume, optimize the center of gravity position of the antenna system, and reduce the deviation caused by vibration or wind load. The non-magnetic property avoids magnetic field interference and ensures the accuracy and stability of the antenna in the transmission of high-frequency microwave signals (such as Ku band or millimeter wave). The low thermal expansion coefficient of the alloy ensures dimensional stability under temperature changes (such as day and night temperature

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difference or high altitude low temperature) and maintains the geometric accuracy of the antenna.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture antenna weight components through powder metallurgy process, usually using metal injection molding (MIM) or cold isostatic pressing technology to form complex-shaped billets to meet the compact design requirements of antenna systems. Liquid phase sintering allows the nickel-copper liquid phase to wet the tungsten particles to form a dense microstructure, enhancing the density and mechanical properties of the weight components. Hot isostatic pressing further eliminates micropores and improves density, making it suitable for high-reliability applications such as satellite communication antennas. Precision machining (such as CNC milling or EDM) ensures the dimensional accuracy of the weight components, and surface treatment (such as electrochemical polishing or PVD coating) improves corrosion resistance and surface finish, reducing signal scattering or environmental erosion.

In antenna applications, tungsten-nickel-copper weight components significantly improve equipment performance. For example, in 5G base station antennas, high-density weights ensure the stability of the antenna under high-frequency vibrations, and the non-magnetic properties avoid signal interference; in satellite communication antennas, the low thermal expansion coefficient maintains pointing accuracy in high-altitude environments. Optimization directions include enhancing thermal conductivity by optimizing the nickel-copper ratio, improving mechanical properties through microstructure design (such as internal reinforcement ribs), or customizing complex shapes in combination with additive manufacturing technology. Quality control verifies component performance through density measurement, magnetization strength testing, and vibration testing to ensure compliance with microwave communication standards.

### 6.2.2 Radar shielding components

Radar shielding components are used to isolate electromagnetic interference, absorb stray signals or protect sensitive electronic components in radar equipment to ensure stable operation of the system in high-frequency and high-power environments. Tungsten -nickel-copper alloy is the preferred material for radar shielding components due to its non-magnetic, high-density and excellent thermal conductivity. The non-magnetic property avoids the interference of magnetic fields on radar signals, which is particularly suitable for high-sensitivity radar systems (such as phased array radars). The high-density property enables the alloy to effectively absorb and shield electromagnetic waves, reducing signal leakage or external interference. Thermal conductivity quickly disperses the heat generated by the radar transmitter or receiver to prevent overheating from affecting equipment performance. The low thermal expansion coefficient ensures that the components remain dimensional stable in high temperature or thermal cycle environments to avoid deformation that affects the shielding effect.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture shielding components through powder metallurgy or MIM technology to meet the needs of complex shapes

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and compact designs. Liquid phase sintering forms a dense microstructure with uniform distribution of nickel-copper bonding phase, enhancing thermal conductivity and mechanical properties. Hot isostatic pressing eliminates residual porosity, improves the density and durability of shielding components, and is suitable for the demanding requirements of military radar or aviation radar. Precision machining (such as grinding or EDM) achieves high-precision geometry to ensure seamless integration of components with radar systems. Surface treatment (such as PVD CrN coating or chemical passivation) enhances corrosion resistance and oxidation resistance, extending the life of components in humid or high-temperature environments.

In radar applications, tungsten-nickel-copper shielding components significantly improve system reliability. For example, in military phased array radars, non-magnetic shielding components avoid signal interference, and high density improves electromagnetic shielding efficiency; in weather radars, thermal conductivity ensures thermal management of high-power transmitters. Optimization directions include improving conductivity by adjusting the nickel-copper ratio, using multi-layer composite coatings to enhance shielding effects, or combining 3D printing technology to manufacture complex shielding structures. Quality control verifies component performance through electromagnetic shielding tests (such as MIL-STD-461), thermal conductivity tests, and salt spray tests to ensure compliance with radar system standards (such as IEC 61000).

### 6.3 Micro-Electro-Mechanical Systems

Microelectromechanical systems (MEMS) are technologies that integrate microelectronics with mechanical structures at the micron to millimeter scale. They are widely used in smartphones, automobiles, medical devices, and aerospace, such as accelerometers, gyroscopes, and microactuators. MEMS devices require materials with high density to achieve miniaturized counterweights, non-magnetic properties to avoid electromagnetic interference, excellent thermal conductivity to manage heat in tiny spaces, and low thermal expansion coefficients to ensure dimensional stability. With its high density and non-magnetic properties, tungsten -nickel-copper alloys can provide sufficient mass in a tiny volume and optimize the center of gravity distribution of MEMS devices; their high thermal conductivity and low thermal expansion coefficient ensure thermal management and long-term stability, making them suitable for applications in high-precision and dynamic environments. The alloys are prepared by metal injection molding (MIM) or precision powder metallurgy, combined with precision machining and surface treatment to meet the miniaturization and high-precision manufacturing requirements of MEMS.

#### 6.3.1 Inertial sensor counterweight

The inertial sensor counterweight is a core component in MEMS accelerometers and gyroscopes. It is used to adjust the inertial properties of the sensor mass block to ensure its high sensitivity response to acceleration or angular velocity. Tungsten -nickel-copper alloy is an ideal material for inertial sensor counterweights due to its high density and non-magnetic properties. The high density property enables the alloy to provide sufficient mass in a small volume, enhance the sensitivity and

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response accuracy of the sensor, and is suitable for miniaturized designs such as MEMS sensors for smartphones or wearable devices. The non-magnetic property avoids the interference of magnetic fields on sensor signals, ensuring high-precision measurements in complex electromagnetic environments (such as automotive electronics or aviation navigation systems). The low thermal expansion coefficient of the alloy ensures the dimensional stability of the counterweight under temperature changes and maintains the long-term reliability of the sensor.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture micro-weights through metal injection molding (MIM) technology to meet the requirements of MEMS devices for complex shapes and high precision. The MIM process mixes tungsten, nickel, and copper powders with a binder, and forms a dense structure through degreasing and liquid phase sintering after injection molding. The nickel-copper liquid phase wets the tungsten particles, reduces porosity, and improves density and mechanical properties. Precision machining (such as micro-milling or laser processing) further optimizes the dimensional accuracy of the counterweight to micron-level tolerances. Surface treatment (such as electrochemical polishing or PVD coating) improves surface finish, reduces friction and thermal resistance, and ensures seamless integration with MEMS structures. Processing and handling must be carried out in a clean room to avoid dust contamination that affects the performance of micro-components.

In inertial sensor applications, tungsten-nickel-copper counterweights significantly improve device performance. For example, in smartphone accelerometers, high-density counterweights improve the sensitivity of motion detection, and non-magnetic properties ensure stable operation in electromagnetic interference environments; in automotive airbag systems, the dimensional stability and thermal conductivity of the counterweights ensure the reliability of sensors in extreme temperatures. Optimization directions include improving thermal conductivity by optimizing the nickel-copper ratio, using microstructure designs (such as porous counterweights) to reduce mass while maintaining inertia, or combining additive manufacturing technology to achieve higher precision miniaturization. Quality control verifies counterweight performance through density measurement, magnetization strength testing, and vibration testing to ensure compliance with MEMS standards (such as ISO 16063). In the future, as MEMS sensors develop towards higher sensitivity and miniaturization, tungsten-nickel-copper counterweights can further optimize performance by integrating nanomaterials.

### 6.3.2 Micro-balance components

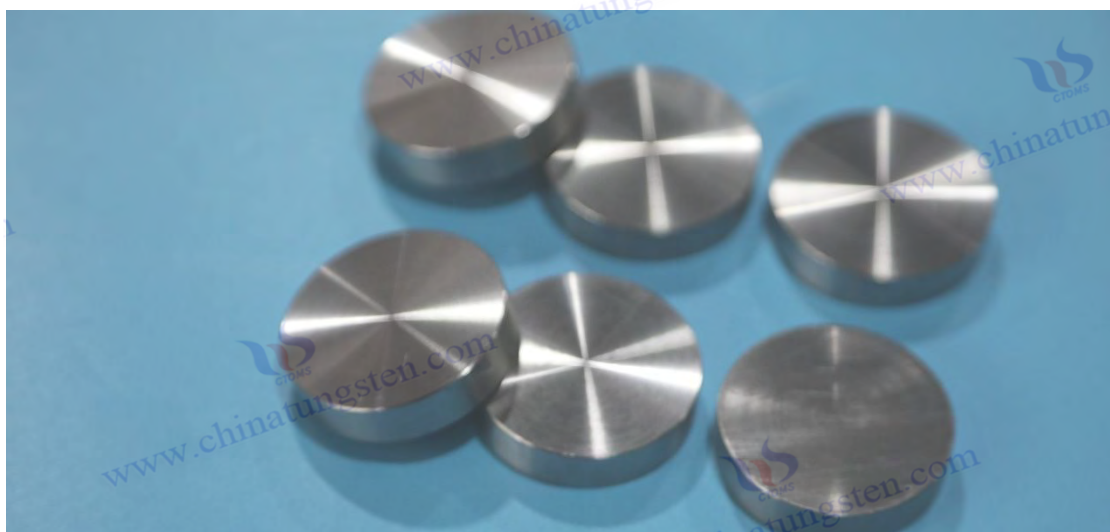
Micro-balanced components are key components in MEMS actuators, oscillators or micro-mirrors. They are used to adjust the dynamic balance and center of gravity distribution of micro-mechanical structures to ensure their stability during high-frequency vibrations or rapid movements. Tungsten-nickel-copper alloys are the preferred materials for micro-balanced components due to their high density, non-magnetic properties and low thermal expansion coefficient. The high density property enables the alloy to provide sufficient mass in a small volume, optimize the center of gravity position of MEMS devices (such as optical micro-mirrors or micro-gyroscopes), and reduce vibration offset

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or mechanical resonance. The non-magnetic property avoids electromagnetic interference and is suitable for high-precision optical or communication equipment. The low thermal expansion coefficient ensures the geometric stability of the components under temperature changes and maintains the operating accuracy of the MEMS structure.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture micro-balanced components through MIM or micro powder metallurgy process to meet the requirements of complex shapes and micron-level precision. The MIM process forms tiny billets through injection molding, and liquid phase sintering and hot isostatic pressing further improve density, eliminate micropores, and enhance mechanical properties and thermal conductivity. Precision machining (such as laser micromachining or electrospark machining) achieves high-precision geometric shapes with tolerances controlled at the micron level, which is suitable for the tiny structures of MEMS oscillators. Surface treatment (such as DLC coating or chemical passivation) improves wear resistance and corrosion resistance, and extends the life of components in dynamic environments. The processing process needs to be carried out in a high-cleanliness environment to prevent dust pollution from affecting the performance of micro components.

In MEMS applications, tungsten-nickel-copper micro-balanced components significantly improve device performance. For example, in laser scanning micromirrors, high-density balance components optimize the center of gravity distribution of the oscillator and improve scanning accuracy and speed; in micro-gyroscopes, non-magnetism and low thermal expansion coefficients ensure high sensitivity and environmental adaptability. Optimization directions include reducing mass through microstructure design (such as hollow structures), using nano-coatings to enhance surface properties, or combining 3D printing technology to achieve rapid customization of complex shapes. Quality control verifies component performance through CMM measurement of dimensional accuracy, thermal conductivity testing, and electromagnetic shielding testing to ensure compliance with MEMS standards (such as IEEE 1833).



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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### Tungsten Nickel Copper Alloy Introduction

#### 1. Overview of Tungsten Nickel Copper Alloy

Tungsten nickel copper alloy is an alloy composed of tungsten with added nickel and copper, typically in a nickel-to-copper ratio of 3:2. This alloy is non-ferromagnetic, exhibits relatively good electrical and thermal conductivity, and is commonly used in specialized applications such as gyroscope rotors, components for devices and instruments operating under magnetic fields, electrical contacts for high-voltage switches, and electrodes for certain electrical machining processes.

#### 2. Features of Tungsten Nickel Copper Alloy

**High Density:** Typically 16.5 – 18.75 g/cm<sup>3</sup>

**High Thermal Conductivity:** Approximately 5 times that of mold steel

Compared to tungsten-nickel-iron alloy, since copper does not have the sintering activation effect of nickel and iron on tungsten, tungsten-nickel-copper alloy has a slightly lower sintered density, lower strength and plasticity, and is generally not subjected to heat treatment or deformation processing.

#### 3. Production Methods for Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy is typically produced using powder metallurgy. First, high-purity tungsten, nickel, and copper powders are mixed in specific proportions, often using equipment like a ball mill to achieve uniform mixing. The mixture is then pressed into shape, commonly using cold isostatic pressing technology under a specific pressure to form a green compact. Subsequently, sintering is performed, generally in a hydrogen protective atmosphere, using a two-step sintering process to address collapse and deformation issues caused by liquid-phase sintering, ensuring the product's density.

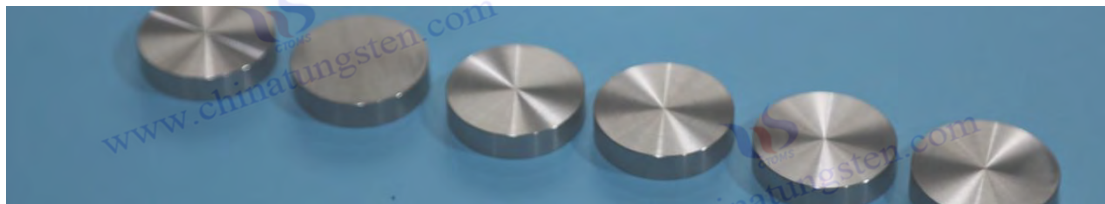
#### 4. Applications of Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy, with its high density and excellent thermal and electrical conductivity, has a wide range of applications. In the aerospace sector, it can be utilized to manufacture components such as rocket engine nozzles and gas rudders. In the medical field, due to its strong radiation absorption capability and non-magnetic properties, it is suitable for radiation shielding in magnetic resonance imaging rooms. Additionally, it can serve as a counterweight material for precision instruments.

#### 5. Purchasing Information

Email: [sales@chinatungsten.com](mailto:sales@chinatungsten.com); Phone: +86 592 5129595; 592 5129696

Website: [www.tungsten-alloy.com](http://www.tungsten-alloy.com)



CTIA GROUP LTD tungsten nickel copper alloy

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## Chapter 7 Application of Tungsten-Nickel-Copper Alloy in Energy and Industry

Tungsten -nickel-copper alloy has shown excellent application potential in the energy and industrial fields with its high density, non-magnetic properties, excellent thermal conductivity and low thermal expansion coefficient, especially in high-demand scenarios such as new energy vehicles, aerospace and industrial equipment. The alloy is prepared by powder metallurgy process, combining the high density of tungsten with the toughness and thermal conductivity of nickel-copper bonding phase, which can meet the strict requirements of energy equipment for thermal management, weight balance and electromagnetic compatibility. With the growth of global demand for clean energy and efficient industrial technology, the application of tungsten-nickel-copper alloy in the field of new energy vehicles is becoming increasingly important, especially in motor rotor counterweights and battery pack heat dissipation substrates.

### 7.1 New Energy Vehicle Field

New energy vehicles (including pure electric vehicles and hybrid vehicles) rely on efficient motor systems and battery management systems, and place high demands on the density, thermal conductivity, non-magnetism and dimensional stability of materials. Tungsten -nickel-copper alloy has become an ideal material for key components in motor and battery systems due to its unique physical and chemical properties. The high density property enables it to provide precise weight balancing and optimize the dynamic balance of the motor rotor; the high thermal conductivity and low thermal expansion coefficient support the thermal management of the battery system and maintain operational stability and safety; the non-magnetic property avoids electromagnetic interference and ensures the performance of the motor and electronic system. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining processes to meet the needs of new energy vehicles for high precision and durability.

#### 7.1.1 Motor rotor weight

The motor rotor counterweight is a core component in the drive system of new energy vehicles. It is used to adjust the center of gravity distribution of the rotor, ensure the dynamic balance of the motor during high-speed rotation, reduce vibration and noise, and improve efficiency and life. Tungsten -nickel-copper alloy is the preferred material for motor rotor counterweights due to its high density and non-magnetic properties. The high density property enables the alloy to provide sufficient mass within a limited volume, accurately control the center of gravity position of the rotor, reduce eccentric vibration during high-speed rotation, and extend the life of the motor bearing. The non-magnetic property avoids magnetic field interference and ensures the stable operation of the motor in a high-frequency electromagnetic environment. It is particularly suitable for permanent magnet synchronous motors or induction motors. The low thermal expansion coefficient of the alloy ensures that the counterweight maintains dimensional stability under the temperature rise generated by the operation of the motor and maintains the rotor balance accuracy. During the preparation process, tungsten-nickel-copper alloy is used to manufacture counterweight components through

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metal injection molding or powder metallurgy process to meet the design requirements of complex shapes and miniaturization. MIM technology forms a high-density structure by mixing tungsten, nickel, and copper powders with a binder, degreasing and liquid phase sintering after injection molding. The nickel-copper liquid phase wets the tungsten particles to enhance mechanical properties and thermal conductivity. Hot isostatic pressing further eliminates micropores, improves the density and strength of the counterweight, and is suitable for high-performance motor applications. Precision machining achieves micron-level tolerances to ensure accurate matching of the counterweight and the rotor. Surface treatment improves corrosion resistance and surface finish, and reduces friction and wear.

In new energy vehicles, tungsten-nickel-copper motor rotor weights significantly improve drive system performance. For example, in electric vehicle main drive motors, high-density weights reduce vibration and noise and improve power output efficiency; in hybrid vehicle motor systems, non-magnetic weights avoid electromagnetic interference and enhance control accuracy. Optimization directions include improving thermal conductivity by optimizing the nickel-copper ratio, reducing mass by using lightweight microstructure design (such as hollow weights), or combining additive manufacturing technology to achieve complex shape customization. Quality control verifies weight performance through density measurement, vibration testing, and magnetization strength testing to ensure compliance with automotive industry standards.

### 7.1.2 Battery Pack Heat Dissipation Substrate

The heat dissipation substrate of the battery pack is a key component in the battery management system of new energy vehicles. It is used to quickly disperse the high heat generated by the battery during operation to prevent overheating from causing performance degradation or safety risks. Tungsten-nickel-copper alloy is an ideal material for the heat dissipation substrate of the battery pack due to its high thermal conductivity and low thermal expansion coefficient. The high thermal conductivity is due to the rapid thermal conductivity of copper, which can quickly transfer the heat generated by the battery (such as lithium-ion batteries) to the heat dissipation system to maintain the ideal operating temperature of the battery. The low thermal expansion coefficient matches the thermal expansion characteristics of battery materials (such as graphite or ceramic diaphragms), reduces deformation or cracking caused by thermal stress, and ensures the structural stability of the battery pack. The non-magnetic property avoids electromagnetic interference and is suitable for use near the electronic control unit (ECU) in the battery management system.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture heat dissipation substrates through powder metallurgy or MIM technology to meet the battery pack's requirements for thin-walled, high-precision structures. Liquid phase sintering forms a dense microstructure, with nickel-copper bonding phases evenly distributed, enhancing thermal conductivity and mechanical properties. Hot isostatic pressing eliminates residual porosity, improves the density and durability of the substrate, and is suitable for high-power battery applications. Precision machining (such as micro-milling or laser processing) realizes complex heat dissipation channels or thin plate structures

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to ensure close contact with the battery module. Surface treatment (such as PVD TiN coating or chemical passivation) improves corrosion resistance and oxidation resistance, and extends the life of the substrate in humid or high-temperature environments. Processing must be carried out in a clean room to avoid dust pollution affecting heat conduction efficiency.

In new energy vehicles, tungsten-nickel-copper heat dissipation substrates significantly improve battery pack performance. For example, in high-performance electric vehicles, the rapid heat dissipation of the substrate reduces battery temperature rise, extending battery life and charging efficiency; in commercial electric buses, the low thermal expansion coefficient ensures the structural stability of the battery pack during thermal cycles. Optimization directions include enhancing heat dissipation efficiency through microchannel design, using composite coatings (such as graphene) to reduce thermal resistance, or combining 3D printing technology to customize complex heat dissipation structures. Quality control verifies substrate performance through thermal conductivity testing (laser flash method), thermal expansion coefficient measurement, and salt spray testing to ensure compliance with automotive industry standards.

## 7.2 Industrial Cooling Solutions

Industrial heat dissipation solutions are the core technology for the stable operation of modern industrial equipment. They involve the efficient management of heat generated by high-power electronic components or systems during operation to prevent overheating from causing performance degradation or equipment failure. Tungsten -nickel-copper alloy is an ideal material for industrial heat dissipation components due to its high thermal conductivity, low thermal expansion coefficient and non-magnetic properties. It can quickly disperse heat, maintain dimensional stability and avoid electromagnetic interference. The high density and excellent mechanical properties of the alloy make it suitable for long-term use in harsh environments, such as data center servers, industrial automation equipment and power semiconductor modules. Tungsten -nickel-copper alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining processes to form a dense microstructure, which meets the needs of industrial heat dissipation for high precision and durability, and provides support for the stable operation of high-performance industrial equipment.

### 7.2.1 Server cooling base

The server heat sink is a key component of the data center server. It is used to quickly disperse the high heat generated by the CPU, GPU or memory module during operation to ensure the stability and reliability of the server under high load. Tungsten -nickel-copper alloy is the preferred material for the server heat sink due to its high thermal conductivity and low thermal expansion coefficient. The high thermal conductivity is due to the fast thermal conductivity of copper, which can quickly transfer the heat generated by the processor to the radiator or liquid cooling system, reduce the chip temperature, and extend the life of the equipment. The low thermal expansion coefficient matches the thermal expansion characteristics of silicon-based chips or ceramic substrates, reduces

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deformation or cracking caused by thermal stress, and ensures the long-term contact stability between the base and the chip. The non-magnetic property avoids electromagnetic interference and is suitable for the high-density electromagnetic environment of the data center.

During the preparation process, tungsten-nickel-copper alloy is manufactured into a heat sink through a powder metallurgy process, usually using cold isostatic pressing or metal injection molding (MIM) technology to form a high-precision billet. Liquid phase sintering allows the nickel-copper liquid phase to wet the tungsten particles, forming a dense microstructure, enhancing thermal conductivity and mechanical properties. Hot isostatic pressing further eliminates micropores, improves the density and durability of the base, and is suitable for high-load server applications. Precision machining (such as CNC milling or laser processing) realizes complex heat dissipation channels or thin plate structures to ensure close contact with the chip. Surface treatment (such as electrochemical polishing or PVD TiN coating) improves surface finish and corrosion resistance, reduces thermal resistance and enhances oxidation resistance. Processing needs to be carried out in a clean room to avoid dust contamination affecting heat conduction efficiency.

In server applications, the tungsten-nickel-copper heat sink significantly improves data center performance. For example, in high-performance computing (HPC) servers, the rapid heat dissipation of the base reduces chip temperature rise and supports continuous high-load operation; in cloud computing servers, the low thermal expansion coefficient ensures structural stability under thermal cycles and reduces maintenance costs. Optimization directions include enhancing heat dissipation efficiency through microchannel design, using nano-coatings (such as graphene) to reduce thermal resistance, or combining 3D printing technology to customize complex heat dissipation structures. Quality control verifies the performance of the base through thermal conductivity testing (laser flash method), thermal expansion coefficient measurement, and durability testing to ensure compliance with data center standards (such as ASHRAE).

## 7.2.2 Power semiconductor packaging substrate

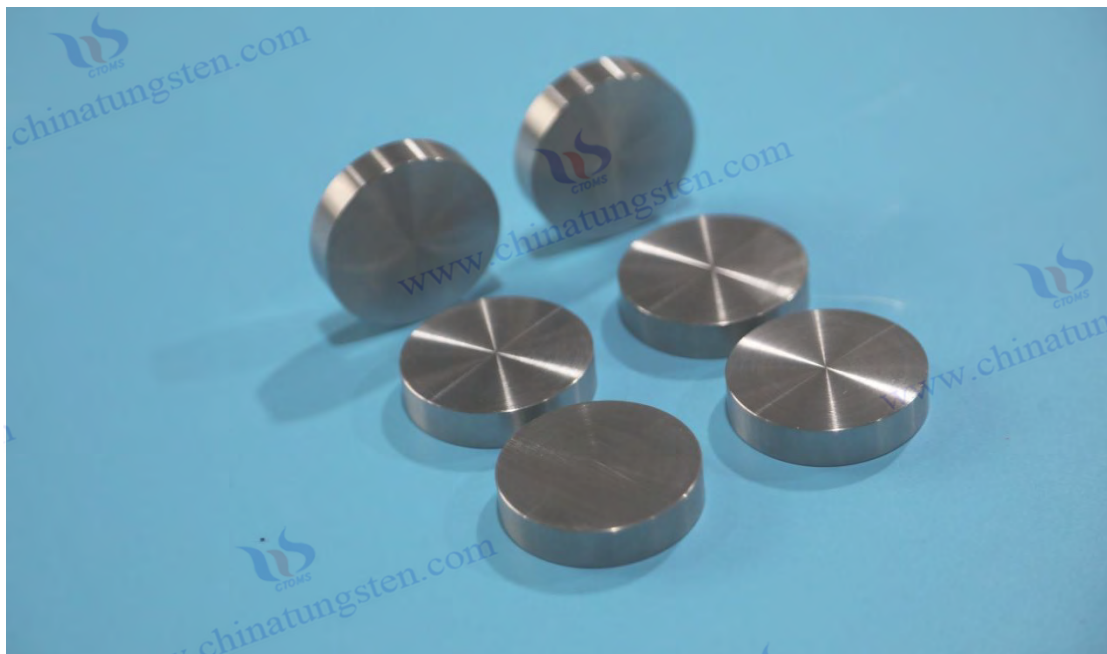
Power semiconductor package substrates are core components of high-power electronic devices. They are used to support the chip and quickly disperse the high heat generated during operation, ensuring the performance and reliability of the device in high-voltage, high-current environments. Tungsten-nickel-copper alloys are ideal materials for power semiconductor package substrates due to their high thermal conductivity, low thermal expansion coefficient, and non-magnetic properties. High thermal conductivity can quickly transfer heat from semiconductor chips to the heat dissipation system, reduce junction temperature, and improve device efficiency and life. The low thermal expansion coefficient matches the thermal expansion characteristics of chip materials (such as silicon or silicon carbide), reducing package failures caused by thermal stress and ensuring long-term stability. The non-magnetic properties avoid electromagnetic interference and are suitable for high-frequency power electronic applications.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture packaging

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substrates through powder metallurgy or MIM technology to meet the needs of thin-walled, high-precision structures. Liquid phase sintering forms a dense microstructure with uniform distribution of nickel-copper bonding phase, enhancing thermal conductivity and mechanical properties. Hot isostatic pressing eliminates residual porosity, improves the density and durability of the substrate, and is suitable for high-power applications. Precision machining (such as micro-milling or electrospark machining) achieves flat surfaces and precise dimensions with tolerances controlled at the micron level to ensure close bonding with the chip. Surface treatment (such as PVD CrN coating or chemical passivation) improves corrosion resistance and oxidation resistance and extends the life of the substrate in high temperature or humid environments. The substrate surface is usually bonded to the chip by welding or thermally conductive adhesive, and the interface thermal resistance must be minimized.

In power semiconductor applications, tungsten-nickel-copper packaging substrates significantly improve device performance. For example, in industrial inverters, the rapid heat dissipation of the substrate improves the power density and reliability of the IGBT module; in wind power inverters, the low thermal expansion coefficient ensures the stability of the package under thermal cycles. Optimization directions include enhancing thermal conductivity by optimizing the nickel-copper ratio, using a multi-layer composite structure to improve heat diffusion efficiency, or combining additive manufacturing technology to customize complex heat dissipation paths. Quality control verifies substrate performance through thermal conductivity testing, thermal expansion coefficient measurement, and high-temperature aging testing to ensure compliance with industrial standards (such as IEC 60747).



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## Chapter 8 Application of Tungsten-Nickel-Copper Alloy in National Defense Industry

Tungsten -nickel-copper alloy has shown excellent application value in the field of national defense and military industry with its high density, non-magnetic properties, excellent thermal conductivity and low thermal expansion coefficient, especially in electronic countermeasure equipment, weapon systems and protective equipment. The alloy is prepared by powder metallurgy process, combining the high density of tungsten and the toughness and thermal conductivity of nickel-copper bonding phase, which can meet the strict requirements of military equipment for weight control, electromagnetic compatibility and resistance to extreme environments. With the increasing demand for high precision, high reliability and concealment in modern warfare, the application of tungsten-nickel-copper alloy in electronic countermeasure equipment is becoming increasingly important, especially in jammer weight components and radar decoy components.

### 8.1 Electronic Countermeasures Equipment

Electronic countermeasure equipment is a core technology in the field of modern national defense and military industry. It is used to interfere with or deceive enemy radars, communication systems and navigation equipment to protect the safety of one's own troops or equipment. Tungsten -nickel-copper alloy is an ideal material for key components in electronic countermeasure equipment due to its high density, non-magnetic properties, high thermal conductivity and low thermal expansion coefficient. The high density property enables it to provide sufficient mass within a limited volume and optimize the weight distribution and dynamic balance of the equipment; the non-magnetic property avoids electromagnetic interference and ensures the stability of operation in high-frequency electromagnetic environments; high thermal conductivity and low thermal expansion coefficient support thermal management and dimensional stability, which is suitable for high-strength and rapidly deployed military scenarios. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining processes to form a dense microstructure that meets the requirements of electronic countermeasure equipment for high precision and durability.

#### 8.1.1 Countermeasures and weight components

The counterweight assembly of the jammer is a key component in electronic countermeasure equipment. It is used to adjust the center of gravity of the jammer (such as coaxial chaff or infrared decoy) to ensure its dynamic stability and trajectory accuracy during high-speed launch and flight. Tungsten -nickel-copper alloy is the preferred material for the counterweight assembly of the jammer due to its high density and non-magnetic properties. The high density property enables the alloy to provide sufficient mass in a small volume, accurately control the center of gravity of the jammer, optimize its aerodynamic performance, extend the flight distance or improve the delivery accuracy. The non-magnetic property avoids the interference of the magnetic field on the internal electronic components of the jammer (such as the seeker or control circuit), ensuring normal operation in a complex electromagnetic environment. The low thermal expansion coefficient of the alloy ensures the dimensional stability of the counterweight assembly under the air friction heat or

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ambient temperature difference generated by high-speed flight.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture counterweight components through metal injection molding (MIM) or powder metallurgy process to meet the requirements of jammers for miniaturization and complex shapes. MIM technology forms a high-density structure by mixing tungsten, nickel, and copper powders with a binder, degreasing and liquid phase sintering after injection molding. The nickel-copper liquid phase wets the tungsten particles to enhance mechanical properties and thermal conductivity. Hot isostatic pressing further eliminates micropores, improves the density and strength of the counterweight, and is suitable for high dynamic load applications. Precision machining (such as CNC milling or EDM) achieves micron-level tolerances to ensure the precise match of the counterweight to the jammer structure. Surface treatment improves corrosion resistance and oxidation resistance, extending the life of components in humid or high temperature environments.

In electronic countermeasure applications, tungsten-nickel-copper counterweight assemblies significantly improve the performance of jammers. For example, in shipborne chaff jammers, high-density counterweights optimize the trajectory of the missile body to ensure accurate coverage of the enemy's radar detection range; in infrared decoy bombs, non-magnetic counterweights avoid interference with the electronic guidance system and improve the induction effect. Optimization directions include enhancing thermal conductivity by optimizing the nickel-copper ratio, reducing mass by using microstructure design (such as hollow counterweights), or customizing complex shapes in combination with additive manufacturing technology. Quality control verifies the performance of the counterweight through density measurement, vibration testing, and magnetization strength testing to ensure compliance with military standards.

### 8.1.2 Radar Decoy Components

Radar decoy components are an important part of electronic countermeasure equipment, used to simulate target signals or interfere with enemy radars, protecting one's own aircraft, ships or ground equipment from detection and attack. Tungsten-nickel-copper alloy is an ideal material for radar decoy components due to its high density, non-magnetism and high thermal conductivity. The high density property enables it to provide sufficient mass in a small volume to simulate the radar cross-sectional area (RCS) of a real target and enhance the deception effect of the decoy. The non-magnetic property avoids the interference of the magnetic field on the internal electronic components of the decoy (such as antennas or signal generators), ensuring stable operation in high-frequency electromagnetic environments. High thermal conductivity quickly disperses the heat generated by the decoy when flying at high speed or running at high power to prevent overheating and failure; the low thermal expansion coefficient ensures the dimensional stability of the components under extreme temperature differences.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture radar decoy components through MIM or powder metallurgy process to meet the requirements of complex

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shapes and high precision. MIM technology forms tiny billets through injection molding, and liquid phase sintering and hot isostatic pressing improve density, eliminate micropores, and enhance thermal conductivity and mechanical properties. Precision machining (such as laser micromachining or electrospark machining) achieves complex geometric shapes with tolerances controlled at the micron level, which is suitable for the miniaturized design of radar decoys. Surface treatment (such as PVD TiN coating or electrochemical polishing) improves corrosion resistance and surface finish, reduces signal scattering and enhances oxidation resistance. Processing needs to be carried out in a clean room to prevent dust pollution from affecting component performance.

In radar decoy applications, tungsten-nickel-copper components significantly improve the countermeasure effect. For example, in drone decoys, high-density components simulate the RCS of real aircraft and deceive enemy radars; in shipborne decoy systems, non-magnetic properties and high thermal conductivity ensure the stability and reliability of decoys under high-power operation. Optimization directions include improving conductivity by adjusting the nickel-copper ratio, using multi-layer composite structures to enhance electromagnetic shielding effects, or combining 3D printing technology to manufacture complex decoy structures. Quality control verifies component performance through electromagnetic shielding tests (MIL-STD-461), thermal conductivity tests, and high-temperature aging tests to ensure compliance with military standards.

## 8.2 Ammunition System

a core component of the defense industry, requiring materials to have high density to optimize weight distribution, good mechanical properties to withstand high-speed impact, and non-magnetic properties to avoid electromagnetic interference. Tungsten -nickel-copper alloy is an ideal material for counterweight and balance components in ammunition systems due to its high density, non-magnetic properties, high strength and low thermal expansion coefficient. The high density enables it to provide sufficient mass within a limited volume to optimize the flight stability and penetration of ammunition; the non-magnetic properties ensure that it does not interfere with the electronic guidance system in the ammunition; the high strength and toughness enable the components to withstand extreme mechanical loads during launch and flight; the low thermal expansion coefficient ensures dimensional stability in high temperature or temperature difference environments. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining processes to form a dense microstructure that meets the ammunition system's requirements for high precision and durability.

### 8.2.1 Projectile warhead counterweight

The counterweight of a projectile warhead is a key component in the design of a projectile. It is used to adjust the center of gravity of the projectile and ensure its dynamic stability and penetration accuracy during high-speed launch and flight. Tungsten -nickel-copper alloy is the preferred material for the counterweight of a projectile warhead due to its high density and non-magnetic properties. The high density property enables the alloy to provide sufficient mass within a limited

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volume, accurately control the center of gravity of the projectile, optimize aerodynamic performance, reduce deflection during flight, and improve hit accuracy. The non-magnetic property avoids the interference of the magnetic field on the electronic components inside the projectile (such as the guidance system or fuze), ensuring reliable operation in a complex electromagnetic environment. The high strength and toughness of the alloy enable it to withstand the huge impact force during the launch of the projectile and the vibration during high-speed flight. The low thermal expansion coefficient ensures dimensional stability under high launch temperatures or ambient temperature differences.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture counterweights through powder metallurgy or metal injection molding (MIM) technology to meet the requirements of complex shapes and high precision for artillery shells. MIM technology forms a high-density structure by mixing tungsten, nickel, and copper powders with a binder, degreasing and liquid-phase sintering after injection molding. The nickel-copper liquid phase wets the tungsten particles to enhance mechanical properties and thermal conductivity. Hot isostatic pressing further eliminates micropores, improves the density and impact resistance of the counterweight, and is suitable for high-performance artillery shells. Precision machining (such as CNC turning or EDM) achieves micron-level tolerances to ensure the precise match of the counterweight with the warhead structure. Surface treatment improves corrosion resistance and oxidation resistance, and extends the life of the counterweight in humid or high-temperature environments.

In artillery shell applications, tungsten-nickel-copper counterweights significantly improve ammunition performance. For example, in tank shells, high-density counterweights optimize the flight stability of the warhead and enhance armor-piercing capabilities; in naval gun ammunition, non-magnetic counterweights avoid interference from electronic fuses and improve hit accuracy. Optimization directions include improving toughness by optimizing the nickel-copper ratio, optimizing the center of gravity distribution using microstructure design (such as gradient density counterweights), or customizing complex shapes in combination with additive manufacturing technology. Quality control verifies counterweight performance through density measurement, impact testing, and magnetization strength testing to ensure compliance with military standards.

### 8.2.2 Missile warhead balance components

The missile warhead balance component is a key component in the missile system, which is used to adjust the center of gravity distribution of the warhead to ensure the stability and precision guidance capability of the missile during high-speed flight and maneuvering. Tungsten -nickel-copper alloy is an ideal material for missile warhead balance components due to its high density, non-magnetism and high strength. The high density property enables the alloy to provide sufficient mass in a small volume, accurately control the center of gravity of the warhead, and optimize the flight trajectory and attitude stability of the missile, especially in supersonic or high-maneuvering flight. The non-magnetic property avoids the interference of the magnetic field on the warhead electronic system (such as radar seeker or inertial navigation system), ensuring high-precision guidance. The high

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strength and toughness of the alloy enable it to withstand the impact of launch and extreme mechanical loads in flight, and the low thermal expansion coefficient ensures dimensional stability under high temperature friction or ambient temperature difference.

During the preparation process, tungsten-nickel-copper alloy is manufactured into balanced components through MIM or powder metallurgy process to meet the needs of missile warheads for miniaturization and complex shapes. MIM technology forms tiny billets through injection molding, and liquid phase sintering and hot isostatic pressing improve density, eliminate micropores, and enhance mechanical properties and thermal conductivity. Precision machining (such as laser micromachining or electrospark machining) achieves complex geometric shapes with tolerances controlled at the micron level, which is suitable for the compact design of warheads. Surface treatment (such as PVD CrN coating or electrochemical polishing) improves corrosion resistance and surface finish, reduces the impact of air friction heat and enhances oxidation resistance. Processing needs to be carried out in a high-cleanliness environment to prevent dust pollution from affecting component performance.

In missile applications, tungsten-nickel-copper balance components significantly improve warhead performance. For example, in anti-ship missiles, high-density balance components optimize the center of gravity distribution of the warhead and improve the stability of high-speed flight; in precision-guided missiles, non-magnetic properties and high strength ensure the reliability and impact resistance of the guidance system. Optimization directions include improving thermal conductivity by adjusting the nickel-copper ratio, using multi-layer composite structures to enhance mechanical properties, or combining 3D printing technology to manufacture complex balance structures. Quality control verifies component performance through density measurement, vibration testing, and electromagnetic shielding testing to ensure compliance with military standards.

### 8.3 Armored protective equipment

Armored protective equipment is a core component of the national defense military industry. It is used to protect personnel, vehicles and facilities from projectiles, explosion fragments or other threats. It requires materials with high density, high strength, toughness and non-magnetism to achieve a balance between lightweight and high protection performance. Tungsten nickel copper alloy can provide strong impact resistance due to its high density and excellent mechanical properties; its non-magnetic properties avoid electromagnetic interference and are suitable for modern armor systems with integrated electronic equipment; its low thermal expansion coefficient ensures dimensional stability at extreme temperatures .

#### 8.3.1 Lightweight armor plate reinforcements

Lightweight armor plate reinforcements are key components in armor protection equipment. They are used to enhance the anti-ballistic performance of armor plates while reducing weight as much as possible. They are suitable for portable protective equipment (such as bulletproof vests) or light

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armored vehicles. Tungsten -nickel-copper alloys are the preferred materials for lightweight armor plate reinforcements due to their high density, high strength and toughness . The high density property enables the alloy to provide sufficient mass within a limited volume, enhance the impact resistance of the armor plate, and effectively absorb and disperse the kinetic energy of projectiles or explosion fragments. The toughness of the nickel-copper bonding phase makes the alloy less prone to brittle fracture under high-speed impact, and can absorb energy through plastic deformation to improve protective performance. The non-magnetic property avoids the interference of magnetic fields on electronic equipment embedded in armor plates (such as communications or sensors), which is suitable for the complex electromagnetic environment of modern battlefields. The low thermal expansion coefficient ensures the dimensional stability of the reinforcement under high-temperature explosions or ambient temperature differences.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture reinforcements through powder metallurgy or metal injection molding (MIM) technology to meet the requirements of lightweight armor plates for complex shapes and lightweight. MIM technology forms a high-density structure by mixing tungsten, nickel, and copper powders with a binder, degreasing and liquid-phase sintering after injection molding, and the nickel-copper liquid phase wets the tungsten particles to enhance toughness and mechanical properties. Hot isostatic pressing further eliminates micropores, improves the density and impact resistance of the reinforcement, and is suitable for high dynamic load applications. Precision machining (such as CNC milling or EDM) achieves precise geometric shapes and dimensional tolerances to ensure seamless integration of reinforcements with armor plates. Surface treatment (such as PVD TiN coating or chemical passivation) improves corrosion resistance and wear resistance, extending the life of reinforcements in harsh environments.

In armor applications, tungsten-nickel-copper reinforcements significantly improve the protective performance of light armor plates. For example, in bulletproof vests, reinforcements improve the ability to resist armor-piercing projectiles while maintaining lightweight and enhancing soldier mobility; in light armored vehicles, high-density reinforcements optimize the impact resistance of armor plates. Optimization directions include improving toughness by optimizing the nickel-copper ratio, using composite structures (such as in combination with ceramics) to enhance protection efficiency, or combining additive manufacturing technology to customize complex reinforcements . Quality control verifies the performance of reinforcements through density measurement, impact testing, and electromagnetic shielding testing to ensure compliance with military standards.

### 8.3.2 Armored vehicle protective lining

The protective lining of armored vehicles is a key protective component inside armored vehicles, used to absorb and disperse the energy of explosion shock waves, projectiles or fragments, and protect occupants and key equipment from harm. Tungsten -nickel-copper alloy has become the preferred material for armored vehicle protective linings due to its high density, high strength and non-magnetic properties. The high density property enables the alloy to effectively absorb impact

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energy, reduce the penetration of explosions or projectiles, and enhance the protective capabilities of the vehicle. The toughness of the nickel-copper bonding phase enables the lining to absorb energy through plastic deformation under high-speed impact, avoid brittle fracture, and improve the ability to resist multiple impacts. The non-magnetic property ensures that the lining does not interfere with the electronic systems inside the vehicle (such as navigation or communication equipment), which is suitable for modern intelligent armored vehicles. The low thermal expansion coefficient ensures the dimensional stability of the lining under high-temperature explosions or ambient temperature differences, and maintains the integrity of the protective structure.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture protective linings through powder metallurgy or MIM technology to meet the needs of armored vehicles for complex shapes and lightweight. Liquid phase sintering forms a dense microstructure, and the nickel-copper liquid phase wets the tungsten particles, enhancing mechanical properties and thermal conductivity. Hot isostatic pressing eliminates micropores, improves the density and impact resistance of the lining, and is suitable for high-intensity protection applications. Precision machining (such as CNC grinding or laser processing) achieves complex geometric shapes, and the tolerance is controlled at the micron level to ensure the precise fit of the lining with the vehicle structure. Surface treatment (such as PVD CrN coating or chemical passivation) improves corrosion resistance and oxidation resistance, and extends the life of the lining in humid or high temperature environments. Processing needs to be carried out in a high-cleanliness environment to prevent dust pollution from affecting performance. In armored vehicle applications, tungsten-nickel-copper protective linings significantly improve protection performance. For example, in main battle tanks, high-density linings effectively absorb explosion impact energy and protect the safety of occupants; in armored personnel carriers, non-magnetic linings ensure the stable operation of electronic equipment. Optimization directions include improving energy absorption efficiency through microstructure design (such as gradient density lining), using composite coatings to enhance wear resistance, or combining 3D printing technology to manufacture customized lining structures. Quality control verifies lining performance through density measurement, impact testing, and high-temperature aging testing to ensure compliance with military standards.

#### 8.4 Space weapons

Space weapons include systems such as rockets, missiles, and spacecraft, which require materials with high density to optimize weight distribution, excellent thermal conductivity and high temperature resistance to withstand extreme thermal environments, non-magnetic properties to avoid electromagnetic interference, and low thermal expansion coefficient to ensure dimensional stability. Tungsten -nickel-copper alloy has become an ideal material for key components in aerospace weapons due to its unique physical and chemical properties. The high density property enables it to provide sufficient mass within a limited volume, optimizing the center of gravity distribution and dynamic balance of the system; high thermal conductivity and high temperature resistance support the performance of components in high heat flow environments; non-magnetic properties avoid interference with precision electronic systems; low thermal expansion coefficient

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ensures geometric stability at extreme temperatures. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining processes to form a dense microstructure that meets the needs of aerospace weapons for high precision and durability.

#### 8.4.1 Rocket engine nozzle components

Rocket engine nozzle components are core components in aerospace weapons. They are used to guide and accelerate high-temperature and high-pressure gases to ensure efficient output of rocket thrust and need to withstand extreme high temperatures, thermal shocks and mechanical stresses. Tungsten-nickel-copper alloys are the preferred materials for nozzle components (such as throat liners or nozzle extensions) due to their high thermal conductivity, high temperature resistance and low thermal expansion coefficient. The high thermal conductivity is due to the rapid thermal conductivity of copper, which can quickly disperse the heat of the nozzle at high temperatures in the combustion chamber to prevent local overheating and material failure. The low thermal expansion coefficient ensures the geometric stability of the nozzle under drastic temperature differences, maintains the precise guidance of the gas flow, and improves thrust efficiency. The high density and toughness of the alloy enable it to withstand the scouring and vibration of high-speed gas flow, and the plasticity of the nickel-copper bonding phase absorbs thermal shock energy to avoid brittle fracture. The non-magnetic properties ensure that there is no interference with the electronic components of the rocket navigation or control system.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture nozzle components through powder metallurgy or metal injection molding (MIM) technology to meet the requirements of complex shapes and high precision. Liquid phase sintering forms a dense microstructure, and the nickel-copper liquid phase wets the tungsten particles, enhancing thermal conductivity and mechanical properties. Hot isostatic pressing eliminates micropores, improves the density and high temperature resistance of the components, and is suitable for high heat flow environments. Precision machining (such as CNC grinding or electrospark machining) achieves complex geometric shapes with tolerances controlled at the micron level to ensure the aerodynamic performance of the nozzle. Surface treatment (such as PVD CrN coating or chemical passivation) improves high temperature oxidation resistance and erosion resistance, and extends the life of the components in extreme environments. Processing needs to be carried out in a high cleanliness environment to prevent dust pollution from affecting performance. In aerospace weapon applications, tungsten-nickel-copper nozzle components significantly improve rocket engine performance. For example, in solid rocket engines, high thermal conductivity nozzle components effectively manage high temperature gas flow and extend service life; in liquid rocket engines, low thermal expansion coefficients ensure the geometric stability of the nozzle during thermal cycles. Optimization directions include enhancing thermal conductivity by optimizing the nickel-copper ratio, using composite coatings to improve high temperature resistance, or combining 3D printing technology to manufacture complex nozzle structures. Quality control verifies component performance through thermal conductivity testing, thermal shock testing, and high temperature aging testing to ensure compliance with aerospace standards.

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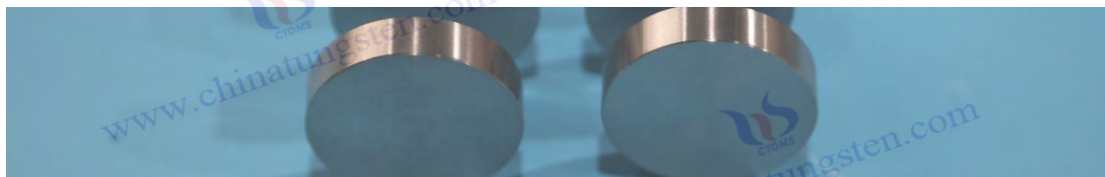


#### 8.4.2 Spacecraft Attitude Control Counterweights

Spacecraft attitude control counterweights are key components in space weapons and satellite systems. They are used to adjust the center of gravity distribution of spacecraft to ensure its attitude stability and precise control during orbital operation or maneuvering. Tungsten-nickel-copper alloy is an ideal material for attitude control counterweights due to its high density, non-magnetic properties and low thermal expansion coefficient. The high density property enables the alloy to provide sufficient mass in a small volume, accurately control the center of gravity of the spacecraft, optimize the efficiency of attitude adjustment, and reduce propellant consumption. The non-magnetic property avoids the interference of magnetic fields on the spacecraft navigation system (such as star sensors or gyroscopes), ensuring high-precision attitude control. The low thermal expansion coefficient ensures the dimensional stability of the counterweight under extreme temperature differences in the space environment and maintains the dynamic balance of the spacecraft.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture counterweights through MIM or powder metallurgy process to meet the needs of spacecraft for miniaturization and complex shapes. MIM technology forms tiny billets through injection molding, and liquid phase sintering and hot isostatic pressing improve density, eliminate micropores, and enhance mechanical properties and thermal conductivity. Precision machining (such as laser micromachining or electrospark machining) achieves complex geometric shapes with tolerances controlled at the micron level, which is suitable for the compact design of spacecraft. Surface treatment improves corrosion resistance and surface finish, and reduces particulate contamination or radiation effects in the space environment. Processing needs to be carried out in a high-cleanliness environment to prevent dust contamination from affecting component performance.

In spacecraft applications, tungsten-nickel-copper counterweights significantly improve attitude control performance. For example, in military reconnaissance satellites, high-density counterweights optimize center-of-gravity distribution and improve the response speed of attitude adjustment; in missile defense systems, non-magnetic counterweights ensure stable operation of navigation systems. Optimization directions include reducing mass through microstructure design, using radiation-resistant coatings to enhance adaptability to space environments, or combining additive manufacturing technology to achieve customized counterweight structures. Quality control verifies counterweight performance through density measurement, vibration testing, and magnetization strength testing to ensure compliance with aerospace standards.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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## Chapter 9 Application of Tungsten Nickel Copper Alloy in Medical Field

Tungsten -nickel-copper alloy has shown excellent application value in the medical field due to its high density, non-magnetic properties, excellent thermal conductivity and good biocompatibility, especially in radiotherapy equipment, imaging equipment and surgical instruments. The alloy is prepared by powder metallurgy process, combining the high density of tungsten with the toughness and thermal conductivity of nickel-copper bonding phase, and can meet the strict requirements of medical equipment for radiation shielding, thermal management and electromagnetic compatibility. With the development of precision medicine and non-invasive treatment technology, the application of tungsten-nickel-copper alloy in radiotherapy equipment is becoming increasingly important.

### 9.1 Radiotherapy Equipment

Radiotherapy equipment (such as linear accelerators and gamma knives ) is a core technology used in modern medicine for cancer treatment. It precisely controls high-energy rays (such as X-rays or gamma rays) to target tumor tissue while protecting surrounding healthy tissue. This type of equipment has extremely high material requirements, requiring high density to effectively shield radiation, non-magnetic properties to avoid interference with precision electronic systems, excellent thermal conductivity to manage the heat generated during operation, and good biocompatibility to ensure safety. Tungsten nickel copper alloy can effectively absorb and shield radiation and protect patients and medical staff due to its high density and non-magnetic properties; its high thermal conductivity and low thermal expansion coefficient support the thermal management and dimensional stability of the equipment during high-power operation; the toughness of the nickel-copper binder phase enhances the durability of the components. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining processes to form a dense microstructure that meets the needs of medical equipment for high precision and reliability.

#### 9.1.1 Radiotherapy shield assembly

Radiotherapy shielding components are key components in radiotherapy equipment, used to shield and limit high-energy rays, ensure that radiation only acts on the target treatment area, and protect patients' healthy tissues and medical staff from unnecessary radiation exposure. Tungsten -nickel-copper alloy is an ideal material for radiotherapy shielding components due to its high density and non-magnetic properties. The high density property enables it to effectively absorb X-rays or gamma rays, significantly reduce radiation leakage, and provide excellent shielding effects. It is lighter and more environmentally friendly than traditional lead materials . The non-magnetic property avoids the interference of magnetic fields on precision electronic systems in radiotherapy equipment (such as magnetic resonance guidance systems), ensuring treatment accuracy. High thermal conductivity quickly disperses the heat generated during operation to prevent the shielding cover from overheating and affecting equipment performance; the low thermal expansion coefficient ensures the dimensional stability of the component during thermal cycles and maintains the accuracy of the shielding structure.

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During the preparation process, tungsten-nickel-copper alloy is used to manufacture shield components through powder metallurgy or metal injection molding (MIM) technology to meet the requirements of complex shapes and high precision. MIM technology forms a high-density structure by mixing tungsten, nickel, and copper powders with a binder, degreasing and liquid phase sintering after injection molding. The nickel-copper liquid phase wets the tungsten particles to enhance mechanical properties and thermal conductivity. Hot isostatic pressing further eliminates micropores, improves the density and radiation absorption capacity of the shield, and is suitable for high-energy radiotherapy applications. Precision machining (such as CNC milling or electrospark machining) achieves complex geometries with tolerances controlled at the micron level to ensure seamless integration with radiotherapy equipment. Surface treatment (such as electrochemical polishing or chemical passivation) improves corrosion resistance and biocompatibility, and prevents erosion in oxidation or sterilization environments during long-term use.

In radiotherapy applications, tungsten nickel copper shielding components significantly improve treatment safety and precision. For example, in linear accelerators, high-density shielding effectively limits radiation scattering and protects patients' healthy tissues; in gamma knife equipment, non-magnetic shielding ensures the electromagnetic compatibility of the treatment system. Optimization directions include improving thermal conductivity by optimizing the nickel-copper ratio, using composite coatings (such as DLC) to enhance corrosion resistance, or combining 3D printing technology to manufacture customized shielding structures. Quality control verifies component performance through radiation shielding tests, thermal conductivity tests, and biocompatibility tests (ISO 10993).

### 9.1.2 Radiation collimator components

The radiation collimator component is a core component in radiotherapy equipment, which is used to accurately control the direction and range of the radiation, ensure that the high-energy radiation is focused on the tumor tissue, and minimize damage to the surrounding healthy tissue. Tungsten - nickel-copper alloy is the preferred material for radiation collimator components due to its high density, non-magneticity and high thermal conductivity. The high density property enables it to effectively absorb and shield scattered radiation, shape the precise radiation beam shape, and improve the targeting of treatment. The non-magnetic property avoids the interference of the magnetic field on the electronic control system (such as servo motors or sensors) near the collimator, ensuring the dynamic adjustment accuracy of the radiation beam. The high thermal conductivity quickly disperses the heat generated by the collimator under the action of high-energy radiation to prevent deformation caused by overheating; the low thermal expansion coefficient ensures the dimensional stability of the component during thermal cycles and maintains the collimation accuracy.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture collimator components through MIM or powder metallurgy process to meet the requirements of complex shapes and micron-level precision. MIM technology forms tiny billets through injection molding,

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and liquid phase sintering and hot isostatic pressing improve density, eliminate micropores, and enhance radiation shielding capabilities and mechanical properties. Precision machining (such as laser micromachining or electrospark machining) realizes complex geometries, such as the thin-sheet structure of the multi-leaf collimator (MLC), with tolerances controlled at the micron level to ensure precise control of the beam. Surface treatment (such as PVD TiN coating or electrochemical polishing) improves corrosion resistance and surface finish, reduces radiation scattering and enhances oxidation resistance. Processing needs to be carried out in a high-cleanliness environment to prevent dust contamination from affecting component performance.

In radiotherapy applications, tungsten nickel copper collimator components significantly improve treatment accuracy and safety. For example, in intensity modulated radiotherapy (IMRT), high-density collimators accurately shape the beam and target complex-shaped tumors; in proton therapy equipment, non-magnetic collimators ensure the stable operation of high-precision electromagnetic control systems. Optimization directions include reducing mass through microstructure design (such as porous collimation blades), using nano-coatings to enhance wear resistance and biocompatibility, or combining additive manufacturing technology to achieve complex collimation structures. Quality control verifies component performance through radiation shielding tests, thermal conductivity tests, and geometric accuracy measurements to ensure compliance with medical standards.

## 9.2 Diagnostic Imaging Equipment

Diagnostic imaging equipment is a core technology used in modern medicine for disease diagnosis and treatment planning. It generates images of the human body's interior through high-precision radiation or magnetic fields, requiring materials to have high density to shield radiation, non-magnetic properties to avoid electromagnetic interference, excellent thermal conductivity to manage equipment operation heat, and good biocompatibility to ensure safety. Tungsten nickel copper alloy can effectively shield X-rays or provide weight balance due to its high density and non-magnetic properties; high thermal conductivity and low thermal expansion coefficient support thermal management and dimensional stability; the toughness of the nickel-copper binder phase enhances the durability of the components. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining processes to form a dense microstructure that meets the needs of diagnostic imaging equipment for high precision and reliability.

### 9.2.1 CT detector protection parts

CT detector shields are key components in computed tomography (CT) equipment, used to shield scattered X-rays, protect detector modules and patients from unnecessary radiation exposure, and ensure the clarity and accuracy of image signals. Tungsten -nickel-copper alloy has become the preferred material for CT detector shields due to its high density and non-magnetic properties. The high density enables it to effectively absorb X-rays and significantly reduce scattered radiation. It is thinner and more environmentally friendly than traditional lead materials , providing excellent shielding effects. The non-magnetic properties prevent magnetic fields from interfering with

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precision electronic components in CT machines (such as detector arrays or signal processing circuits), ensuring the stability of image acquisition. High thermal conductivity quickly disperses the heat generated by the detector during operation to prevent overheating from affecting the sensitivity of the detector; the low thermal expansion coefficient ensures the dimensional stability of the shield during thermal cycles and maintains precise fit with the detector module.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture protective parts through metal injection molding (MIM) or powder metallurgy process to meet the requirements of CT machines for complex shapes and high precision. MIM technology forms a high-density structure by mixing tungsten, nickel, and copper powders with a binder, degreasing and liquid phase sintering after injection molding, and the nickel-copper liquid phase wets the tungsten particles to enhance mechanical properties and thermal conductivity. Hot isostatic pressing further eliminates micropores, improves the density and radiation absorption capacity of protective parts, and is suitable for high-energy X-ray environments. Precision machining achieves complex geometric shapes with tolerances controlled at the micron level to ensure seamless integration of protective parts with detector modules. Surface treatment (such as electrochemical polishing or chemical passivation) improves corrosion resistance and biocompatibility, and prevents erosion by oxidation or disinfection environments during long-term use.

In CT machine applications, tungsten-nickel-copper protective parts significantly improve image quality and equipment safety. For example, in high-resolution CT scanners, high-density protective parts effectively reduce scattered rays and improve image contrast; in mobile CT equipment, non-magnetic and lightweight designs support equipment portability and electromagnetic compatibility. Optimization directions include improving thermal conductivity by optimizing the nickel-copper ratio, using nano-coatings (such as DLC) to enhance corrosion resistance, or combining 3D printing technology to manufacture customized protective structures. Quality control verifies the performance of protective parts through radiation shielding tests (in accordance with IEC 60601 standards), thermal conductivity tests, and biocompatibility tests (ISO 10993).

### 9.2.2 Counterweights for MRI equipment

The counterweight of the magnetic resonance imaging (MRI) equipment is a key component used in the MRI system to adjust the center of gravity of the equipment or the balance of the mechanical structure, ensuring the stability and accuracy of the scanning platform or magnet assembly during operation. Tungsten -nickel-copper alloy is an ideal material for the counterweight of MRI equipment due to its high density, non-magnetism and low thermal expansion coefficient. The high density property enables the alloy to provide sufficient mass in a small volume, accurately control the center of gravity distribution of MRI equipment (such as scanning beds or gradient coils), reduce vibration or mechanical offset, and improve image clarity. The non-magnetic property is crucial to avoid the interference of the magnetic field with the high-intensity magnetic field (1.5T-7T) of MRI, ensuring the uniformity of the magnetic field and the accuracy of signal acquisition. The low thermal expansion coefficient ensures the dimensional stability of the counterweight under the temperature

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rise of the equipment operation or the temperature difference of the environment, and maintains the long-term reliability of the mechanical structure.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture counterweights through MIM or powder metallurgy process to meet the needs of MRI equipment for complex shapes and miniaturization. MIM technology forms tiny billets through injection molding, and liquid phase sintering and hot isostatic pressing improve density, eliminate micropores, and enhance mechanical properties and thermal conductivity. Precision machining (such as CNC milling or EDM) achieves complex geometric shapes with tolerances controlled at the micron level, which is suitable for the compact design of MRI equipment. Surface treatment (such as PVD TiN coating or electrochemical polishing) improves corrosion resistance and surface finish, and reduces the risk of oxidation or contamination in a sterilized environment. Processing needs to be carried out in a high-cleanliness environment to prevent dust contamination from affecting component performance or MRI magnetic fields. In MRI applications, tungsten-nickel-copper counterweights significantly improve equipment performance. For example, in high-field MRI equipment, high-density counterweights optimize the dynamic balance of the scanning platform and reduce the impact of vibration on image quality; in portable MRI systems, non-magnetic counterweights ensure magnetic field stability and electromagnetic compatibility. Optimization directions include reducing mass through microstructure design (such as hollow counterweights), using corrosion-resistant coatings to enhance biocompatibility, or combining additive manufacturing technology to achieve customized counterweight structures. Quality control verifies counterweight performance through density measurement, magnetization strength testing, and vibration testing to ensure compliance with medical standards.

### 9.3 Surgical instruments

Surgical instruments are core tools for precise diagnosis and treatment in modern medicine, covering surgical navigation systems, minimally invasive interventional instruments and implantable medical devices. They require materials with high density to optimize weight balance, non-magnetic properties to avoid electromagnetic interference, excellent mechanical properties to ensure durability, and good biocompatibility to meet safety standards for use in vivo or on the surface of the body. Tungsten -nickel-copper alloys can provide precise weight control and electromagnetic compatibility due to their high density and non-magnetic properties; the toughness and high thermal conductivity of the nickel-copper bonding phase enhance the durability and thermal management capabilities of the instrument; and the low thermal expansion coefficient ensures dimensional stability at body temperature or in a sterilized environment. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining to form a dense microstructure that meets the needs of surgical instruments for high precision and reliability.

#### 9.3.1 High-precision surgical navigation positioning components

High-precision surgical navigation positioning parts are key components used to locate and guide

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surgical tools in surgical navigation systems. They are widely used in neurosurgery, orthopedics and cardiovascular surgery to ensure the accuracy and safety of surgical paths. Tungsten -nickel-copper alloy is the preferred material for surgical navigation positioning parts due to its high density, non-magneticity and low thermal expansion coefficient. The high-density characteristics enable the alloy to provide sufficient mass in a small volume, optimize the center of gravity distribution of the positioning parts, enhance the stability of the surgical navigation system, and especially improve positioning accuracy in dynamic adjustments (such as robot-assisted surgery). The non-magnetic characteristics avoid interference of magnetic fields on electronic components in the navigation system (such as electromagnetic trackers or optical sensors), ensuring reliability in magnetic resonance guidance or electromagnetic navigation environments. The low thermal expansion coefficient ensures the dimensional stability of the positioning parts at body temperature or in a sterilized environment, maintaining navigation accuracy.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture positioning parts through metal injection molding (MIM) or powder metallurgy process to meet the requirements of surgical navigation systems for complex shapes and micron-level precision. MIM technology forms a high-density structure by mixing tungsten, nickel, and copper powders with a binder, degreasing and liquid-phase sintering after injection molding. The nickel-copper liquid phase wets the tungsten particles to enhance mechanical properties and thermal conductivity. Hot isostatic pressing further eliminates micropores, improves the density and durability of positioning parts, and is suitable for high-precision applications. Precision machining (such as laser micromachining or electrospark machining) achieves complex geometries with tolerances controlled at the micron level to ensure seamless integration with navigation systems. Surface treatment (such as electrochemical polishing or PVD TiN coating) improves corrosion resistance and biocompatibility, prevents oxidation during sterilization or in vivo environments, and meets ISO 10993 biocompatibility standards.

In surgical navigation applications, tungsten-nickel-copper positioning parts significantly improve surgical precision and safety. For example, in neurosurgical navigation, high-density positioning parts optimize the stability of the guidance system and ensure brain surgery with micron-level precision; in orthopedic surgery, non-magnetic positioning parts avoid electromagnetic interference and improve the reliability of the navigation system. Optimization directions include improving toughness by optimizing the nickel-copper ratio, using nano-coatings to enhance wear resistance and biocompatibility, or combining 3D printing technology to manufacture customized positioning structures. Quality control verifies the performance of positioning parts through density measurement, magnetization strength testing, and surface roughness testing to meet medical standards.

### 9.3.2 Minimally invasive interventional device guide components

Key components used to guide guidewires, catheters or stents in minimally invasive surgeries (such as cardiovascular interventions or endoscopic surgeries). They require high precision,

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biocompatibility and durability to ensure surgical success and patient safety. Tungsten - nickel - copper alloy is an ideal material for guide components due to its high density, non-magnetic properties and excellent mechanical properties. The high density property enables the alloy to provide sufficient mass in a small volume, optimize the center of gravity distribution of the guide component, and enhance the maneuverability and stability of the guidewire or catheter, especially for precise guidance in complex vascular pathways. The non-magnetic property avoids the interference of magnetic fields on electronic components (such as sensors or imaging modules) in interventional devices, and is suitable for minimally invasive surgeries guided by magnetic resonance. The toughness of the nickel-copper binder phase enables the component to withstand repeated bending and torsion, and the low thermal expansion coefficient ensures dimensional stability at body temperature or in a sterilized environment.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture guide components through MIM or micro powder metallurgy process to meet the needs of minimally invasive devices for miniaturization and complex shapes. MIM technology forms tiny billets through injection molding, and liquid phase sintering and hot isostatic pressing increase density, eliminate micropores, and enhance mechanical properties and thermal conductivity. Precision machining (such as laser micromachining or electrospark machining) achieves complex geometries, such as guide wire guide rings or catheter tips, with tolerances controlled at the micron level to ensure precise manipulation during surgery. Surface treatment (such as DLC coating or chemical passivation) improves wear resistance, corrosion resistance and biocompatibility, reduces friction with vascular tissue, and prevents oxidation or disinfection erosion during long-term use. Processing needs to be carried out in a high-cleanliness environment to prevent dust pollution from affecting component performance.

In minimally invasive surgery applications, tungsten-nickel-copper guide components significantly improve surgical efficiency and safety. For example, in cardiovascular stent implantation, high-density guide components optimize the maneuverability of the guide wire and ensure precise positioning; in neurointerventional surgery, non-magnetic guide components avoid interference from the MRI environment and improve the reliability of imaging guidance.

Optimization directions include reducing mass through microstructure design (such as hollow guides), using biocompatible coatings to enhance tissue affinity, or combining additive manufacturing technology to achieve personalized guide structures. Quality control verifies component performance through mechanical property testing, biocompatibility testing (ISO 10993) and surface roughness measurement.

#### 9.4 Rehabilitation assistive devices

Rehabilitation assistive devices (such as prostheses, orthoses, and rehabilitation training equipment) are important tools in modern medicine to help patients restore motor function or improve their quality of life. They require materials with high density to optimize weight distribution, excellent

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mechanical properties to ensure durability, non-magnetic properties to avoid electromagnetic interference, and good biocompatibility to meet safety standards for long-term use. Tungsten nickel copper alloy can provide precise weight control and electromagnetic compatibility due to its high density and non-magnetic properties; the toughness and high thermal conductivity of the nickel-copper bonding phase enhance the durability and thermal management capabilities of the components; and the low thermal expansion coefficient ensures dimensional stability at body temperature or ambient temperature difference. The alloy is prepared by liquid phase sintering, hot isostatic pressing and precision machining to form a dense microstructure that meets the requirements of high precision and reliability for rehabilitation assistive devices.

#### 9.4.1 Prosthetic joint weight components

Prosthetic joint weight components are key components in prosthetic design, used to adjust the center of gravity distribution of the prosthesis, optimize the movement balance and natural gait, and improve the patient's comfort and functionality. Tungsten -nickel-copper alloy has become the preferred material for prosthetic joint weight components due to its high density, non-magnetism and excellent mechanical properties. The high density property enables the alloy to provide sufficient mass in a small volume, accurately control the center of gravity of the prosthetic joint, simulate the weight distribution of natural limbs, and reduce the patient's fatigue when using the prosthesis. The non-magnetic property avoids the interference of the magnetic field on the electronic components embedded in the prosthesis, which is suitable for intelligent prosthetic systems. The toughness of the nickel-copper binder phase enables the weight components to withstand repeated mechanical loads and impacts, such as stress during walking or running; the low thermal expansion coefficient ensures the dimensional stability of the components at body temperature or ambient temperature difference, and maintains the movement accuracy of the joint.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture weight components through metal injection molding (MIM) or powder metallurgy process to meet the requirements of prosthesis for miniaturization, complex shapes and high precision. MIM technology forms a high-density structure by mixing tungsten, nickel and copper powders with a binder, degreasing and liquid phase sintering after injection molding, and the nickel-copper liquid phase wets the tungsten particles to enhance mechanical properties and thermal conductivity. Hot isostatic pressing further eliminates micropores, improves the density and durability of the weight components, and is suitable for long-term prosthetic applications. Precision machining (such as laser micromachining or CNC milling) achieves complex geometries with tolerances controlled at the micron level to ensure precise fit with the prosthetic joint. Surface treatment improves corrosion resistance and biocompatibility, prevents oxidation during long-term use or irritation when in contact with the skin, and meets ISO 10993 biocompatibility standards.

#### 9.4.2 Balance adjustment parts for rehabilitation equipment

Balance adjustment parts for rehabilitation equipment are key components in rehabilitation training

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equipment (such as gait trainers or strength training equipment). They are used to adjust the center of gravity or movement resistance of the equipment to ensure stability and safety during training, while optimizing the patient's rehabilitation effect. Tungsten -nickel-copper alloy is an ideal material for balance adjustment parts for rehabilitation equipment due to its high density, non-magnetic properties and excellent mechanical properties. The high-density property enables the alloy to provide sufficient mass within a limited volume, accurately control the center of gravity distribution of the equipment, enhance the stability of the equipment in dynamic motion, and reduce the interference of vibration or offset to the patient. The non-magnetic property avoids the interference of magnetic fields on electronic components in rehabilitation equipment (such as motion sensors or control systems), which is suitable for intelligent rehabilitation equipment. The toughness of the nickel-copper bonding phase enables the adjustment parts to withstand repeated mechanical loads, and the low thermal expansion coefficient ensures dimensional stability at body temperature or ambient temperature difference, maintaining adjustment accuracy.

During the preparation process, tungsten-nickel-copper alloy is used to manufacture balance adjustment parts through MIM or powder metallurgy process to meet the requirements of rehabilitation equipment for complex shapes and high precision. MIM technology forms tiny billets through injection molding, and liquid phase sintering and hot isostatic pressing increase density, eliminate micropores, and enhance mechanical properties and thermal conductivity. Precision machining (such as EDM or CNC grinding) achieves complex geometric shapes, and tolerances are controlled at the micron level to ensure the precise fit of the adjustment parts with the device structure. Surface treatment (such as DLC coating or chemical passivation) improves wear resistance, corrosion resistance and biocompatibility, reduces friction with the patient's skin, and prevents oxidation in a sterilized environment. Processing needs to be carried out in a high-cleanliness environment to prevent dust pollution from affecting component performance.

In rehabilitation equipment applications, tungsten-nickel-copper balance adjusters significantly improve training results and equipment reliability. For example, in gait trainers, high-density adjusters optimize the center of gravity of the device and enhance stability during training; in strength rehabilitation equipment, non-magnetic adjusters avoid interference from electronic control systems and improve the accuracy of motion trajectories. Optimization directions include optimizing weight distribution through microstructure design (such as gradient density adjusters), using nano-coatings to enhance durability and biocompatibility, or combining additive manufacturing technology to achieve personalized adjustment structures. Quality control verifies the performance of the adjusters through density measurement, vibration testing, and biocompatibility testing to ensure compliance with medical standards (such as ISO 13485).



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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### Tungsten Nickel Copper Alloy Introduction

#### 1. Overview of Tungsten Nickel Copper Alloy

Tungsten nickel copper alloy is an alloy composed of tungsten with added nickel and copper, typically in a nickel-to-copper ratio of 3:2. This alloy is non-ferromagnetic, exhibits relatively good electrical and thermal conductivity, and is commonly used in specialized applications such as gyroscope rotors, components for devices and instruments operating under magnetic fields, electrical contacts for high-voltage switches, and electrodes for certain electrical machining processes.

#### 2. Features of Tungsten Nickel Copper Alloy

**High Density:** Typically 16.5 – 18.75 g/cm<sup>3</sup>

**High Thermal Conductivity:** Approximately 5 times that of mold steel

Compared to tungsten-nickel-iron alloy, since copper does not have the sintering activation effect of nickel and iron on tungsten, tungsten-nickel-copper alloy has a slightly lower sintered density, lower strength and plasticity, and is generally not subjected to heat treatment or deformation processing.

#### 3. Production Methods for Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy is typically produced using powder metallurgy. First, high-purity tungsten, nickel, and copper powders are mixed in specific proportions, often using equipment like a ball mill to achieve uniform mixing. The mixture is then pressed into shape, commonly using cold isostatic pressing technology under a specific pressure to form a green compact. Subsequently, sintering is performed, generally in a hydrogen protective atmosphere, using a two-step sintering process to address collapse and deformation issues caused by liquid-phase sintering, ensuring the product's density.

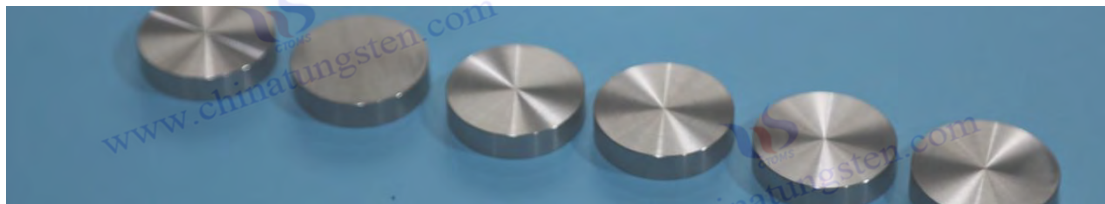
#### 4. Applications of Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy, with its high density and excellent thermal and electrical conductivity, has a wide range of applications. In the aerospace sector, it can be utilized to manufacture components such as rocket engine nozzles and gas rudders. In the medical field, due to its strong radiation absorption capability and non-magnetic properties, it is suitable for radiation shielding in magnetic resonance imaging rooms. Additionally, it can serve as a counterweight material for precision instruments.

#### 5. Purchasing Information

Email: [sales@chinatungsten.com](mailto:sales@chinatungsten.com); Phone: +86 592 5129595; 592 5129696

Website: [www.tungsten-alloy.com](http://www.tungsten-alloy.com)



CTIA GROUP LTD tungsten nickel copper alloy

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## Chapter 10 Comparison between Tungsten Nickel Copper Alloy and Other Materials

Tungsten -nickel-copper alloy has shown wide application value in aerospace, medical, electronic information, national defense and energy fields due to its high density, non-magnetic properties, excellent thermal conductivity and low thermal expansion coefficient. Prepared by powder metallurgy, tungsten-nickel-copper alloy combines the high density of tungsten with the toughness and thermal conductivity of the nickel-copper bonding phase to meet the needs of a variety of high-demand scenarios. However, in actual applications, tungsten-nickel-copper alloy is often compared with other high-performance materials such as tungsten-nickel-iron alloy and copper-tungsten alloy to evaluate its performance advantages and applicability. The physical and chemical properties, preparation processes and cost differences of different materials determine their competitiveness in specific applications.

### 10.1 Analysis of Competitive Materials of Tungsten Nickel Copper Alloy

Tungsten -nickel-copper (W-Ni-Cu) alloy is widely used in weight, heat dissipation, shielding and protection components due to its high density ( $15-18 \text{ g/cm}^3$ ), non-magnetic properties, good thermal conductivity and biocompatibility. However, it has significant differences in performance and cost from tungsten-nickel-iron (W-Ni-Fe) and copper- tungsten (W-Cu). Tungsten -nickel-iron alloys have an advantage in the military and industrial fields due to their high strength and low cost, but their magnetism limits applications with high electromagnetic compatibility requirements. Copper-tungsten alloys excel in the fields of electronics and thermal management due to their excellent thermal and electrical conductivity , but have low density and poor toughness. The selection of competing materials needs to be weighed against application requirements (such as non-magnetic properties, thermal conductivity or cost).

#### 10.1.1 Comparison with tungsten-nickel-iron alloy

Tungsten -nickel-iron (W-Ni-Fe) is a common high-density alloy widely used in military industry (such as armor-piercing cores), aerospace counterweights and industrial equipment. Its main components include tungsten (85%-98%), nickel and iron, and its density range is similar to that of tungsten-nickel-copper alloy. Compared with tungsten-nickel-copper alloy, tungsten-nickel-iron alloy has significant differences in mechanical properties, cost and application scenarios.

**Performance comparison :** The strength and hardness of tungsten -nickel-iron alloy are generally higher than those of tungsten -nickel-copper alloy. The addition of iron enhances the mechanical properties of the nickel-iron bonding phase, making it more advantageous in impact-resistant and wear-resistant scenarios (such as armor-piercing projectile cores or mechanical counterweights). However, the addition of iron makes it weakly magnetic, which limits its use in applications with high electromagnetic compatibility requirements (such as MRI equipment and electronic countermeasure equipment). The non-magnetic nature of tungsten -nickel-copper alloy is its core advantage, and it is suitable for scenarios where electromagnetic interference needs to be avoided,

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such as medical equipment and radar systems. The thermal conductivity of tungsten -nickel-copper alloy is slightly higher than that of tungsten -nickel-iron alloy. Because copper has better thermal conductivity than iron, it is suitable for heat dissipation applications (such as electronic heat sinks). The thermal expansion coefficients of the two are similar, and both can provide good dimensional stability.

**Comparison of preparation processes :** Both alloys are prepared by powder metallurgy, including powder mixing, pressing and liquid phase sintering, but the sintering temperature of tungsten-nickel-iron alloy is slightly lower, and the process cost is lower, because the price of iron is much lower than that of copper. The preparation of tungsten -nickel-copper alloy requires stricter environmental control (such as high-purity argon or vacuum) to prevent copper oxidation, which increases production costs. The processing performance of tungsten -nickel-iron alloy is slightly inferior, because its higher hardness may cause tool wear, while the toughness of tungsten-nickel-copper alloy makes it easier to achieve complex shapes in precision machining (such as MIM or CNC machining).

**Applicable scenarios and advantages and disadvantages :** Tungsten -nickel-iron alloy is widely used in the military field (such as armor-piercing cores, missile counterweights) and industrial counterweights (such as vibration suppressors) due to its high strength and low cost, but its weak magnetism makes it unsuitable for electromagnetic sensitive environments. Tungsten -nickel-copper alloy has more advantages in medical (MRI counterweights, radiotherapy shielding), electronic information (5G radio frequency modules) and aerospace weapons (attitude control counterweights). Its non-magnetic properties and biocompatibility meet high precision and safety requirements. The disadvantage of tungsten -nickel-copper alloy is its high cost, which affects its economic efficiency, especially when copper prices fluctuate. Optimization directions include improving performance by adjusting the nickel-copper ratio, or using additive manufacturing to reduce processing costs.

#### 10.1.2 Comparison with Copper Tungsten Alloy

Copper-tungsten alloy (W-Cu) is a composite material with tungsten as the matrix and copper as the binder phase. It is widely used in electronic heat dissipation, electrical contact and high-temperature components. The typical composition includes tungsten (70%-90%) and copper, and the density ranges from 12-17 g/cm<sup>3</sup>. Compared with tungsten -nickel-copper alloy, copper-tungsten alloy has significant differences in thermal conductivity, electrical conductivity and application scenarios.

**Performance comparison :** The thermal conductivity and electrical conductivity of copper-tungsten alloy are better than those of tungsten -nickel-copper alloy. Its higher copper content (10%-30%) enhances the efficiency of heat and electricity conduction, making it excellent in high-power electronic heat dissipation (such as power semiconductor substrates, server heat sinks) and electrode materials. However, the density of copper-tungsten alloy is lower than that of tungsten -nickel-copper alloy, which limits its application in applications that require high weight balancing (such as aerospace counterweights and missile balance components). The mechanical properties of copper-

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tungsten alloy are weak, and its toughness and impact resistance are not as good as those of tungsten-nickel-copper alloy. Due to the lack of strengthening effect of nickel, it is easy to break under high stress. The non-magnetic nature of tungsten-nickel-copper alloy is its advantage, which is suitable for electromagnetic sensitive environments. Although copper-tungsten alloy is also non-magnetic, its lower density makes its shielding ability slightly inferior. The thermal expansion coefficients of the two are similar, and both are suitable for scenarios that require dimensional stability.

**Comparison of preparation processes :** Copper-tungsten alloy and tungsten-nickel-copper alloy are both prepared by powder metallurgy, but copper-tungsten alloy is usually prepared by infiltration (first sintering the tungsten skeleton, then infiltrating liquid copper), which is complex and energy-intensive. Tungsten-nickel-copper alloy uses liquid phase sintering, which is more flexible and can achieve complex shapes through MIM, making it suitable for miniaturized components (such as medical collimators and MEMS counterweights). Copper-tungsten alloy is difficult to process because of its high hardness and soft copper phase, which can easily lead to uneven surfaces, while the toughness of tungsten-nickel-copper alloy makes it more advantageous in precision machining. Copper-tungsten alloy has a high copper content, and the sintering atmosphere needs to be strictly controlled to prevent oxidation, which increases the process cost.

**Applicable scenarios and advantages and disadvantages :** Copper-tungsten alloy is widely used in the electronics industry (such as power semiconductor packaging, electrical contacts) and high-temperature components (such as rocket nozzle linings) due to its excellent thermal conductivity and electrical conductivity, but its lower density and poor toughness limit its application in high-density counterweights or high-impact scenarios. Tungsten-nickel-copper alloy has more advantages in medical (radiotherapy shielding, MRI counterweights), national defense (radar decoys, missile counterweights) and new energy vehicles (motor counterweights). Its high density and toughness meet complex mechanical and electromagnetic requirements. The cost of copper-tungsten alloy fluctuates greatly due to its high copper content, while the cost of tungsten-nickel-copper alloy is affected by the prices of nickel and copper, and the ratio needs to be optimized to reduce economic pressure. Optimization directions include improving the toughness of copper-tungsten alloys through composite coatings, or using nano-scale tungsten powder to improve the performance of tungsten-nickel-copper alloys.

## 10.2 Research and Development of Cutting-Edge Technology for Tungsten-Nickel-Copper Alloy

As the demand for high-performance materials grows, the research and development of tungsten-nickel-copper alloys is shifting from traditional performance optimization to microstructure design and functional innovation. Nanostructured alloys significantly improve the strength, toughness and thermal conductivity of materials by reducing the size of powder particles to the nanoscale, making them suitable for high-precision and extreme environment applications. Functional gradient materials achieve customized performance by introducing a gradual distribution of composition or structure within the alloy to meet complex and multifunctional needs. These technologies promote

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new applications of tungsten -nickel-copper alloys in the medical, electronic, defense and energy fields through advanced preparation processes, providing support for the next generation of high-performance components.

### 10.2.1 Nanostructured Alloys

Nanostructured tungsten -nickel-copper alloys are prepared using nanoscale tungsten, nickel and copper powders , which significantly improve the microstructure and properties of the alloy . Nanoscale particles have high specific surface area and surface activity, which can form a more uniform microstructure during sintering, reduce porosity, and improve density, strength and toughness. Compared with traditional micron-scale tungsten-nickel-copper alloys, the mechanical properties of nanostructured alloys are significantly improved, because the grain boundary strengthening effect of nanoparticles enhances impact resistance and fatigue resistance. Non-magnetic properties are retained, which is suitable for applications with high electromagnetic compatibility requirements (such as MRI equipment, radar systems). In addition, the uniform distribution of nanoscale particles improves thermal conductivity, making the alloy perform better in heat dissipation applications (such as power semiconductor substrates, 5G RF modules). The fine grains of the nanostructure also reduce the coefficient of thermal expansion, further improving dimensional stability.

**Preparation method :** Nanostructured alloys are usually prepared by high-energy ball milling, chemical vapor deposition (CVD) or plasma-assisted method to prepare nanoscale powders, and then dense alloys are formed by powder metallurgy processes (such as liquid phase sintering or spark plasma sintering, SPS). High-energy ball milling refines powder particles to nanoscale by mechanical grinding, and the grinding time and environment (high-purity argon or vacuum) must be controlled to avoid the introduction of impurities. SPS technology uses high voltage and pulsed current to quickly sinter nanopowders, shorten sintering time, inhibit grain growth, and maintain nanostructure characteristics. Hot isostatic pressing (HIP) further improves density and eliminates micropores. Precision machining (such as laser micromachining) achieves complex shapes, and surface treatment enhances corrosion resistance and biocompatibility. The preparation process requires strict control of powder purity and sintering conditions to ensure the stability and performance consistency of the nanostructure.

**Applications and Advantages :** Nanostructured tungsten -nickel-copper alloys have significant advantages in high-precision applications. For example, in the medical field, nanostructured alloys are used in radiotherapy collimator components to improve radiation shielding efficiency and dimensional accuracy; in the electronic information field, the excellent thermal conductivity of nanoalloys makes them suitable for high-power server heat dissipation bases; in the defense field, high-strength nanoalloys can be used in missile balance components to enhance impact resistance. Optimization directions include developing more efficient nanopowder preparation technology, using composite nanocoatings to further improve performance, or combining additive manufacturing to achieve complex nanostructures. The challenge lies in the high cost of

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nanopowders and oxidation control during the preparation process, which requires the use of automated equipment and online monitoring technology to improve production efficiency.

### 10.2.2 Functionally Graded Materials

Functionally graded materials (FGMs) achieve a smooth transition from high density to high thermal conductivity or high toughness by introducing a gradual distribution of composition or structure inside tungsten-nickel-copper alloys to meet the needs of multifunctional components. The uniform composition of traditional tungsten -nickel-copper alloys limits their adaptability under complex working conditions, while FGMs optimize performance through gradient design (such as a gradual change in tungsten content from high to low, or a regional change in the nickel-copper ratio). For example, high-copper content areas near the surface can improve thermal conductivity and are suitable for heat dissipation needs; internal high-tungsten content areas provide high density to meet weight requirements. The non-magnetic properties of FGM are retained, making it suitable for electromagnetically sensitive environments; the gradient structure also enhances thermal shock resistance and interface bonding, making it suitable for high temperature or high stress scenarios.

**Preparation method** : FGM tungsten -nickel-copper alloys are usually prepared by layered powder stacking combined with liquid phase sintering or additive manufacturing technology. Layered powder stacking forms a gradient structure by placing tungsten, nickel, and copper powders of different composition ratios in a mold layer by layer (such as a gradient from a high tungsten layer to a high copper layer), and then forms a gradient structure through liquid phase sintering. The temperature and atmosphere must be precisely controlled during the sintering process to ensure interface bonding. Additive manufacturing (such as selective laser melting, SLM) directly constructs a gradient structure by depositing powders of different compositions layer by layer, which is suitable for complex-shaped parts. Hot isostatic pressing further improves density and eliminates micropores in the gradient interface. Precision machining (such as CNC milling or electrospark machining) achieves precise geometry, and surface treatment (such as chemical passivation or PVD coating) enhances corrosion resistance and biocompatibility. The preparation process requires optimization of powder distribution and sintering parameters to avoid stress concentration at the gradient interface.

**Applications and Advantages** : Functionally gradient tungsten -nickel-copper alloys have significant advantages in multifunctional components. For example, in the heat dissipation substrate of new energy vehicle battery packs, the high copper content on the surface improves thermal conductivity, and the high tungsten content inside provides structural support; in medical radiotherapy shielding covers, the gradient structure optimizes radiation shielding and lightweight; in aerospace weapon nozzle components, the gradient design enhances thermal shock resistance. Optimization directions include developing more precise gradient control technologies (such as multi-material 3D printing), using composite coatings to improve surface properties, or optimizing gradient distribution through simulation. The challenge lies in the high preparation cost and the stability of the gradient interface, which needs to be reduced through automated production and

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online monitoring.

### 10.3 Green Manufacturing Technology of Tungsten-Nickel-Copper Alloy

tungsten -nickel-copper alloys involves high-energy powder metallurgy processes and chemical treatments, which may produce waste gas, waste liquid and solid waste, placing a certain burden on the environment. Green manufacturing technology significantly reduces environmental impact by improving preparation processes and developing efficient waste recycling methods, while improving resource utilization and production efficiency. Environmentally friendly preparation processes achieve clean production by optimizing production processes, reducing the use of harmful chemicals and reducing energy consumption; waste recycling technology reduces resource waste and environmental pollution by recycling waste and scrapped parts in production. These technologies not only meet the requirements of environmental regulations, but also enhance the market competitiveness of tungsten-nickel-copper alloys in fields such as medical, electronics and defense, providing a new path for sustainable manufacturing.

#### 10.3.1 Environmentally friendly preparation process

The environmentally friendly preparation process aims to create a clean and efficient manufacturing process by optimizing the production process of tungsten -nickel-copper alloy, reducing energy consumption, exhaust emissions and the use of harmful chemicals. Traditional powder metallurgy processes involve high-energy sintering and chemical cleaning steps, which may produce oxide exhaust gas or acidic waste liquid. The environmentally friendly preparation process significantly reduces environmental impact by adopting low-energy sintering technology, green binders and clean processing methods. Low-energy sintering technology uses fast sintering methods such as spark plasma sintering (SPS), which heats quickly through pulsed current and high pressure to shorten sintering time and reduce energy consumption while maintaining the density and performance of the alloy. Green binders use degradable or non-toxic materials to replace traditional paraffin or polymer binders, reduce volatile organic compound emissions in metal injection molding (MIM), and reduce exhaust gas pollution during degreasing. Clean processing methods reduce harmful waste liquids during processing by using water-based coolants instead of oil-based coolants, while optimizing precision machining processes to reduce dust and waste generation.

Environmentally friendly preparation processes also focus on the control of the production environment. By sintering and processing in a high-purity inert gas or vacuum environment, the oxidation of tungsten, nickel, and copper powders is prevented and the generation of oxide waste gas is reduced. The wastewater recycling treatment system collects and purifies the cleaning fluid in production to reduce water waste and environmental pollution. Process optimization also includes the use of automated control systems to accurately control sintering temperature and atmosphere, improve production consistency, and reduce waste caused by process errors. The advantage of environmentally friendly preparation processes is that while reducing energy consumption and emissions, they maintain the high density, non-magnetism, and thermal conductivity of the alloy to

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meet the needs of medical radiotherapy shielding, electronic heat dissipation substrates, and national defense counterweight components. Optimization directions include developing more efficient rapid sintering technology, exploring the application of bio-based binders, and integrating intelligent manufacturing systems to further improve production efficiency.

### 10.3.2 Waste recycling technology

Reduces resource waste and environmental pollution and improves the economic and sustainability of materials by recycling waste materials (such as powders, chips) and scrapped parts (such as medical shielding parts and counterweights) in the production of tungsten -nickel-copper alloys. Traditional recycling methods may involve high-energy smelting or chemical treatment, which produces secondary pollution. Green waste recycling technology achieves high recovery rates and low environmental impact through physical separation, chemical purification and efficient reuse processes. Physical separation uses mechanical grinding and screening to initially separate the tungsten, nickel and copper components in the waste, reducing the need for chemical treatment. Chemical purification uses environmentally friendly solvents (such as water-based solutions or low-toxic acid liquids) to separate and purify metal components, avoiding the waste gas and waste liquid generated by traditional strong acid or high-temperature smelting. The efficient reuse process re-proportions the recovered metal powder for powder metallurgy or MIM processes to prepare new alloy parts and maintain performance consistency.

Waste recycling technology also includes the recycling of scrapped parts. By disassembling and sorting scrapped medical collimators, electronic heat sinks or defense counterweights, usable tungsten-nickel-copper materials are extracted, which are then cleaned, ground and re-sintered to convert them into high-quality powder raw materials. The recycling process must be carried out in a clean environment to avoid impurity contamination that affects the non-magnetic and biocompatibility of the alloy. Advanced online monitoring technology is used to detect the composition and purity of the recycled powder to ensure that it meets production standards. The advantage of waste recycling technology is that it significantly reduces dependence on primary tungsten, nickel and copper minerals, reduces the environmental impact of mining and refining, and reduces the accumulation of solid waste. Optimization directions include developing more efficient separation technologies (such as electromagnetic sorting or laser sorting), exploring closed-loop recycling systems, and integrating additive manufacturing technology to directly use recycled powders for complex component production.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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## Chapter 11 Common Problems and Solutions of Tungsten Nickel Copper Alloy

Tungsten -nickel-copper alloy is widely used in aerospace, medical, electronic information, defense and energy fields due to its high density, non-magnetic properties, excellent thermal conductivity and low thermal expansion coefficient. Prepared by powder metallurgy, the alloy combines the high density of tungsten with the toughness and thermal conductivity of the nickel-copper bonding phase to meet the needs of high precision and harsh environments. However, a variety of problems may be encountered during the preparation process, such as sintering defects, uneven composition or processing difficulties, which affect the performance and reliability of the alloy. Solving these problems requires optimizing process flows, improving equipment control and adopting advanced technologies to ensure the high quality and consistency of the alloy.

### 11.1 Preparation process of tungsten-nickel-copper alloy

Tungsten -nickel-copper alloy mainly relies on powder metallurgy process, including powder mixing, pressing, sintering and post-processing. Problems may arise in each link due to improper raw materials, equipment or process parameters. Sintering, as a key step, directly affects the density, microstructure and performance of the alloy, but it is prone to defects such as porosity, cracks or component segregation. These problems may lead to decreased mechanical properties, insufficient thermal conductivity or damaged non-magnetic properties of the alloy, affecting its application in medical shielding parts, electronic heat dissipation substrates or national defense counterweight components. Solving the preparation process problems requires starting with raw material selection, process optimization and quality control to ensure that the alloy performance meets the needs of high-demand applications.

#### 11.1.1 Sintering Defect Solutions

Sintering defects are common problems in the preparation process of tungsten-nickel-copper alloys, mainly manifested as pores, cracks, composition segregation or uneven sintering. These defects will reduce the density, mechanical properties and thermal conductivity of the alloy, affecting its reliability in high-precision applications. Porosity is usually caused by incomplete filling of the gaps between powder particles or residual gas, which may lead to insufficient density and weaken the radiation shielding or counterweight effect. Cracks are often caused by thermal stress or uneven cooling rate during sintering, affecting the toughness and durability of the alloy. Composition segregation is caused by uneven distribution of tungsten, nickel and copper powders or insufficient fluidity during liquid phase sintering, which may lead to inconsistent local properties, such as reduced thermal conductivity or impaired non-magnetic properties. Uneven sintering is related to improper temperature gradient or atmosphere control in the furnace, which affects the uniformity of the alloy's microstructure.

**Solution :** For sintering defects, they can be solved by optimizing raw material selection, improving sintering process and strengthening process control. Use high-purity, uniform particle size tungsten,

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nickel and copper powders to ensure that the chemical composition and physical properties of the powders are consistent and reduce the occurrence of porosity and segregation. Use high-energy ball milling or mechanical alloying technology to mix powders to improve the uniformity and contact area of particles and promote the wetting and filling effect of nickel and copper phases during liquid phase sintering. Optimize sintering process parameters, adopt a staged temperature rise sintering strategy, slowly heat to the liquid phase sintering temperature, so that the nickel and copper liquid phase can flow fully, fill the gaps between tungsten particles, and reduce pore formation; at the same time, control the cooling rate to avoid cracks caused by thermal stress. Use high-purity inert gas (such as argon) or vacuum environment for sintering to prevent oxide formation and maintain the non-magnetic and thermal conductivity of the alloy. Introduce rapid sintering technology, such as spark plasma sintering (SPS), which uses pulsed current and high pressure to quickly heat, shorten sintering time, inhibit grain growth, and reduce porosity and segregation.

Strengthen the quality control during the sintering process, and use an online monitoring system to detect the temperature, atmosphere and pressure in the furnace in real time to ensure the stability of the sintering conditions. Hot isostatic pressing (HIP) is used as a post-processing process to further eliminate residual pores and microcracks through high temperature and high pressure, improve the density and uniformity of the alloy, and is particularly suitable for high-demand applications such as medical collimators or aerospace counterweight components. Regularly calibrate the sintering equipment to ensure a uniform temperature field in the furnace and avoid uneven sintering caused by local overheating or cold areas. In addition, combine simulation technology to optimize sintering parameters, predict liquid phase flow and stress distribution, and reduce trial and error costs. The advantage of the solution is that it significantly improves the density, mechanical properties and performance consistency of the alloy to meet the strict requirements of the medical, electronic and defense fields. Optimization directions include developing more efficient rapid sintering equipment, exploring automated control systems to improve process stability, and integrating additive manufacturing technology to directly prepare complex shapes and reduce subsequent processing defects. In the future, by combining with green manufacturing technology, the sintering process can further reduce energy consumption and emissions and promote the sustainable development of tungsten -nickel-copper alloys.

### 11.1.2 Composition uniformity control

The problem of composition uniformity is a common challenge in the preparation of tungsten-nickel-copper alloys. It refers to the uneven distribution of tungsten, nickel, and copper components in the alloy, which may lead to local density differences, reduced thermal conductivity, or impaired non-magnetic properties. Compositional inhomogeneity is usually caused by insufficient powder mixing, particle size differences, or poor fluidity during liquid phase sintering. The high density of tungsten makes it easy to settle during the powder mixing process, while the uneven distribution of the nickel-copper binding phase may cause local segregation after sintering, affecting the performance consistency of the alloy. For example, in medical radiotherapy shielding parts, uneven composition may reduce the radiation shielding effect; in electronic heat sinks, it may cause unstable

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thermal conductivity and affect the heat dissipation efficiency.

**Solution :** To ensure the uniformity of composition, this can be solved by optimizing powder selection, improving powder mixing process and strengthening sintering control. Select high-purity tungsten, nickel and copper powders with consistent particle size to reduce particle sedimentation and stratification tendency and ensure uniformity in the initial stage of mixing. Use high-energy ball milling or mechanical alloying technology for powder mixing. Through long-term high-intensity grinding, the tungsten, nickel and copper particles are fully dispersed, the contact uniformity between particles is enhanced, and the introduction of impurities is avoided. Use three-dimensional powder mixing equipment or ultrasonic-assisted powder mixing to further improve the dispersion and fluidity of the powder and reduce sedimentation. Optimize the liquid phase sintering process, and control the melting and flow of the nickel-copper liquid phase through a staged heating strategy to ensure that it fully wets the tungsten particles, fills the gaps between particles, and reduces segregation. Use high-purity inert gas or vacuum environment during the sintering process to prevent copper oxidation from causing composition imbalance.

Strengthening process control is the key to ensuring composition uniformity. An online monitoring system is used to detect the powder mixing degree and composition distribution during sintering in real time, and the uniformity is verified by X-ray fluorescence analysis or electron microscopy. Hot isostatic pressing (HIP) is a post-processing process that eliminates local segregation and micropores through high temperature and high pressure, improves the density and composition consistency of the alloy, and is particularly suitable for high-precision applications such as aerospace counterweights or medical collimators. Regularly calibrate powder mixing and sintering equipment to ensure stable process parameters and avoid composition inhomogeneity caused by equipment deviation. In addition, simulation technology is combined to optimize powder mixing and sintering parameters, predict liquid flow and composition distribution, and reduce test costs. The advantage of the solution is that it significantly improves the performance consistency of the alloy to meet the stringent requirements of the medical, electronic and defense fields. Optimization directions include developing an automated powder mixing system , exploring nano-scale powders to further improve uniformity, and integrating additive manufacturing technology to directly control composition distribution.

## 11.2 Application Failure Analysis of Tungsten-Nickel-Copper Alloy

Tungsten -nickel-copper alloys may fail in demanding applications (such as medical radiotherapy shielding, electronic heat dissipation substrates, and defense counterweight components) due to material defects, environmental factors, or improper use, resulting in performance degradation or component damage. Application failures may manifest as insufficient mechanical properties, reduced thermal conductivity, surface corrosion, or dimensional instability, affecting the safety and reliability of the equipment. For example, in medical equipment, failures may lead to reduced radiation shielding effectiveness; in electronic devices, overheating failures may occur; in defense equipment, counterweight accuracy or impact resistance may be affected. Analyzing the causes of

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failure and proposing solutions are the key to improving the reliability of alloy applications, starting with material preparation, environmental adaptability, and usage conditions.

**Failure causes and solutions :** Common causes of application failure include preparation defects, environmental erosion, and mechanical overload. Preparation defects such as pores, cracks, or uneven composition directly weaken the mechanical properties and thermal conductivity of the alloy. Defects can be eliminated by optimizing the sintering process (such as spark plasma sintering) or using hot isostatic pressing to ensure a dense and uniform microstructure. Environmental erosion is mainly caused by moisture, chemical disinfection, or high-temperature oxidation, leading to surface corrosion or performance degradation, especially in medical equipment or marine environments. Solutions include using corrosion-resistant surface treatments such as PVD TiN coatings or chemical passivation to form a dense protective layer to enhance oxidation and corrosion resistance; while optimizing alloy composition and increasing the nickel-copper ratio to improve corrosion resistance. Mechanical overload is common in high-impact or vibration scenarios (such as missile counterweights, armor protection), which may cause cracks or deformation. Impact resistance can be enhanced by improving alloy toughness (such as using nanostructured design) or optimizing component geometry (such as adding fillets or gradient structures).

Environmental adaptability is the focus of failure analysis. In high temperature or thermal cycle environments, thermal stress may cause dimensional instability or interface peeling, affecting the performance of heat dissipation substrates or shielding components. Solutions include the use of low thermal expansion coefficient formulation design, combined with functional gradient materials (FGM) to optimize thermal stress distribution. Electromagnetic interference may cause non-magnetic failure, especially in MRI equipment or radar systems, which can be ensured by strictly controlling the iron impurity content and online magnetization testing. Improper use, such as overload operation or installation not in accordance with design requirements, may cause component failure, and human errors need to be reduced through user training and standardized installation processes. Quality control uses scanning electron microscopy to analyze microstructure, salt spray test to verify corrosion resistance, and vibration test to evaluate mechanical properties to ensure that components meet application standards. The advantage of the solution is to comprehensively improve the reliability and life of the alloy to meet the demanding requirements of the medical, electronic and defense fields. Optimization directions include developing self-healing coatings to cope with environmental erosion, exploring intelligent monitoring technology to detect failure risks in real time, and integrating additive manufacturing technology to customize anti-failure structures.

### 11.2.1 Thermal Cycle Failure Solutions

Thermal cycle failure is a common failure mode of tungsten-nickel-copper alloy in high temperature or temperature difference environment, which manifests as microcracks, interface peeling or dimensional deformation caused by repeated thermal expansion and contraction, affecting the structural integrity and performance stability of the alloy. Thermal cycle failure is mainly caused by

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thermal stress. When the alloy undergoes rapid temperature changes in high temperature operation or extreme temperature difference environment, stress concentration occurs inside the material or at the interface with the matrix due to differences in thermal expansion coefficients, which may lead to crack propagation or component failure. For example, in the detector shield of a medical CT machine, thermal cycling may cause deformation of the shielding component and reduce the radiation shielding effect.

**Solution :** Thermal cycle failure can be solved by optimizing alloy composition, improving microstructure and adopting advanced processes. Adjust the nickel-copper ratio and increase the copper content to improve thermal conductivity, accelerate heat dispersion, reduce local temperature differences and reduce thermal stress accumulation. Use functional gradient material (FGM) design to optimize thermal expansion coefficient matching and relieve interface stress by introducing a gradual distribution of tungsten, nickel and copper content inside the alloy. It is particularly suitable for heat dissipation substrates or shielding parts combined with silicon, ceramics and other substrates. Introduce nanostructured alloys and use the grain boundary strengthening effect of nano-scale particles to enhance thermal fatigue resistance and reduce the formation of microcracks. Optimize the sintering process and use spark plasma sintering (SPS) to quickly form a dense structure and reduce pores and stress concentration points; hot isostatic pressing (HIP) further eliminates micropores and improves the alloy's thermal shock resistance.

Surface treatment is an important measure to deal with thermal cycling failure. Applying high-performance coatings to form a thermal barrier layer can reduce the impact of thermal shock on the alloy surface, while enhancing the interfacial bonding force to prevent peeling. Optimize component geometry design, such as increasing fillets or gradient thickness, to disperse thermal stress and reduce the risk of cracks. Quality control simulates actual use conditions through thermal cycle tests, combined with scanning electron microscopy to analyze micro cracks and verify the thermal stability of the alloy. The advantage of the solution is that it significantly improves the reliability of the alloy in high temperature and temperature difference environments, meeting the stringent requirements of the medical, electronic and aerospace fields. Optimization directions include developing adaptive coatings to dynamically relieve thermal stress and exploring 3D printing technology to manufacture complex gradient structures.

### 11.2.2 Environmental corrosion protection

Environmental corrosion is a common failure mode of tungsten-nickel-copper alloys in humid, chemically sterilized or high-temperature oxidizing environments, which manifests as surface oxidation, corrosion pits or material degradation, affecting the performance and life of the alloy. Corrosion is mainly caused by environmental factors such as humidity, salt spray or chemical cleaning agents, especially in medical equipment (frequent disinfection is required), marine environments (such as shipborne radar counterweights) or high-temperature applications (such as rocket nozzle components). Copper as a bonding phase is susceptible to oxidation or chemical attack, resulting in surface roughness, decreased thermal conductivity or impaired non-magnetic properties.

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For example, in medical radiotherapy shielding covers, corrosion may reduce the radiation shielding effect; in new energy vehicle motor counterweights, it may cause surface wear and affect dynamic balance.

**Solution** : Environmental corrosion can be solved by optimizing alloy composition, applying protective coatings and improving environmental management. Increasing nickel content or optimizing nickel-copper ratio can enhance the corrosion resistance of the bonding phase and reduce the oxidation tendency of copper in humid or chemical environments. Surface treatment technology, such as PVD TiN or CrN coating, can be used to form a dense protective layer to isolate oxygen, moisture and chemicals, significantly improving corrosion resistance; chemical passivation treatment can further enhance oxidation resistance and biocompatibility by forming an oxide protective film on the surface, which is suitable for medical prostheses or surgical navigation components. Electrochemical polishing optimizes surface finish, reduces corrosion starting points and improves corrosion resistance.

Improve the preparation process to reduce corrosion sensitivity. Use high-purity raw materials and clean sintering environment (such as vacuum or high-purity argon) to prevent the introduction of impurities (such as iron or oxygen) and maintain the non-magnetic and corrosion-resistant properties of the alloy. Hot isostatic pressing (HIP) increases the density of the alloy and reduces the possibility of pores as the starting point of corrosion. Optimize the use environment management, such as using neutral disinfectants instead of strong acid and alkali cleaners in medical equipment to reduce chemical corrosion; combine sealing design in marine environments to isolate salt spray and humidity. Quality control verifies corrosion resistance through salt spray tests, wet heat cycle tests and surface analysis (SEM or XPS) to ensure compliance with medical and military standards. The advantage of the solution is that it significantly extends the life of the alloy in harsh environments and meets the reliability requirements of the medical, electronic and defense fields. Optimization directions include developing self-healing coatings to dynamically repair corrosion damage, exploring nano-composite coatings to improve protection efficiency, and integrating online monitoring technology to evaluate the corrosion status in real time.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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### Tungsten Nickel Copper Alloy Introduction

#### 1. Overview of Tungsten Nickel Copper Alloy

Tungsten nickel copper alloy is an alloy composed of tungsten with added nickel and copper, typically in a nickel-to-copper ratio of 3:2. This alloy is non-ferromagnetic, exhibits relatively good electrical and thermal conductivity, and is commonly used in specialized applications such as gyroscope rotors, components for devices and instruments operating under magnetic fields, electrical contacts for high-voltage switches, and electrodes for certain electrical machining processes.

#### 2. Features of Tungsten Nickel Copper Alloy

**High Density:** Typically 16.5 – 18.75 g/cm<sup>3</sup>

**High Thermal Conductivity:** Approximately 5 times that of mold steel

Compared to tungsten-nickel-iron alloy, since copper does not have the sintering activation effect of nickel and iron on tungsten, tungsten-nickel-copper alloy has a slightly lower sintered density, lower strength and plasticity, and is generally not subjected to heat treatment or deformation processing.

#### 3. Production Methods for Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy is typically produced using powder metallurgy. First, high-purity tungsten, nickel, and copper powders are mixed in specific proportions, often using equipment like a ball mill to achieve uniform mixing. The mixture is then pressed into shape, commonly using cold isostatic pressing technology under a specific pressure to form a green compact. Subsequently, sintering is performed, generally in a hydrogen protective atmosphere, using a two-step sintering process to address collapse and deformation issues caused by liquid-phase sintering, ensuring the product's density.

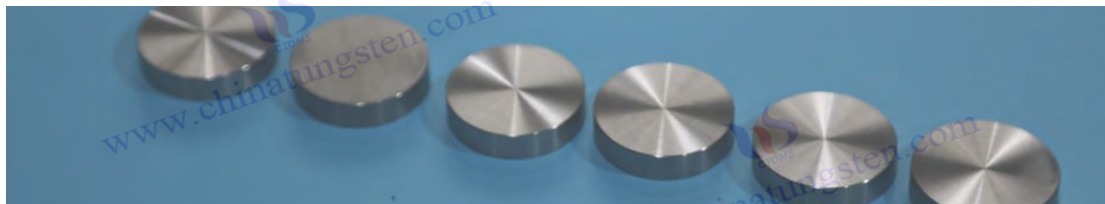
#### 4. Applications of Tungsten Nickel Copper Alloy

Tungsten-nickel-copper alloy, with its high density and excellent thermal and electrical conductivity, has a wide range of applications. In the aerospace sector, it can be utilized to manufacture components such as rocket engine nozzles and gas rudders. In the medical field, due to its strong radiation absorption capability and non-magnetic properties, it is suitable for radiation shielding in magnetic resonance imaging rooms. Additionally, it can serve as a counterweight material for precision instruments.

#### 5. Purchasing Information

Email: [sales@chinatungsten.com](mailto:sales@chinatungsten.com); Phone: +86 592 5129595; 592 5129696

Website: [www.tungsten-alloy.com](http://www.tungsten-alloy.com)



CTIA GROUP LTD tungsten nickel copper alloy

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Appendix

Tungsten Nickel Copper Alloy Terminology

The term	Definition and Explanation
Powder Metallurgy	Process for preparing metal materials by mixing metal powders, pressing and sintering for the production of tungsten -nickel-copper alloys, ensuring high density and homogeneous microstructure.
Liquid Phase Sintering	During the sintering process, the nickel-copper phase melts at high temperature to form a liquid, which wets the tungsten particles and fills the gaps, thereby improving the density and performance of the alloy.
Hot Isostatic Pressing (HIP)	A process that treats alloys under high temperature and high pressure under omnidirectional pressure to eliminate micropores and defects and improve density and mechanical properties.
Metal Injection Molding (MIM)	A process for preparing complex-shaped, high-precision parts by mixing metal powder with a binder, debinding and sintering after injection molding, suitable for miniaturization applications.
High Density	tungsten -nickel-copper alloys refer to their high mass per unit volume, making them suitable for counterweight and shielding applications, such as medical radiotherapy shielding parts and aerospace counterweights.
Non-magnetic	The alloy does not generate magnetic fields or is not disturbed by magnetic fields, making it suitable for electromagnetically sensitive environments such as MRI equipment and radar systems.
Thermal conductivity	The alloy's ability to transfer heat, and the addition of the copper phase makes it excel in heat dissipation applications (such as electronic heat sinks, battery substrates).
Low coefficient of thermal expansion	The alloy's small dimensional change under temperature changes ensures geometric stability during thermal cycles and is suitable for high-precision components.
Functionally Graded Materials (FGM)	Materials with optimized performance through compositional or structural gradient design, such as the combination of a high-density core and a high thermal conductivity surface layer.
Nanostructured alloys	The alloy is made from nano-scale powder and has a fine grain structure, which improves strength, toughness and thermal conductivity.
Sintering defects	The pores, cracks or component segregation produced during the sintering process affect the performance and can be solved by optimizing the process and post-treatment.
Composition uniformity	The uniform distribution of tungsten, nickel and copper in the alloy ensures consistent performance, which is controlled by high-energy ball milling and online monitoring.
Thermal Cycling	Cracks or interfacial debonding caused by repeated temperature changes can be

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Failure	alleviated by gradient design and coating.
Environmental corrosion	Surface oxidation or degradation caused by humid or chemical environments can be optimally protected by corrosion-resistant coatings and components.
Biocompatibility	not cause adverse reactions when in contact with human tissue makes it suitable for medical applications such as prosthetics and surgical navigation components.



CTIA GROUP LTD Tungsten Nickel Copper Alloy

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