What Is Tungsten 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

INTRODUCTION TO CTIA GROUP

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

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

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

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

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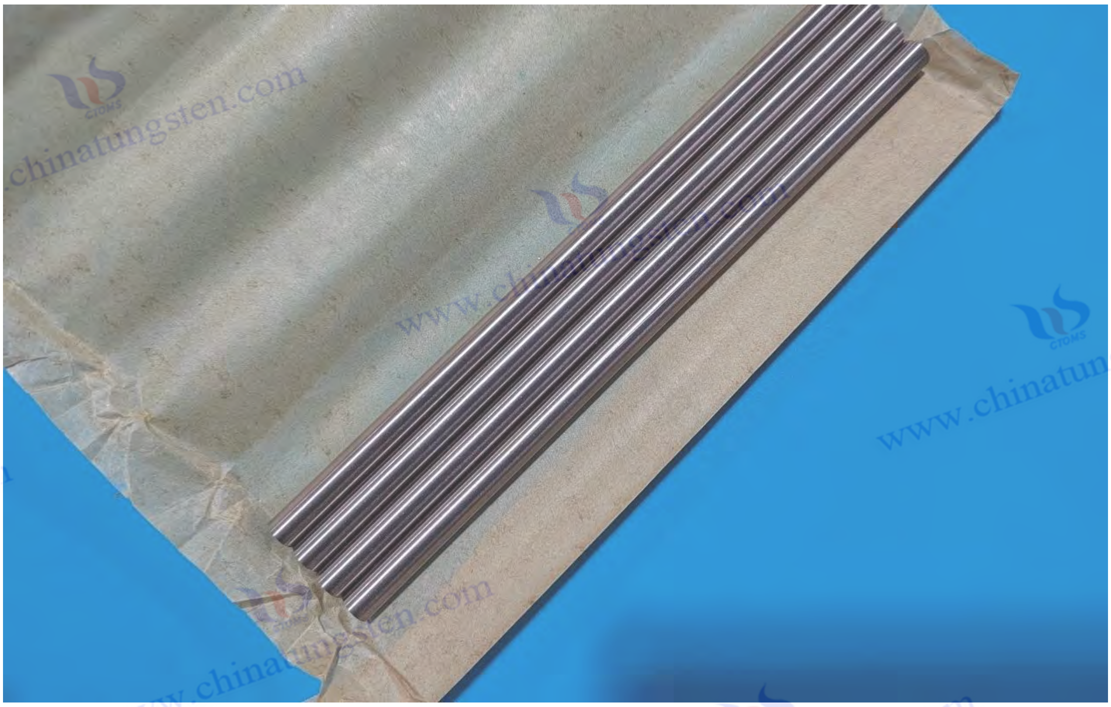

CTIA GROUP LTD Tungsten Copper Alloy

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Tungsten Copper Alloy Introduction

1. Overview of Tungsten Copper Alloy

Tungsten Copper Alloy is a composite material made from tungsten and copper, typically containing 10% to 50% copper by weight. This alloy combines the outstanding properties of both metals—retaining tungsten's high-temperature resistance and excellent arc erosion resistance, while benefiting from copper's superior thermal and electrical conductivity. It delivers exceptional comprehensive performance in high-end fields such as electrical engineering, power systems, electronics, and aerospace. CTIA GROUP LTD offers a wide range of customized tungsten copper alloy solutions, featuring high density, stable performance, and precise processing tailored to customer requirements for components such as electrodes, thermal management parts, and vacuum system elements.

2. Typical Properties of Tungsten Copper Alloy

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm³)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten Copper Alloys

Power Equipment: Contacts for high-voltage vacuum switches; Conductive parts for circuit breakers; Components for high-power relays and arc-fault interrupters

Electronics and Semiconductor Industry: Heat-dissipating substrates for IGBT modules; Cooling plates for microwave components; Package lids and electronic base plate

Electrical Discharge Machining (EDM): Electrode materials for EDM, especially suitable for machining hard alloy molds; High-precision forming electrodes for fine EDM processes

Aerospace and Defense: High-temperature structural parts such as rocket nozzles and tail cones

4. Purchasing Information

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Chapter 1 Introduction

1.1 Overview of Tungsten Copper Alloy

As a composite material composed of tungsten and copper , tungsten copper alloy combines the core advantages of both metals and occupies an irreplaceable position in the industrial field. Tungsten's high melting point (3422℃), high strength, high hardness and excellent wear resistance complement copper's high electrical conductivity, high thermal conductivity and good plasticity, making tungsten copper alloy able to withstand the test of high temperature environment and maintain stable electrical and thermal conductivity. Therefore, it is widely used in many key fields such as electronics, electricity, aerospace, and national defense.

From the perspective of material properties, the performance of tungsten-copper alloy is not a simple superposition of "tungsten + copper", but through a reasonable composition ratio and preparation process, the performance is optimized and balanced. For example, in a high-temperature environment, the skeleton structure of tungsten can provide support for the alloy and resist high-temperature deformation, while copper can quickly conduct heat through its own thermal conductivity to avoid local overheating; in conductive scenarios, the conductive advantage of copper can be brought into play, and the addition of tungsten improves the overall strength of the alloy, avoiding the problem of pure copper being easy to wear and easy to deform. This "strong combination" feature makes tungsten-copper alloy an ideal material for dealing with complex working conditions.

With the continuous development of industrial technology, the performance requirements of materials are becoming increasingly stringent, and the research and application of tungsten copper alloys are also continuing to deepen. From the initial basic model to the special ratio alloys customized for different scenarios, its application scope is constantly expanding, and its performance is more accurately meeting various industrial needs. Next, we will have a deeper understanding of this special alloy from two aspects: definition and composition.

1.1.1 Definition of Tungsten Copper Alloy

Tungsten copper alloy refers to a pseudo alloy (i.e., two metals that are immiscible in the solid state and form a mechanically bonded composite material) made of tungsten (W) and copper (Cu) as the main components through processes such as powder metallurgy . Unlike traditional single metals or completely miscible alloys, in tungsten copper alloy , tungsten and copper exist in the form of a physical mixture - tungsten forms a continuous skeleton structure, and copper fills the pores of the tungsten skeleton. The two are combined through the interface to form a whole. Therefore, it retains the high melting point, high strength, high hardness and wear resistance of tungsten, and has the high electrical conductivity, high thermal conductivity and good plasticity of copper, achieving the characteristics of "high temperature resistance and electrical and thermal conductivity" and "balance between high strength and easy processing". From the core of the definition, the key to tungsten copper alloy lies in "composite advantages" and "process dependence". On the one hand, its performance is determined by the synergistic effect of tungsten and copper : for example, in electrospark machining, the high conductivity of tungsten copper alloy ensures that the electrode can efficiently transmit current, while the high melting point of tungsten prevents the electrode from melting in high-temperature spark discharge; in heat dissipation components, the thermal conductivity of copper is responsible for the rapid heat dissipation, and the high strength of tungsten ensures that the components are not easily deformed during installation and use. On the other hand, its definition also includes the direction of the preparation process - since tungsten and copper are not miscible in the solid state , they cannot be produced by smelting, and powder metallurgy (such as pressing, sintering, infiltration, etc.) must be used. This has also become one of the important characteristics that distinguish tungsten copper alloy from other alloys.

This definition not only clarifies the composition and structure of tungsten copper alloy , but also reveals its "custom-made" characteristics: by adjusting the content ratio of tungsten and copper , alloys with different properties can be prepared (such as alloys with high tungsten content focusing on high temperature resistance and high strength, and alloys with high copper content focusing on electrical conductivity and thermal conductivity), so as to meet the personalized needs of different fields such as electronic packaging, high-voltage switches, and aerospace engines. Therefore, the definition of tungsten copper alloy is not only a description of its material composition, but also a summary of its core feature of "structure determines performance, and performance adapts to the scene".

1.1.2 Alloy composition

tungsten copper alloy is based on tungsten (W) and copper (Cu), of which the tungsten content is usually between 50% and 90% (mass fraction), and the copper content is 10% to 50%. The specific ratio needs to be determined according to the performance requirements of the application scenario. In addition to the two main components of tungsten and copper , some tungsten copper alloys for special purposes will add trace amounts of other elements as auxiliary components to optimize the forming performance or specific functions of the material, but the content of these auxiliary elements usually does not exceed 1%, so it will not change the core component structure of "tungsten-copper".

From the perspective of the role of the main components, tungsten, as a high melting point metal (melting point 3422℃), is the main provider of alloy strength, hardness, high temperature resistance and wear resistance. The higher the tungsten content, the higher the melting point of the alloy, the greater the strength and hardness, and the better the high temperature resistance. For example, a tungsten copper alloy with a tungsten content of 90% can have a compressive strength of more than 800MPa, and can maintain structural stability in a high temperature environment above 1000℃, which is suitable for high-temperature components of aerospace engines. Copper, as a highly conductive and thermally conductive metal, is mainly responsible for giving the alloy electrical conductivity, thermal conductivity and a certain plasticity. The higher the copper content, the better the electrical and thermal conductivity of the alloy, and the better the processing performance. For example, a tungsten copper alloy with a copper content of 50% has a conductivity of more than 40×10^{6} S/m, which is suitable as a heat dissipation electrode in electronic packaging. The addition of auxiliary components is to improve process performance or make up for the deficiency of the main components. For example, adding trace amounts of nickel (Ni) can enhance the bonding force between tungsten particles and copper phases , avoiding the problem of separation of the tungsten skeleton and copper phase when the alloy is subjected to force ; adding a small amount of iron (Fe) or cobalt (Co) can improve the pressing performance of tungsten powder, making it easier for the alloy to obtain a dense structure during the molding process. However, the addition of auxiliary components needs to be strictly controlled in proportion, otherwise it may affect the performance of the main components - for example, excessive nickel will reduce the electrical and thermal conductivity of the alloy, and excessive iron may increase the brittleness of the alloy.

In general, the composition of tungsten-copper alloy is a typical example of "the main component determines the core performance, and the auxiliary component optimizes the process and details". By adjusting the tungsten-copper ratio , the strength, electrical and thermal conductivity, and high temperature resistance of the alloy can be precisely controlled, making it suitable for a variety of scenarios from electronic packaging to national defense and military industry; and the addition of trace auxiliary elements further improves the practicality and stability of the alloy, allowing this composite material to better cope with the complex needs of the industry.

1.2 Historical Origin and Development Process of Tungsten Copper Alloy

1.2.1 Early Exploration

tungsten-copper alloy can be traced back to the late 19th century and early 20th century. The research in this stage was not aimed at "tungsten-copper alloy", but originated from the separate study of the properties of tungsten and copper metals and the initial attempt of composite materials. At that time, the industrial revolution promoted the demand for high-strength and high-conductivity materials. Tungsten was paid attention to for its high melting point and high strength (especially in the field of incandescent lamp filaments), and copper became the core material of the electrical industry for its excellent electrical and thermal conductivity. However, the defects of both metals gradually emerged - pure tungsten was brittle and difficult to process, and pure copper was low in strength and poor in high temperature resistance. People began to think about "whether the advantages of the two metals can be combined by compounding them".

Early explorations were mainly small-scale laboratory trials, and the technical means were relatively primitive. Around 1900, German and American material researchers first mechanically mixed tungsten powder and copper powder, and made the earliest "tungsten-copper composite block" through simple pressing and sintering. Although a stable process was not formed, the feasibility of "tungsten-copper composite" was verified. However, the product performance at this stage was extremely poor: the combination of tungsten and copper was loose, the mechanical strength was insufficient, and the electrical and thermal conductivity did not meet expectations. In addition, due to the lack of precise control of powder particle size and sintering temperature, the yield rate was extremely low, and it remained only at the theoretical verification level and did not enter practical application.

What really pushed the early exploration towards application orientation was the needs of the military and electrical industries. In the 1920s, with the development of radio technology and artillery manufacturing, a material that could withstand instantaneous high temperatures and conduct electricity at the same time was needed (such as the electrodes of artillery electric ignition devices). Pure copper melts easily at high temperatures, and pure tungsten is not conductive enough. Researchers once again turned their attention to tungsten-copper composites . Around 1925, General Electric Company of the United States made the first batch of tungsten-copper products that could be used for simple electrodes by improving the powder mixing process (such as increasing the ball milling time to refine the powder). Although the performance was still unstable, it was the first time to "replace pure tungsten or pure copper in specific scenarios", becoming the starting point for tungsten-copper alloys to move from the laboratory to practical use. Although the exploration at this stage did not form a systematic technical system, it laid two foundations for subsequent research: first, it clarified the core direction of "tungsten-copper composites can balance strength and electrical and thermal conductivity"; second, it accumulated preliminary experience in powder mixing, pressing and sintering.

1.2.2 Key Technology Breakthrough Nodes

Tungsten-copper alloy is inseparable from a number of key technological breakthroughs, which have driven its transformation from "laboratory samples" to "industrial materials".

The first key node appeared in the 1940s. The maturity of the infiltration process solved the core problem of "loose bonding of tungsten and copper". The previous sintering process made it difficult for tungsten and copper to be fully combined, while the infiltration process (pre-sintering the tungsten skeleton and then infiltrating molten copper into its pores) greatly improved the density of the material. In 1943, in order to solve the high temperature resistance problem of aircraft machine gun ignition electrodes, the US military jointly optimized the infiltration process with scientific research institutions: by controlling the porosity of the tungsten skeleton (adjusted to 20%~30%) and the melting temperature of copper (accurate to 1100~1200℃), the density of the tungsten-copper alloy was increased to more than 95%, and the strength and conductivity were increased by 40% compared with before. It was successfully used in the ignition system of aircraft machine guns. This was the first time that tungsten-copper alloy was put into practical use on a large scale.

The second key node was the refinement of powder metallurgy technology in the 1960s. With the emergence of electron microscopes and precision temperature control equipment, researchers can accurately control the particle size of tungsten powder and copper powder (from the early 100 mesh to more than 500 mesh) and the sintering atmosphere (introducing inert gas protection to avoid oxidation). In 1962, Japan's Sumitomo Metal developed the "ultrafine powder + vacuum sintering" process, which made the tungsten particles in the tungsten-copper alloy more evenly distributed and the copper phase filled more completely. Not only the mechanical properties (compressive strength exceeded 600MPa) and electrical conductivity (conductivity reached more than 60% of pure copper) were stable, but also the processing of complex-shaped products (such as thin sheets and special-shaped electrodes) was realized, promoting its expansion from the military field to the electronics industry (such as the heat sink of early transistors).

The third key node was the introduction of the concept of "functional customization" in the 1980s. Previously , tungsten-copper alloys were mainly based on a single ratio, and the needs of different fields varied greatly - the aerospace field requires a high-temperature resistant type with a high tungsten content (more than 80%), and the electronics field requires a high-conductivity type with a high copper content (more than 50%). In 1985, the Beijing Research Institute of Nonferrous Metals in China established a "tungsten-copper ratio-performance correspondence model" to achieve customized composition according to demand: by adjusting the gradient ratio of tungsten content from 50% to 90%, combined with corresponding process parameters, the strength, conductivity and heat resistance of the alloy can be accurately controlled. This breakthrough has transformed tungsten-copper alloys from "general materials" to "scenario-adaptive materials", and its application range has expanded rapidly.

1.2.3 Modern Development Trends

Entering the 21st century, the development of tungsten-copper alloys has shown three major trends: "extreme performance, diversified applications, and intelligent processes", becoming one of the key materials in the field of high-end manufacturing. Extreme performance is the core direction of modern development. As the requirements for materials in the fields of chips, aerospace, and new energy have shifted from "meeting basic needs" to "breaking performance limits", the performance indicators of tungsten-copper alloys have been continuously refreshed: through nanopowder preparation technology (such as plasma ball milling), the particle size of tungsten powder can be controlled within 100 nanometers, and the interface with copper is closer. The conductivity of the latest product has reached more than 85% of pure copper, and the compressive strength has exceeded 1000MPa, far exceeding the level of the 20th century; in terms of high temperature resistance, tungsten-copper alloys with high tungsten content (90%) can maintain structural stability at 1200°C, and by adding reinforcing phases such as graphene, the wear resistance is increased by more than 30%, meeting the needs of extreme scenarios such as the fifth-generation mobile communication base station and aerospace engine combustion chamber.

The diversification of applications is reflected in the extension from traditional fields to high-end emerging fields. Traditionally, tungsten copper alloys are mainly used for electrical contacts, electrodes, etc., but now they have been expanded to: chip packaging (as a heat dissipation substrate for high-power chips, using high thermal conductivity to quickly remove heat), new energy vehicles (conductive contacts of on-board high-voltage relays, which can withstand high currents and arc erosion), and nuclear fusion experimental devices (as divertor materials to resist high-temperature plasma erosion). According to industry data, since 2020, the annual growth rate of global demand for tungsten copper alloys in the semiconductor field has exceeded 25%, becoming a new growth pole.

Intelligent technology is the technical foundation supporting modern development. Traditional tungsten copper alloy production relies on manual experience, but now the whole process is controllable through "digital twins" and automated production lines: from online particle size monitoring in the powder mixing stage, to real-time temperature-pressure regulation in the sintering process, to non-destructive testing of finished product performance, all can be completed through intelligent systems; the introduction of 3D printing technology has broken the molding limitations - in 2022, the Fraunhofer Institute in Germany used metal 3D printing technology to directly print tungsten copper heat dissipation components with complex internal flow channels. Structures that cannot be achieved by traditional processes can be mass-produced, providing new solutions for special-shaped and integrated components.

At the same time, modern development also faces challenges: as a strategic resource, tungsten has large price fluctuations, which has promoted the development of "tungsten copper alloy recycling and reuse" technology (the current recycling rate has reached more than 80%); the competition from alternative materials (such as silicon carbide ceramics and copper-aluminum composite materials) has also forced tungsten copper alloys to maintain their advantages through performance upgrades. In general, driven by the demand for high-end manufacturing, tungsten copper alloys are changing from "auxiliary materials" to "core materials", and their development is deeply bound to innovations in cutting-edge science and technology, and there is still broad room for breakthroughs in the future.

CTIA GROUP LTD Tungsten Copper Alloy

Chapter 2 Characteristics of Tungsten Copper Alloy

2.1 Analysis of the characteristics of tungsten copper alloy

Tungsten copper alloy originate from its unique composite structure and composition. It does not simply inherit the single properties of tungsten and copper , but forms a series of balanced and practical properties through the synergy of the two. From a macroscopic perspective, it has both good electrical and thermal conductivity similar to metals, and mechanical strength sufficient to cope with complex working conditions; from an application perspective, the core of its characteristics lies in "balance" - finding the critical point between hardness and toughness, high temperature resistance and electrical and thermal conductivity to adapt to industrial needs, which enables it to play a role in a variety of scenarios with demanding material properties. Whether in mechanical parts that require frequent friction or in electrical equipment that faces high temperatures and current shocks at the same time, the characteristics of tungsten copper alloy can be specifically reflected.

2.1.1 High hardness formation mechanism and advantages

Tungsten copper alloy is its distinctive feature that distinguishes it from pure copper and most copper alloys. The formation of this characteristic is closely related to the synergistic effect of the internal structure, and it also provides a basis for its application in wear-resistant scenarios. Unlike the soft properties of pure copper, the hardness of tungsten copper alloy does not come from the strengthening of a single component, but from performance optimization achieved through structural design. This allows it to maintain a certain plasticity while resisting deformation caused by external friction and extrusion, making it a material that is both practical and durable.

2.1.1.1 Microstructural mechanism

Tungsten copper alloy comes from its "skeleton-filling" microstructure. Inside the alloy, tungsten exists in the form of a continuous skeleton, which has a high inherent hardness. These tungsten particles are interconnected to form a rigid support network throughout the material, just like the steel skeleton in a building, providing basic hardness support for the alloy. Copper, as a filling phase, is evenly distributed in the pores of the tungsten skeleton. Although copper itself has a low hardness, its presence does not weaken the integrity of the tungsten skeleton - on the contrary, copper can fill the gaps between tungsten particles, reduce the "weak points" in the skeleton structure, and allow external pressure to be transmitted to the tungsten skeleton through the copper phase, avoiding structural damage caused by local stress concentration.

In addition, the interface bonding between tungsten and copper also has an important influence on hardness. During the preparation process, after proper process treatment, a stable bonding interface will be formed between the tungsten particles and the copper phase . This bonding can prevent the tungsten particles from sliding relative to each other when subjected to force, further strengthening the rigidity of the overall structure. Therefore, the high hardness of tungsten-copper alloy is not the result of the action

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of a single component, but the result of the combined action of the rigid skeleton of tungsten, the filling reinforcement of copper, and the interface bonding. This microstructure allows it to maintain structural integrity when subjected to external friction or extrusion.

2.1.1.2 Advantages of wear-resistant applications

Tungsten copper alloy makes it show obvious advantages in wear-resistant applications. The core is that it can resist the surface loss caused by long-term friction and extend the service life of components. In scenes that require frequent contact or relative movement, the surface of the material is prone to gradual wear due to friction, which eventually leads to changes in component size or functional failure. The high hardness of tungsten copper alloy can reduce this wear - when it comes into contact with other objects, the surface is not easily scratched or dented, and can maintain its original shape and dimensional stability for a long time.

At the same time, its wear-resistant advantage is also reflected in its adaptability to "fluctuations in friction conditions". In practical applications, the friction environment is often not constant, and there may be load changes, temperature fluctuations, etc. The hardness of tungsten copper alloy will not decrease significantly due to slight temperature increases or load changes, and it can continue to maintain wear resistance under complex conditions. For example, in some mechanical transmission parts, even if they are subjected to different degrees of friction impact for a long time, their surfaces can still remain flat, and the transmission accuracy will not be affected by excessive wear, which extends the maintenance cycle of related equipment and reduces the cost and downtime losses caused by component replacement.

2.1.1.3 Hardness comparison and advantages with other alloys

Compared with pure copper and common copper alloys, the hardness advantage of tungsten copper alloy is very obvious. Pure copper is soft in texture and is prone to surface deformation under slight external friction. Although the hardness of most copper alloys is increased by adding other elements, the overall hardness is still "medium to low" and it is difficult to cope with high-intensity friction scenarios. Tungsten copper alloy has much higher hardness than these materials due to the presence of tungsten skeleton, and its surface wear degree will be significantly lower under the same friction conditions.

Compared with pure tungsten, the hardness of tungsten copper alloy is slightly lower, but it has more advantages in practical applications. Although pure tungsten has extremely high hardness, it is brittle. If it is slightly impacted during friction, it is easy to break or peel off, which affects the wear resistance. The copper phase in tungsten copper alloy plays a certain "buffer" role. While maintaining a high hardness, it can absorb part of the impact energy and reduce the risk of brittle fracture. It is more suitable for the "friction + impact" composite scenario that may be encountered in actual working conditions.

Compared with some iron-based alloys, the hardness of tungsten copper alloy may not necessarily have an absolute advantage, but it is more competitive in performance other than hardness. Iron-based alloys tend to have poor electrical and thermal conductivity, while tungsten copper alloy can maintain high hardness while also having good electrical and thermal conductivity, which makes it an irreplaceable choice in scenarios where both wear resistance and electrical conductivity (or thermal conductivity) are required. For example, in some electrical components that need to resist contact friction and conduct current, iron-based alloys cannot meet the electrical conductivity requirements, while tungsten copper alloys can do both.

2.1.2 Principle and performance of arc erosion resistance

Arc erosion resistance is one of the core properties of tungsten copper alloy that is widely used in the electrical field. In high-voltage switches, relays and other equipment, arcs are inevitably generated when the current is turned on and off. The high temperature and energy of the arc will corrode the contact material and cause component failure. Tungsten copper alloy can effectively resist this erosion and maintain long-term stable operation of components due to its unique composition and structure. Its arc erosion resistance is not the result of a single factor, but a manifestation of the combined influence of material composition, microstructure and arc action mechanism. It will also show different performances due to differences in the use environment, and there is a clear direction for performance optimization.

2.1.2.1 Arc erosion mechanism

Arc erosion refers to the process of surface damage and loss of materials under the action of an arc. Its core driving force comes from the high temperature and energy released by the arc. When an arc occurs, the local temperature rises sharply, enough to melt or even evaporate the surface of the material; at the same time, the electric force generated by the arc will push the molten material particles away from the surface, forming splash loss. In addition, in a high temperature environment, the material may also react chemically with the surrounding medium (such as oxygen in the air) to generate brittle substances such as oxides, which are easy to peel off under subsequent arc or mechanical action, further exacerbating erosion.

From the process point of view, arc erosion is a compound effect of "thermal damage-mechanical peeling-chemical degradation": high temperature first destroys the integrity of the material surface, making the surface material unstable; the electric force and airflow peel off these unstable substances; and the chemical reaction weakens the bonding force of the material surface, making the erosion more likely to continue. This mechanism will cause pits , cracks or deformations to gradually form on the material surface , ultimately affecting the conductivity and structural stability of the component.

2.1.2.2 Intrinsic principle of arc erosion resistance

Tungsten-copper alloy to resist arc erosion originates from the synergistic effect of tungsten and copper . Its internal principle can be attributed to the triple mechanism of "high temperature resistant skeleton + efficient heat dissipation + self-repairing buffer".

Tungsten, as a high-melting-point component, constitutes the rigid skeleton of the alloy. It is not easily melted by the high temperature of the arc. It can maintain the integrity of the structure under the action of the arc and prevent large-scale damage to the surface. At the same time, the presence of tungsten reduces the overall evaporation rate of the material and reduces the material loss caused by high temperature.

Copper, with its excellent thermal conductivity, quickly conducts the heat generated by the arc away from the action area, avoiding excessive local temperature rise, thereby reducing the degree of melting and evaporation. More importantly, when the arc temperature is extremely high, copper will melt before tungsten , and the molten copper will fill the tiny pits on the surface, forming a temporary "buffer layer" that can absorb part of the arc energy and reduce the area of the tungsten skeleton directly exposed to the arc, thus playing a protective role.

In addition, the interface bonding strength between tungsten and copper is relatively high, which can resist the tearing effect caused by the electric force of the arc and reduce the splash loss of material particles. This internal mechanism of "tungsten resistance to melting, copper heat dissipation, and synergistic anti-peeling" enables the tungsten-copper alloy to maintain good surface integrity under repeated arc action.

2.1.2.3 Performance differences in different usage environments

Tungsten copper alloy is not static and will vary significantly due to different usage environments. It is mainly affected by factors such as ambient temperature, atmosphere composition, arc energy density and mechanical load.

In a high-temperature environment, the surrounding environment already has a relatively high base temperature, which will weaken the heat dissipation efficiency of copper, making it difficult for the heat in the arc action area to diffuse quickly, which may intensify the melting and evaporation of the material and accelerate the erosion rate.

In an environment with high oxygen content or the presence of corrosive gases (such as sulfur dioxide and hydrogen sulfide), the high temperature of the arc will cause a more violent chemical reaction between the material and the gas, generating more brittle oxides or sulfides, which are easy to peel off, thereby accelerating erosion. In an environment protected by inert gas, chemical reactions are suppressed, erosion is mainly physical loss (melting, spattering), and performance is more stable.

When the arc energy density is high (such as high current switching scenarios), even the high melting point of tungsten cannot completely resist the instantaneous high temperature, which may cause the tungsten skeleton to partially melt. At this time, the buffering effect of copper will be enhanced, but the overall erosion degree will still be higher than that of low-energy arc scenarios. If there is mechanical vibration or pressure at the same time, the erosion products on the surface of the material (such as the solidified layer after melting) are more likely to peel off due to external forces, further expanding the damage area and reducing the arc erosion resistance.

2.1.2.4 Ways to improve performance

The arc erosion resistance of tungsten copper alloy , we can start from three aspects: material design, process optimization and function enhancement, and enhance its ability to resist arc damage through targeted improvements. In material design, the performance balance can be optimized by adjusting the tungsten-copper ratio : appropriately increasing the tungsten content can enhance the stability of the high-temperature resistant skeleton and reduce high-temperature melting; while a reasonable copper content can ensure heat dissipation efficiency and avoid local overheating. For specific high-energy arc scenarios, you can also try to add a small amount of high-melting-point, anti-oxidation elements, which can be integrated into the tungsten skeleton to improve its resistance to melting and oxidation without significantly reducing the thermal conductivity of copper.

Process optimization is a key means to improve performance. By refining the particle size of tungsten powder and copper powder, the two can be distributed more evenly in the microstructure, reducing the weak points caused by local component segregation; using vacuum sintering or atmosphere protection sintering process can reduce the porosity inside the material, enhance the bonding strength of the tungsten-copper interface, and reduce particle splashing under the action of the arc. In addition, surface strengthening treatment of the finished product (such as plasma spraying of wear-resistant coating) can form an additional protective barrier on the surface to delay the erosion of the substrate by the arc.

In terms of functional enhancement, by simulating actual arc working conditions, we can design a tungsten-copper alloy with a "gradient structure" - the surface tungsten content is higher to enhance melting resistance, and the inner copper content is higher to ensure heat dissipation, so that the material can play a targeted role at different depths. At the same time, we develop alloy recycling and reuse technology to extend the service life of components by repairing the eroded surface, which also indirectly improves the material's arc erosion resistance over the entire life cycle.

2.1.3 Analysis of anti-adhesion and anti-welding capabilities

Anti-adhesion and anti-welding capabilities are crucial properties of tungsten copper alloy in mechanical contact and electrical connection scenarios. Adhesion refers to the phenomenon that two contact surfaces are partially bonded and difficult to separate under the action of pressure or temperature; welding is a more serious adhesion, which means that the contact surface is melted at high temperature and then cooled and solidified to form a permanent connection. Both of these situations will cause components to get stuck and fail, and tungsten copper alloy , with its own characteristics, shows obvious advantages in resisting such problems. The core of its ability lies in reducing the "interface bonding tendency" of the contact surface, which not only avoids mechanical adhesion caused by pressure, but also prevents melting welding caused by high temperature.

2.1.3.1 Causes of adhesion and welding

The cause of adhesion is mainly related to "surface contact state" and "mechanical action". When the surfaces of two parts are in close contact and under pressure, the microscopic protrusions on the contact surface will embed into each other. If the material itself has strong plasticity, the protrusions may be locally deformed and fit together. At the same time, if the surface oxide layer or impurities are squeezed and destroyed, the fresh metal surface will directly contact, which will generate adsorption force due to the diffusion between atoms, and eventually lead to local adhesion of the contact surface. This situation is more likely to occur in scenarios with long-term pressure or low-speed relative motion.

Welding is the result of the combined effects of "high-temperature melting" and "cooling and solidification". When there are heat sources such as electric arcs and high friction temperatures on the contact surface, the surface of the material may be heated to a molten state, and the molten metals on the two contact surfaces will mix with each other; as the temperature decreases, the mixed molten metals solidify, forming a connection similar to welding on the contact surface. In addition, if there are impurities on the contact surface (such as residues from burning oil), low-melting-point eutectics may form at high temperatures, further promoting the bonding of the molten metal and intensifying the welding phenomenon.

2.1.3.2 Anti-adhesion performance

Tungsten copper alloy is mainly reflected in the fact that it is not easy to form a stable bond with other parts in the contact state. Even if a brief contact occurs, it can reduce surface damage during separation. In mechanical contact scenarios, the rigid skeleton formed by tungsten improves the deformation resistance of the material surface, and the microscopic protrusions on the contact surface are not easily crushed or embedded, reducing the basis for adhesion caused by mechanical bite ; at the same time, the presence of copper enables the surface to maintain a certain lubricity (relative to pure tungsten), reduces the friction coefficient during contact, and avoids the aggravation of surface adsorption due to frictional heat. Therefore, in components with long-term pressure contact, the surface of tungsten copper alloy is not easy to form adhesion marks with the matching material, and the force required for separation is smaller, which can maintain the integrity of the contact surface.

In electrical contact scenarios, even if there is a slight arc causing local temperature rise, tungsten copper alloy is not prone to adhesion due to surface melting. This is because the thermal conductivity of copper will quickly disperse the heat to prevent the surface from continuing to melt; while the high melting point of tungsten prevents large-area melting, making it difficult for the contact surface to form a stable bonding layer, and no "tearing" damage will occur during separation.

2.1.3.3 Factors affecting anti-adhesion and anti-welding capabilities

Tungsten copper alloy are not fixed and will be affected by the state of the material itself, contact conditions and environmental factors.

The surface state of the material itself is a key factor. If there are impurities such as oxide layers and oil stains on the surface, the surface finish will be reduced. Impurities may become "joining points" for adhesion under pressure or high temperature, weakening the anti-adhesion ability; on the contrary, a smooth surface that has been polished has fewer microscopic protrusions, a smaller contact area, and better anti-adhesion performance. In addition, the density of tungsten copper alloy also has an impact - materials with many internal pores are prone to form tiny pits on the surface, impurities are easy to deposit, and local adhesion is more likely to occur.

The influence of contact conditions is mainly reflected in pressure, temperature and relative motion. Excessive pressure will increase the microscopic bite of the contact surface and promote adhesion; excessive temperature (even if it does not reach the melting point) will increase the atomic diffusion rate and enhance the surface adsorption; and high-speed relative motion without lubrication may aggravate surface damage due to frictional heat generation, indirectly increasing the risk of adhesion.

Among the environmental factors, humidity and medium composition are more important. A high humidity environment will accelerate surface oxidation, forming a loose oxide layer that is easy to fall off when in contact and become an adhesion medium; if there are corrosive gases in the environment, brittle compounds may form on the surface, which may take away the surface metal when they fall off, reducing adhesion, but will destroy the surface integrity and indirectly affect the welding resistance.

2.1.4 Principle and application of excellent conductivity

The excellent electrical conductivity of tungsten-copper alloy is one of its core advantages that distinguish it from pure tungsten and most high-temperature resistant alloys. This performance is derived from the characteristics of the components themselves and also benefits from the synergistic effect of the composite structure. It does not pursue a single "extreme conductivity", but achieves "sufficient and stable" electrical conductivity on the basis of maintaining a certain mechanical strength and high temperature resistance, which enables it to play a role in scenarios that need to deal with current conduction and complex working conditions at the same time. In principle, its conductivity is the result of the movement of electrons inside the metal; in terms of application, this property makes it a key material that connects "electrical function" and "structural support".

2.1.4.1 Physical nature and conduction mechanism of conductivity

The physical essence of conductivity is the ability of free electrons in a material to move in a directional manner under the action of an electric field. When an external electric field is present, the free electrons in the material will break free from the constraints of the atomic nuclei and move along the direction of the electric field, forming an electric current. The less obstacles there are to the movement of electrons (such as atomic vibration, impurity scattering, etc.), the better the conductivity.

Tungsten-copper alloy mainly depends on the role of copper phase . Copper is a typical good conductor with a large number of free electrons inside and its atoms are arranged regularly. The scattering effect of electrons during movement is weak, so it can conduct current efficiently. In tungsten-copper alloy , copper is filled in the pores of the tungsten skeleton in a continuous or semi-continuous form to form a through "conductive channel" - when current passes through the alloy, electrons mainly flow through the copper phase channel. Although tungsten itself has a much lower conductivity than copper, as a skeleton it does not block the continuity of the copper phase , but maintains the stability of the copper phase channel through the supporting structure. In addition, the interface between tungsten and copper is tightly bonded, which reduces the scattering loss of electrons at the interface and further ensures the conductivity efficiency. This mechanism of "copper phase-dominated conductivity and tungsten phase-stabilized structure" allows the alloy to maintain excellent conductivity while maintaining mechanical properties.

2.1.4.2 Changes in conductivity at different component ratios

The conductivity of tungsten-copper alloy will show obvious regularity with the change of the composition ratio of tungsten to copper . The core trend is "the higher the copper content, the better the conductivity; the higher the tungsten content, the weaker the conductivity". This change stems from the essential difference in the conductivity of the two.

When the copper content is high, the conductive channel formed by the copper phase in the alloy is more complete and denser, the path for electron flow is smoother and less obstructed, so the overall conductivity is closer to the level of pure copper. At this time, the tungsten phase exists in the form of dispersed particles, which will have a slight impact on the continuity of the copper phase, but because the content is low, it is not enough to block the conductive channel, and the conductivity can still be maintained at a high level.

As the tungsten content increases, the proportion of the tungsten skeleton gradually increases, the distribution of the copper phase will be divided by the tungsten particles, some conductive channels may be cut off or narrowed, and electrons need to bypass the tungsten particles when flowing, the path becomes longer and the scattering increases, and the conductivity decreases accordingly. If the tungsten content is too high, the copper phase may not be able to form a continuous channel and can only exist in isolated small areas. At this time, it is difficult for electrons to move freely inside the alloy, and the conductivity will be significantly weakened.

This change is not a linear "monotonic decrease", but is closely related to the continuity of the copper phase - as long as the copper phase can remain basically continuous, even if the tungsten content increases, the decrease in conductivity is relatively gentle; once the copper phase is completely divided, the conductivity will decay significantly.

2.1.4.3 Advantages of Conductive Applications in Electrical Equipment

In electrical equipment, the conductive application advantage of tungsten-copper alloy is mainly reflected in "taking into account both conductivity and adaptability to working conditions", which can fill the performance gap between pure copper and pure tungsten in specific scenarios.

In high-voltage switches, relays and other equipment that need to frequently switch currents on and off, the contact material needs to conduct current and withstand the arc temperature and mechanical impact during switching. Although pure copper has excellent conductivity, it is easy to melt at high temperatures and lacks mechanical strength. It is prone to deformation or ablation failure after long-term use; although pure tungsten is resistant to high temperatures and has high strength, it has poor conductivity and is difficult to meet the needs of large current conduction. Tungsten-copper alloy can cope with both - the copper phase ensures efficient current flow and avoids excessive heating of the contacts; the tungsten phase resists arc temperature and mechanical impact, prolongs the service life of the contacts, and reduces equipment failures.

In parts that require sliding contact, such as motor brushes and conductive sliders, the material needs to resist friction and wear while conducting current. Pure copper has poor wear resistance, and long-term sliding will cause unstable conductivity due to wear; ordinary copper alloys have limited wear resistance and may reduce conductivity due to added elements. The tungsten phase of tungsten-copper alloy improves surface wear resistance and reduces losses during sliding; the copper phase maintains stable conductivity. Even if there is slight wear on the surface, the continuity of the internal copper phase can still ensure current conduction and ensure the stability of equipment operation. In addition, in some components that require the dual functions of "conductivity + heat dissipation" (such as electrodes of high-power devices) , the conductivity of tungsten-copper alloy and the thermal conductivity of copper phase form a synergy - it not only conducts current, but also removes the heat generated when the device is working, avoiding local overheating and affecting performance. This advantage of " one material for multiple uses" further enhances its application value in electrical equipment.

2.1.5 Good thermal conductivity

Tungsten-copper alloy is one of the core supports for its role in high-temperature and high-power scenarios. This performance does not rely solely on a certain component, but is the result of the synergy of tungsten and copper in structure and properties. It not only retains the efficient thermal conductivity of copper, but also ensures the stability of the heat conduction process through the skeletal structure of tungsten. Compared with pure copper, its thermal conductivity is slightly compromised, but in exchange for stronger mechanical support; compared with pure tungsten, its thermal conductivity efficiency is greatly improved, which can cope with the problem of heat accumulation. This "balanced" thermal conductivity property makes it irreplaceable in scenarios where heat transfer and structural load-bearing need to be handled simultaneously.

2.1.5.1 Basic principles of thermal conductivity and thermal conduction mechanism

The basic principle of thermal conductivity is the ability of heat to transfer from a high-temperature area to a low-temperature area through microscopic movement inside the material. Its essence is the kinetic energy transfer of molecules, atoms or electrons - particles in the high-temperature area vibrate more violently and transfer energy to adjacent particles in the low-temperature area through collision, gradually realizing heat diffusion.

The thermal conductivity mechanism of tungsten-copper alloy is mainly based on the "electronic thermal conductivity" of the copper phase , supplemented by the "phonon thermal conductivity" of the tungsten phase . Copper, as a metal, has a large number of free electrons inside. After these electrons gain energy in the high-temperature area, their movement intensifies, and they quickly transfer heat to the low-temperature area through collisions. This is an efficient way of thermal conductivity; while the thermal conductivity of tungsten mainly depends on lattice vibrations (i.e. "phonons"), and the vibrations of atoms near the equilibrium position transfer heat through the lattice. Although the efficiency is lower than the electronic thermal conductivity of copper, it is more stable. In the alloy structure, the copper phase forms a continuous thermal conduction channel, and the heat first diffuses rapidly through the copper phase . The tungsten skeleton serves as an "auxiliary path for heat transfer" and supports the integrity of the copper phase channel at the same time, avoiding the breakage of the thermal conduction path due to high-temperature deformation. This "copper phase-dominated, tungsten phase-assisted" mechanism allows the alloy to both efficiently transfer heat and maintain the stability of the thermal conduction structure under thermal shock.

2.1.5.2 Relationship between thermal conductivity and heat dissipation effect

Thermal conductivity is the core foundation of heat dissipation effect, and the two show a "positive correlation" relationship - the better the thermal conductivity of the material, the faster the heat is transferred from the heat source to the outside world, and the more significant the heat dissipation effect. However, the heat dissipation effect is not only determined by thermal conductivity, but also related to the heat dissipation area of the material, the contact state with the heat dissipation medium, etc. The advantage of tungsten copper alloy is that it "amplifies the effect of other heat dissipation conditions through efficient thermal conductivity." When the heat source generates heat, the tungsten copper alloy with good thermal conductivity can quickly conduct the heat from the surface of the heat source to avoid local accumulation of heat; the conducted heat will be transferred to the heat dissipation medium such as air and coolant through the material surface. At this time, if the thermal conductivity of the material itself is insufficient, even if the heat dissipation area is large, it is difficult for the heat to reach the surface, and the heat dissipation effect will be greatly reduced. In addition, the thermal conductivity of tungsten copper alloy is good, which can prevent heat from forming "hot spots" (local high temperature areas) inside the material. Hot spots are often the key to causing component failure due to overheating. Therefore, uniform thermal conductivity indirectly improves the reliability of overall heat dissipation. It can be said that the thermal conductivity of tungsten copper alloy provides the "basic power" for the heat dissipation effect, allowing the heat dissipation design to function more effectively.

2.1.5.3 Application value of thermal conductivity in high temperature working environment

In a high-temperature working environment, the thermal conductivity of the material needs to be not only "efficient" but also "stable" - that is, it will not decrease significantly due to the increase in ambient temperature . The thermal conductivity application value of tungsten copper alloy is reflected in this point. In the parts near the combustion chamber of aerospace engines, the ambient temperature is very high, and the parts will also generate additional heat due to work. If the thermal conductivity is unstable, the heat accumulation may cause the parts to exceed the tolerance temperature. Although the copper phase in the tungsten copper alloy may soften at high temperatures, its thermal conductivity will not be greatly reduced as long as it does not reach the melting point; and the tungsten skeleton can maintain structural stability and prevent the copper phase from deforming due to high temperature and blocking the heat conduction path, so it can continuously conduct heat and ensure the safe operation of the parts at high temperatures.

In the heat dissipation substrate of high-power semiconductor devices, a large amount of heat is generated when the device is working, and the ambient temperature increases with the working time. When the temperature of ordinary thermal conductive materials (such as pure aluminum) exceeds a certain range, the thermal conductivity will drop significantly, resulting in heat dissipation failure. Tungsten copper alloy can maintain stable thermal conductivity at higher temperatures, continuously transfer the heat generated by the device to the heat dissipation device, and avoid performance degradation or damage of the device due to overheating.

In addition, in the electrode parts of arc welding, the electrode must not only conduct current, but also withstand the instantaneous high temperature generated by the arc. If the thermal conductivity is poor, the electrode itself will be quickly burned due to the inability to dissipate heat. Tungsten copper alloy can timely conduct the heat of the arc through efficient thermal conductivity, reduce the temperature of the electrode itself, extend its life, and ensure the stability of the welding process. This characteristic of "maintaining thermal conductivity efficiency at high temperatures" makes it a key material that connects "heat generation" and "heat dissipation" in high-temperature environments.

2.1.6 Corrosion resistance and mechanism

Tungsten copper alloy is not its most outstanding characteristic, it shows practical value in moist environments with slightly corrosive media. Its corrosion resistance is not achieved by a single component, but the result of the structural synergy of tungsten and copper and the "passive resistance" to the corrosion process. It not only avoids the rapid oxidation of pure copper in certain environments, but also makes up for the local corrosion defects of pure tungsten in complex media, and can maintain the stability of structure and performance in a variety of industrial environments.

2.1.6.1 Influence of different corrosion environments

The difference in corrosion environment will affect the corrosion degree of tungsten copper alloy , which is mainly reflected in the three aspects of medium type, humidity and temperature. In a humid atmospheric environment, water vapor will form a water film on the surface of the alloy. If there is a small amount of pollutants (such as sulfur dioxide and salt) in the air, the water film will become a weak electrolyte and cause slight electrochemical corrosion. The copper phase may be oxidized and an oxide film will form on the surface, but this oxide film is dense and can prevent the corrosion from spreading further to a certain extent. Tungsten is more tolerant to this kind of environment and is almost not corroded, so the overall corrosion rate is slow.

In acidic or alkaline media, the degree of corrosion will be significantly aggravated. Acidic environments will destroy the oxide film on the copper surface, causing the copper phase to continue to dissolve; alkaline environments may react chemically with copper to generate soluble substances, accelerating the loss of the copper phase . At this time, although the tungsten phase can resist acid and alkali corrosion, as the copper phase continues to lose, the alloy structure will gradually become loose, ultimately affecting the overall performance. In a high-temperature dry environment, corrosion is mainly oxidation. High temperatures will accelerate the oxidation reaction of copper, and a thicker oxide layer may form on the surface. If the oxide layer falls off, the new copper surface will be exposed to continue oxidation; tungsten oxidizes slowly at high temperatures, and the generated oxide layer can adhere to the surface to protect the interior, so the overall corrosion level is lower than in a humid or acidic or alkaline environment.

2.1.6.2 Internal mechanism of corrosion resistance

Tungsten-copper alloy can be summarized as the synergistic effect of "tungsten phase corrosion-resistant skeleton + copper phase oxidation self-protection + structural density barrier" .

The tungsten phase itself has high chemical stability and is not easy to react with the medium in most common corrosive environments. The continuous skeleton it forms provides the basic support for the alloy's corrosion resistance - even if the copper phase is slightly corroded, the tungsten skeleton can still maintain its structural integrity and avoid overall damage to the alloy.

In a humid or slightly oxidizing environment, an oxide film will form on the copper surface. Although this film will cause the surface color to change, its texture is relatively dense and can prevent the medium from further contacting the copper inside. It is equivalent to forming a "natural barrier" to slow down the continued spread of corrosion.

In addition, the dense structure of the alloy can also enhance corrosion resistance. By optimizing the preparation process, the porosity inside the tungsten copper alloy is low, reducing the channels for corrosive media to penetrate into the interior; at the same time, the interface between tungsten and copper is tightly bonded, avoiding the medium from gathering at the interface to form local corrosion points, further reducing the risk of corrosion. This mechanism of "skeleton corrosion resistance, oxidation self-protection, and structural penetration resistance" allows the alloy to maintain good stability in non-extreme corrosion environments.

2.1.6.3 Technical means to improve corrosion resistance

To improve the corrosion resistance of tungsten copper alloy , it is necessary to start from the three directions of "blocking the corrosion path", "enhancing surface protection" and "optimizing the internal structure", and reduce the impact of corrosive media on materials through targeted technical means. Surface treatment is the most direct technical means. A corrosion-resistant coating is formed on the surface of the alloy through electroplating (such as chrome and nickel plating). This coating has high chemical stability and can completely isolate the alloy matrix from the corrosive medium. At the same time, the coating itself is not easily oxidized or dissolved, which greatly reduces the probability of corrosion. Chemical passivation treatment can also be used to form a denser and more stable oxide film on the copper phase surface through a specific solution to enhance the "self-protection" ability without affecting the core properties of the alloy such as conductivity.

Internal structure optimization can improve corrosion resistance from the root. By refining the particle size of tungsten powder and copper powder and improving the uniformity of mixing, the component segregation and porosity inside the alloy can be reduced, and the corrosive medium can be avoided from gathering locally. The use of advanced sintering processes (such as hot isostatic pressing) can improve the density of the alloy, eliminate internal micro cracks and voids, block the channels for corrosive media to penetrate into the interior, and enhance the corrosion resistance from a structural perspective. Adding corrosion-resistant auxiliary elements is also an effective technical path. Adding a small amount of elements with strong corrosion resistance (such as chromium and silicon) to the alloy will enrich these elements in the copper phase or at the tungsten-copper interface, which will not affect the conductivity of copper and the skeleton effect of tungsten, but will also improve the oxidation resistance of the copper phase , or enhance the interface bonding strength, and reduce the occurrence of local corrosion.

2.2 Effect of composition ratio on properties of tungsten copper alloy

Tungsten copper alloy is composed of tungsten (high hardness, high melting point, brittleness) and copper (good plasticity, electrical conductivity, thermal conductivity). The composition ratio of the two (usually expressed as tungsten content, such as W70Cu30 means tungsten accounts for 70% and copper accounts for 30%) is the core factor that determines its performance. Since there are significant differences in the mechanical and physical properties between tungsten and copper, changes in the composition ratio will directly lead to regular changes in the mechanical properties of the alloy (hardness, strength, and toughness). This change is the result of the synergistic effect of "tungsten phase skeleton support" and "copper phase plastic buffering."

2.2.1 Effect on mechanical properties

Tungsten copper alloy are the embodiment of the balance between the high strength and hardness of tungsten and the plasticity and toughness of copper. As the tungsten content increases, the alloy gradually changes from "copper as matrix and tungsten as reinforcement phase" to "tungsten as skeleton and copper as filling phase", and the mechanical properties also transition from "plasticity-dominated" to "rigidity-dominated"; conversely, when the copper content increases, the plasticity and toughness of the alloy will increase significantly, but the hardness and strength will decrease.

2.2.1.1 Effect on hardness

Tungsten copper alloy is closely related to the proportion of its components, among which tungsten element plays a leading role in improving hardness. When the tungsten content in the alloy is low, the copper phase occupies a dominant position, forming a continuous matrix with a small amount of dispersed tungsten particles embedded in it. At this time, the alloy is softer as a whole, and its hardness is close to that of pure copper. This is because copper is relatively soft in texture and has limited ability to resist external deformation such as indentations and scratches. For example, tungsten copper alloy containing 10%-20% tungsten has a Brinell hardness of approximately 80-120HB, which is more suitable for some scenarios that do not require high hardness but require good processing performance and other properties (such as conductivity).

As the tungsten content gradually increases, for example to around 50%, the internal structure of the alloy changes significantly. The tungsten particles approach each other and begin to form a certain degree of skeleton structure. Although the copper phase still exists and fills the gaps in the tungsten skeleton, the supporting role of the tungsten phase begins to become prominent at this time. Since tungsten itself has extremely high hardness, the skeleton it forms greatly enhances the alloy's ability to resist deformation, and the alloy's hardness is significantly increased, up to 200-250HB. This hardness level enables the alloy to effectively maintain surface integrity when facing moderate friction and wear environments, and is suitable for parts that are subject to certain friction, such as mechanical transmission components.

When the tungsten content is further increased to 70%-80% or even higher, the tungsten phase has formed a continuous and solid skeleton, and the copper phase is only filled in the tiny pores of the tungsten skeleton. At this time, the hardness of the alloy is close to that of pure tungsten, which can exceed 300HB. Tungsten copper alloys with high tungsten content perform well under extreme working conditions of high stress and high wear. For example, EDM electrodes are frequently subjected to high temperature and high pressure shocks generated by discharge during operation, and the material needs to have extremely high hardness to ensure the shape accuracy and service life of the electrode; high-voltage discharge contacts also require high-hardness materials to resist arc erosion and mechanical wear during frequent opening and closing. Tungsten copper alloys with high tungsten content can meet these needs well.

2.2.1.2 Impact on strength

In terms of strength, the tensile strength and compressive strength of tungsten copper alloys show different changes due to the influence of the composition ratio. For tensile strength, when the tungsten content is low (such as ≤50%), the copper phase bears the main tensile force as a continuous matrix. At this time, the tensile strength of the alloy mainly depends on the plastic bearing capacity of copper. Since the strength of copper is relatively low and the reinforcement effect of the tungsten particles dispersed in it is limited, the tensile strength of the alloy increases slowly. For example, the tensile strength of a tungsten copper alloy containing 30% tungsten is about 300-350MPa.

As the tungsten content increases to 50%-80%, the tungsten phase gradually forms a semi-continuous or even continuous skeleton structure, and the copper phase fills the gaps in the tungsten skeleton to play a role in bonding and transferring stress. At this point, when the alloy is subjected to stress, the stress can be more effectively transmitted and dispersed through the tungsten skeleton, and the tensile strength is significantly improved. Because tungsten itself has high strength, its skeleton structure greatly enhances the overall bearing capacity of the alloy. At the same time, the copper phase alleviates the problem of local stress concentration. For example, the tensile strength of tungsten-copper alloy containing 60% tungsten can reach 450-550MPa. When it contains 70%-80% tungsten, the tensile strength is further increased to about 600-700MPa.

However, when the tungsten content continues to increase (≥80%), the tensile strength will decrease slightly after reaching the peak value. This is because the copper phase accounts for too low a proportion and cannot fully fill the gaps between tungsten particles, resulting in a weakened tungsten-tungsten interface bond. When subjected to tension, these weak interfaces are prone to crack first, which in turn causes overall fracture, reducing the tensile strength of the alloy. For example, a tungsten-copper alloy containing 90% tungsten has a tensile strength of about 600-650MPa, slightly lower than an alloy containing 80% tungsten.

In terms of compressive strength, the rule is relatively simple and direct. As the tungsten content increases, the compressive strength continues to rise. Because during the compression process, the alloy mainly relies on the skeleton structure formed by the tungsten phase to resist compression deformation. The higher the tungsten content, the stronger the skeleton and the greater the pressure it can withstand. For example, a tungsten-copper alloy containing 90% tungsten has a compressive strength of more than 1000MPa, while an alloy containing 50% tungsten has a compressive strength of only about 600-700MPa.

2.2.1.3 Impact on toughness

The toughness of tungsten-copper alloy is mainly determined by the copper phase and is significantly negatively correlated with the tungsten content. When the tungsten content is low (≤50%), the copper phase exists in the form of a continuous matrix, giving the alloy good toughness. When subjected to impact or external force, the copper phase can absorb a large amount of energy through plastic deformation, disperse stress, and reduce the possibility of crack generation and expansion. At this time , although a small amount of dispersed tungsten particles have a certain influence on the continuity of the copper phase, it does not change the alloy's overall energy absorption mode of mainly plastic deformation. The alloy has good impact toughness. For example, the impact toughness of a tungsten-copper alloy containing 30% tungsten is about 15-20J/cm², which is close to the toughness level of pure copper. It can maintain structural integrity in an environment with certain impacts and is suitable for some structural parts that require certain impact resistance.

As the tungsten content increases to 50%-80%, the tungsten phase gradually forms a skeleton in the internal structure of the alloy , and the copper phase changes to a dispersed phase filling the gaps in the tungsten skeleton. This structural change leads to a significant reduction in the plastic deformation space of the copper phase . When impacted by external force, it is difficult for the copper phase to deform fully as before to absorb energy. Stress is easily concentrated at the tungsten-copper interface, causing interface cracking. Therefore, the toughness of the alloy decreases significantly with the increase of tungsten content. For example, the impact toughness of a tungsten-copper alloy containing 60% tungsten drops to

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5-10J/cm², at which point the alloy is more susceptible to damage when subjected to impact.

When the tungsten content is further increased to ≥80%, the continuous tungsten skeleton has almost no plastic deformation ability, and the copper phase only fills in the tiny gaps, which cannot effectively relieve stress concentration. Under impact load, the tungsten skeleton is very easy to break directly, the alloy absorbs very little energy, showing obvious brittleness, and the impact toughness is extremely low. For example, the impact toughness of tungsten copper alloy containing 90% tungsten is only 1-3J/cm², which is close to the brittle state of pure tungsten. This high tungsten content alloy should avoid being subjected to large impacts during use, and is mainly used in scenes with high requirements for hardness and strength but low requirements for toughness.

2.2.2 Impact on physical properties

Tungsten copper alloy are not fixed, but will change regularly with the change of the composition ratio of tungsten and copper . This is because the physical properties of tungsten and copper themselves are obviously different. When the proportion of the two in the alloy increases and decreases, the alloy will combine the characteristics of the two metals to form new physical properties. Whether it is properties related to the inherent properties of the material such as density and melting point, or properties related to temperature changes such as thermal expansion coefficient, the influence of the composition ratio can be clearly seen, and this influence also allows tungsten copper alloy to adapt to the physical performance requirements of different scenarios by adjusting the composition.

2.2.2.1 Impact on density

Tungsten-copper alloy is closely related to the proportion of its components, showing a clear pattern of change. Tungsten, as a high-density metal, has a large atomic weight and a dense arrangement of atoms, which gives it extremely high density characteristics. Although the density of copper is at a medium level among metals, it is much lower than that of tungsten . When the tungsten content in the alloy system is at a low level, the copper phase occupies the main position in the alloy structure and presents a continuous distribution state. At this time, the density characteristics of the alloy are mainly affected by the copper phase , and the overall density is close to the density value of pure copper. In this case, the alloy has advantages in some scenarios that are sensitive to weight and have other material properties (such as good conductivity, certain processing performance, etc.). For example, in some internal connection components of electronic equipment with strict weight restrictions, tungsten-copper alloys with low tungsten content can meet electrical performance requirements while reducing the overall weight as much as possible.

As the tungsten content in the alloy gradually increases, the proportion of the high-density tungsten phase in the internal structure of the alloy continues to increase, and its contribution to the overall density of the alloy becomes more and more prominent. In this process, the continuous structure originally dominated by the copper phase is gradually broken, the tungsten particles begin to approach each other and gradually build a skeleton structure, and the copper phase fills the gaps in the tungsten skeleton.

Since the density of the tungsten phase is much higher than that of the copper phase, the density of the alloy increases steadily with the increase of the tungsten content. This characteristic of gradually increasing density allows the alloy to play a role in application scenarios that need to resist greater impact forces or require stable counterweights. For example, in some mechanical equipment with complex vibration environments, appropriately increasing the tungsten content in the tungsten-copper alloy and increasing its density can enhance the stability of the components in a vibration environment and reduce the risk of displacement or damage caused by vibration.

When the tungsten content in the alloy reaches a high proportion, the tungsten phase has formed a continuous and stable skeleton structure in the alloy, and the copper phase is only filled in the tiny pores of the tungsten skeleton. At this time, the density characteristics of the alloy are almost completely dominated by the tungsten phase , and the alloy density is also close to the density of pure tungsten. Tungsten copper alloys with high tungsten content show unique value in some special fields. For example, in the manufacturing of certain parts in the aerospace field, the material needs to maintain structural integrity when subjected to extreme pressure and high-speed airflow impact. The high-density tungsten copper alloy can effectively cope with these extreme working conditions with its high density and the high strength and hardness brought by the tungsten phase ; in some nuclear industry-related scenarios that need to absorb high-energy particle impact or resist high-energy impact, tungsten copper alloys with high tungsten content and high density can also play a key role, using their high density to absorb and disperse impact energy to ensure the safe operation of equipment.

2.2.2.2 Effect on melting point

The variation pattern of alloy melting point is complex and closely related to the proportion of components. Tungsten has an extremely high melting point, ranking among the highest among common metals. This is due to its strong bonding force between atoms and its complex crystal structure. The melting point of copper is much lower than that of tungsten , and the difference between the two melting points is significant. When the tungsten content in the alloy is at a low level, the microstructure of the alloy is based on the copper phase as a continuous matrix. At this time, the melting point of the alloy is mainly determined by the properties of the copper phase , and the overall melting point is close to the melting point of pure copper. However, since there are a small amount of tungsten particles dispersed in the alloy, these high-melting-point tungsten particles will increase the melting point of the alloy to a certain extent. Although this improvement effect is not very significant at the low tungsten content stage, it has already increased the melting point of the alloy to a certain extent compared to pure copper. This melting point characteristic allows tungsten-copper alloys with low tungsten content to be used in some scenarios that do not require a particularly high melting point but require a certain degree of high temperature resistance and other properties such as good electrical conductivity and thermal conductivity. For example, in the manufacture of heat dissipation components for some electronic equipment, this type of alloy can maintain structural stability and perform good heat dissipation functions in an environment where a certain amount of heat is generated during normal operation of the equipment.

As the tungsten content in the alloy gradually increases, the internal structure of the alloy changes significantly, and the tungsten phase begins to gradually form a skeleton structure. At this time, the influence of the high melting point tungsten phase on the melting point in the alloy system becomes more and more obvious. Since the melting point of the tungsten phase is much higher than that of the copper phase, the skeleton structure it forms limits the fluidity and atomic diffusion of the copper phase during the heating process to a certain extent , so that the alloy as a whole needs to absorb more energy to reach the melting state, thereby greatly increasing the melting point of the alloy. At this stage, the increase in the melting point of the alloy gradually increases with the increase in tungsten content, showing a relatively obvious upward trend. This property gives the alloy an advantage in the manufacture of some components that work in medium and high temperature environments. For example, in the manufacture of internal connecting parts of some industrial furnaces or protective shells of high-temperature sensors, appropriately increasing the tungsten content in the tungsten copper alloy and raising its melting point can ensure that the components can operate stably for a long time in a high temperature environment without melting and deformation due to temperature increases, thereby ensuring the normal operation of the equipment. When the tungsten content in the alloy reaches a high level, the continuous and stable tungsten skeleton structure dominates, and the copper phase only fills the tiny pores of the tungsten skeleton. At this point, the melting point of the alloy has increased significantly, approaching the melting point of tungsten. In this case, the alloy exhibits remarkable stability in extremely high temperature environments. For example, in the manufacturing of combustion chamber components of aircraft engines and thermal protection components for re-entry into the atmosphere of spacecraft, these components will face a high temperature environment of thousands of degrees during operation. Tungsten -copper alloy with high tungsten content can withstand such extreme high temperatures due to its high melting point characteristics, effectively preventing the components from melting and deforming at high temperatures, and ensuring the safe operation of the aircraft or engine. At the same time, the presence of the copper phase can provide the alloy with good thermal conductivity to a certain extent, help dissipate the heat generated by high temperature, and further improve the reliability of the alloy in high temperature environments.

2.2.2.3 Influence on thermal expansion coefficient

The thermal expansion coefficient is an important indicator to measure the dimensional stability of a material when the temperature changes. There is a close relationship between the thermal expansion coefficient of tungsten copper alloy and the proportion of alloy components. Copper has a relatively large thermal expansion coefficient, which means that when the temperature changes, the thermal motion of copper atoms intensifies and the distance between atoms increases, resulting in a more obvious expansion or contraction of the overall size of the copper material. The thermal expansion coefficient of tungsten is relatively small, its atomic structure is relatively stable, and the change in the distance between atoms is relatively small when the temperature changes. When the tungsten content in the alloy is at a low level, the copper phase dominates the alloy structure and presents a continuous distribution state. At this time, the thermal expansion characteristics of the alloy are mainly determined by the copper phase , and the thermal expansion coefficient of the alloy is close to the thermal expansion coefficient value of pure copper. In this case, when the ambient temperature of the alloy changes, the alloy will produce a large volume change. For example, in the early design of some electronic equipment, if a tungsten copper alloy with a low tungsten content is used as a connecting component, when the equipment is running for a long time and heating up or the ambient temperature fluctuates greatly, due to the large thermal expansion coefficient of the alloy, the connecting component may become loose due to thermal expansion and contraction, affecting the electrical connection stability and overall performance of the equipment.

As the tungsten content in the alloy gradually increases, the proportion of the low expansion coefficient tungsten phase in the internal structure of the alloy continues to increase, and its inhibitory effect on the overall thermal expansion of the alloy gradually becomes prominent. In this process, the continuous structure originally dominated by the copper phase is gradually broken, and the tungsten phase begins to form a certain skeleton structure, and the copper phase fills the gaps in the tungsten skeleton. Since the thermal expansion coefficient of the tungsten phase is much smaller than that of the copper phase, it plays a role in stabilizing the structure and limiting the overall thermal expansion in the alloy. As the tungsten content further increases, the thermal expansion coefficient of the alloy gradually decreases. This characteristic of the change in thermal expansion coefficient with the tungsten content makes the alloy have wide application potential in some scenarios with high requirements for thermal expansion coefficient matching. For example, in the field of electronic packaging, different electronic components are often composed of a variety of different materials, and the thermal expansion coefficient of each material is different.

In order to ensure that during the operation of the equipment, the connection parts between different components will not cause stress concentration due to the difference in thermal expansion and contraction caused by temperature changes, causing connection failure or damage, it is necessary to select packaging materials with thermal expansion coefficients that match those of other component materials. By adjusting the tungsten content in the tungsten-copper alloy , its thermal expansion coefficient can be precisely adjusted within a certain range, thereby meeting the thermal expansion coefficient matching requirements of various electronic component materials (such as ceramic substrates, semiconductor chips, etc.), ensuring that electronic equipment can operate stably and reliably under different temperature environments.

When the tungsten content in the alloy reaches a high proportion, the continuous and stable tungsten skeleton structure dominates the alloy, and the copper phase is only filled in the tiny pores of the tungsten skeleton. At this time, the thermal expansion coefficient of the alloy has approached that of tungsten. When the temperature changes, the dimensional stability of the alloy is greatly improved, and the amplitude of thermal expansion and contraction becomes very small. This characteristic makes the tungsten copper alloy with high tungsten content play an irreplaceable role in some high-precision fields such as precision instrument manufacturing and aerospace that require extremely high dimensional stability. For example, in the manufacture of optical instrument components for spacecraft, these instruments will face extremely complex and drastically changing temperature environments in space, from the extremely cold deep space of the universe to the high temperature environment close to the sun, and the temperature range can reach hundreds of degrees Celsius. Tungsten copper alloys with high tungsten content and low thermal expansion coefficient can ensure that the structural dimensions of optical instruments are almost unchanged under such extreme temperature changes, thereby ensuring that

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the high-precision optical performance of optical instruments is not affected, and providing stable and reliable observation data support for space exploration missions.

2.2.2.4 Effect on conductivity

Tungsten copper alloy is closely related to the composition ratio. Copper is a good conductive metal with high electrical conductivity, while tungsten has relatively low electrical conductivity. As the tungsten content in the alloy increases, the electrical conductivity will gradually decrease. This is because tungsten has a large interatomic distance and a low electron cloud density. When added to the copper matrix, it will form a dispersed phase and stacking structure, resisting the flow of electrons at the grain boundaries and inside the grains, introducing more ion defects and impurity atoms, thereby hindering the free transmission of electrons in the lattice. When the tungsten content exceeds a certain proportion, the rate of conductivity decrease begins to slow down, probably because the electronic barriers formed by the higher content of tungsten begin to interact and restrict the flow of more electrons. On the contrary, increasing the copper content will increase the conductivity of the alloy because the high electrical conductivity characteristics of copper can better conduct current.

2.2.2.5 Effect on thermal conductivity

In terms of thermal conductivity, copper has significantly higher thermal conductivity than tungsten. Therefore, in general, the higher the copper content in the tungsten-copper alloy , the higher the thermal conductivity. This is because pure metals conduct heat mainly through free electrons, and copper has a relatively high concentration of free electrons, which can transfer heat more efficiently. However, too high a copper content will lead to a reduction in tungsten content, which may have an adverse effect on other properties of the alloy, such as an increase in the coefficient of thermal expansion. At the same time, the thermal conductivity of the alloy is also affected by other factors, such as density. Gas is a poor carrier of heat. When pores exist in the material, the thermal conductivity will decrease with the increase of porosity, so tungsten-copper alloys with high density usually have higher thermal conductivity.

2.2.3 Impact on chemical properties

Tungsten copper alloy has good chemical stability. In terms of oxidation resistance, tungsten has a higher melting point and better oxidation resistance. As the tungsten content increases, the oxidation resistance of the alloy will be enhanced to a certain extent. However, copper in the alloy is easily oxidized at high temperatures, so the oxidation resistance of the alloy needs to comprehensively consider factors such as the ratio of tungsten to copper and the use environment. In terms of corrosion resistance, tungsten and copper themselves have certain corrosion resistance, and tungsten copper alloy has good resistance to some common chemicals and environments. However, in certain specific chemical media such as strong oxidizing acids, copper may undergo corrosion reactions. At this time, increasing the tungsten content can improve the corrosion resistance of the alloy to a certain extent. In addition, impurity content and preparation process will also affect the chemical properties of tungsten copper alloy . For example, too high oxygen content will cause oxidation of tungsten copper alloy , reducing the strength and conductivity of the alloy.

2.2.3.1 Effect on corrosion resistance

Tungsten copper alloy is significantly affected by its composition ratio and exhibits diverse performance in different corrosive environments. Tungsten itself has good chemical stability and can maintain its structure from being easily corroded in many common corrosive media. When the tungsten content in the alloy is relatively high, the skeleton structure formed by the tungsten phase can provide a basis for the alloy to resist corrosion to a certain extent. For example, in some weakly acidic environments, tungsten-copper alloys with high tungsten content can effectively slow down the corrosion rate of the entire alloy due to the chemical stability of tungsten. This is because in order for the corrosive medium to penetrate the alloy surface and reach the interior, it first needs to break through the relatively stable "barrier" formed by the tungsten phase . The strong binding force between tungsten atoms and the relatively stable electronic structure make it difficult for the ions in the corrosive medium to react chemically with it, thereby hindering the further penetration of corrosion.

However, copper is relatively active in certain corrosive environments. In some highly oxidizing acid solutions, such as nitric acid, copper easily undergoes redox reactions with nitric acid to generate corresponding copper salts and release nitrogen oxide gas. When the copper content in the alloy is high, the negative impact of this activity on the corrosion resistance of the alloy will become prominent. In such an environment, the copper phase becomes the main "breakthrough" for the corrosion of the alloy , and the corrosive medium will preferentially react with copper , resulting in corrosion pits, rust spots and other phenomena on the surface of the alloy, thereby destroying the overall structure of the alloy and reducing its performance.

But in some neutral or weakly alkaline aqueous solution environments, the situation is different. At this time, if the copper content is within a certain range, copper can form a thin passivation film on the surface of the alloy. The main component of this passivation film is some copper oxides or hydroxides. It has a certain density and can prevent dissolved oxygen and other corrosive ions in the solution from further contacting the interior of the alloy, thereby improving the corrosion resistance of the alloy to a certain extent. For example, in the selection of lining materials for some industrial water pipes, if a tungsten-copper alloy with a moderate copper content is used , this passivation property of copper can be used to maintain the integrity of the pipe lining during long-term contact with water and reduce the occurrence of problems such as corrosion perforation. At the same time, the presence of tungsten phase can also enhance the overall structural strength of the alloy, so that the passivation film is not easily destroyed when it is subjected to external forces such as water flow impact, further ensuring the corrosion resistance of the alloy.

2.2.3.2 Effect on high temperature oxidation resistance

High temperature oxidation resistance is a key indicator to measure the performance of tungsten copper alloy in high temperature oxygen environment, and it is closely related to the composition ratio. Tungsten has an extremely high melting point of 3410°C, and at high temperature, a relatively stable oxide film can be formed on its surface. The main components of this oxide film are oxides such as WO_3, which have good density and stability, and can prevent oxygen from further diffusing into the alloy, thereby protecting the alloy. When the tungsten content in the alloy is high, in a high temperature oxygen environment, an oxide film mainly composed of tungsten oxide is preferentially formed on the surface of the alloy. As the temperature rises and the time increases, this oxide film continues to thicken, and due to its stable structure, it can effectively prevent further reaction between oxygen and the inside of the alloy, greatly improving the high temperature oxidation resistance of the alloy. For example, in the internal structural parts of some high temperature furnaces, if a tungsten copper alloy with a high tungsten content is used , it will work for a long time at a temperature of 1000°C or even higher. The stable oxide film formed on the surface of the alloy can ensure that the structural parts are not over-oxidized for a long time, maintaining their mechanical properties and structural integrity.

In contrast, copper has a relatively low melting point of 1080°C, and copper oxidizes relatively quickly at high temperatures. When the copper content in the alloy is high, copper will be oxidized to oxides such as Cu_2O or CuO more quickly in a high-temperature aerobic environment . Compared with tungsten oxides, these copper oxides have a relatively loose structure and cannot form an effective barrier layer like the tungsten oxide film. As the oxidation process continues, copper oxides continue to accumulate, which not only consumes the copper element in the alloy, but also may cause cracks and peeling of the oxide film, making it easier for oxygen to penetrate the oxide film and react with other components inside the alloy, thereby reducing the alloy's high-temperature oxidation resistance. In some electrical contact materials that need to operate stably for a long time in a high-temperature aerobic environment, if a tungsten-copper alloy with too high a copper content is used , the contact will oxidize rapidly due to the increase in temperature during frequent power on and off . The loose copper oxide film formed on the surface will affect the conductivity and contact stability of the contact, and in severe cases, it may even cause the contact to stick and fail.

However, within a specific composition ratio and temperature range, some interactions may occur between tungsten and copper oxides, which will have a complex effect on the high-temperature oxidation resistance of the alloy. For example, in some medium temperature ranges (800°C-1200°C), when the content ratio of tungsten and copper in the alloy is appropriate, copper oxide may combine with tungsten oxide to a certain extent to form a relatively more stable composite oxide film structure. This composite oxide film has a certain density and flexibility. It can not only utilize the barrier properties of tungsten oxide, but also use copper oxide to fill the tiny cracks in the oxide film to a certain extent, thereby improving the high-temperature oxidation resistance of the alloy in this temperature range to a certain extent. However, this synergistic effect has a relatively demanding requirement on the composition ratio, and the content of tungsten and copper needs to be precisely controlled to achieve the best high-temperature oxidation resistance effect.

2.3 CTIA GROUP LTD Tungsten Copper Alloy MSDS

Tungsten copper alloy is a composite material made of tungsten (W) and copper (Cu) through powder metallurgy process, usually containing 70%-90% tungsten and 10%-30% copper, widely used in electrical contacts, high-voltage switches and electro-machining electrodes. Product uses include scientific research and industrial manufacturing, and specific applications may involve heat sinks, electrodes, etc. The purpose of MSDS is to provide safe use guidance for workers and emergency rescue personnel, including chemical composition, potential hazards and handling recommendations.

According to the general tungsten copper alloy MSDS, tungsten copper alloy is not generally classified as a hazardous material (in accordance with OSHA 29 CFR 1910.1200), so there is no specific signal word or hazard statement.

Tungsten copper alloy include tungsten (CAS No.: 7440-33-7, content 70%-90%) and copper (CAS No.: 7440-50-8, content 10%-30%).

Tungsten copper alloy is not easy to burn under normal conditions, but the dust generated during processing may cause fire. It is recommended to use dry powder, foam or carbon dioxide fire extinguishing agents. Never use a direct stream of water to extinguish metal powder fires, as water may cause the reaction to intensify. Metal oxide fumes may be released during heating. Firefighters should wear self-contained breathing apparatus to avoid inhalation of toxic fumes.

Tungsten copper alloy meets the requirements of TSCA inventory and has no significant ecological hazard, but processing waste may cause slight impact on the environment. A chemical safety assessment has not been fully completed and caution and compliance with local regulations is recommended.

CTIA GROUP LTD Tungsten Copper Alloy

CTIA GROUP LTD

Tungsten Copper Alloy Introduction

1. Overview of Tungsten Copper Alloy

Tungsten Copper Alloy is a composite material made from tungsten and copper, typically containing 10% to 50% copper by weight. This alloy combines the outstanding properties of both metals—retaining tungsten's high-temperature resistance and excellent arc erosion resistance, while benefiting from copper's superior thermal and electrical conductivity. It delivers exceptional comprehensive performance in high-end fields such as electrical engineering, power systems, electronics, and aerospace. CTIA GROUP LTD offers a wide range of customized tungsten copper alloy solutions, featuring high density, stable performance, and precise processing tailored to customer requirements for components such as electrodes, thermal management parts, and vacuum system elements.

2. Typical Properties of Tungsten Copper Alloy

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm³)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten Copper Alloys

Power Equipment: Contacts for high-voltage vacuum switches; Conductive parts for circuit breakers; Components for high-power relays and arc-fault interrupters

Electronics and Semiconductor Industry: Heat-dissipating substrates for IGBT modules; Cooling plates for microwave components; Package lids and electronic base plate

Electrical Discharge Machining (EDM): Electrode materials for EDM, especially suitable for machining hard alloy molds; High-precision forming electrodes for fine EDM processes

Aerospace and Defense: High-temperature structural parts such as rocket nozzles and tail cones

4. Purchasing Information

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Chapter 3 Correlation between Microstructure and Properties of Tungsten Copper Alloy

Tungsten copper alloy has wide application potential in electrical, electronic, defense and industrial fields due to its excellent electrical conductivity, thermal conductivity, high temperature resistance and arc corrosion resistance. The alloy is prepared by powder metallurgy process, with tungsten (W) as the matrix or reinforcement phase, providing high melting point and hardness, and copper (Cu) as the bonding phase, contributing high electrical conductivity and thermal conductivity, and can meet the demanding requirements of high current, high temperature or high wear environment. The performance of tungsten copper alloy is closely related to its microstructure. The grain morphology, phase distribution and interface characteristics directly affect its mechanical properties, electrical conductivity and durability.

3.1 Insights into the Microstructural Characteristics of Tungsten-Copper Alloy

Tungsten copper alloy is the basis of its performance, reflecting the mixing, pressing, sintering and post-processing processes in the powder metallurgy process. Microstructural characteristics include grain morphology and size, phase distribution and interface, which are analyzed by microscopes (such as scanning electron microscope SEM and transmission electron microscope TEM). The high melting point of tungsten (3422°C) keeps it solid during sintering, and the lower melting point of copper (1085°C) forms a liquid phase, which wets the tungsten particles and fills the gaps, forming a unique composite structure. This structure directly affects the electrical conductivity, thermal conductivity, hardness and arc erosion resistance of the alloy. The grain morphology and size and phase distribution and interface will be analyzed in detail below.

3.1.1 Grain morphology and size

Tungsten copper alloy are the core of microstructural characteristics, which determine the mechanical and thermal properties of the alloy. The grain morphology is mainly composed of tungsten particles. Since tungsten remains solid during the sintering process, its morphology retains the characteristics of the initial powder and is usually polyhedral or nearly spherical. The copper phase, as a liquid bonding phase, penetrates the gap between tungsten particles at high temperatures and forms an irregular network structure or filling phase after cooling. The uniformity of grain morphology directly affects the consistency of performance. Regular distribution of tungsten particles helps to disperse stress, while irregular morphology may lead to local weak points.

The grain size is significantly affected by the preparation process. The particle size of the initial tungsten powder is usually in the range of 1-10 microns, which can be further reduced to nanometer scale by high-energy ball milling. Sintering temperature and time play an important role in grain size, with lower temperatures retaining smaller grains and higher temperatures possibly inducing grain growth. During the liquid phase sintering process, the fluidity of the copper liquid phase promotes the rearrangement and growth of tungsten particles, and the grain size is usually between 5-20 microns, depending on the tungsten content and process parameters. The application of nano-scale tungsten powder can control the grain size to submicron level, significantly improving the performance.

Grain morphology and size have a significant impact on performance. Smaller grain size enhances the strength and hardness of the alloy through the Hall-Page effect, and fine grains increase the grain boundary density, block dislocation movement, and improve deformation resistance. For example, when tungsten particle size is reduced to the nanometer level, the hardness can be increased by 20%-30%, making it suitable for high-wear applications such as electromachining electrodes. Grain size also affects electrical conductivity and thermal conductivity. Too small grains may increase grain boundary resistance and reduce the efficiency of electron and heat transfer, but the network structure of the copper phase can make up for this defect. Uniform grain morphology reduces stress concentration points and enhances fatigue resistance, especially in thermal cycling or mechanical shock environments.

Optimization of the preparation process is the key to controlling grain morphology and size. Spark plasma sintering (SPS) inhibits excessive grain growth and maintains a fine grain structure through rapid heating and high pressure. Hot isostatic pressing (HIP) eliminates porosity and improves the consistency of grain distribution through omnidirectional pressure. Adding trace elements (such as nickel or iron) can adjust the grain boundary energy and stabilize the microstructure. The reduction in grain size also improves the alloy's resistance to arc erosion. The fine tungsten particles disperse the arc energy and reduce the risk of surface melting. Optimization directions include developing ultrafine nanopowders or using additive manufacturing technology to achieve more precise grain control. In short, the grain morphology and size of tungsten-copper alloys provide basic support for their performance, especially in scenarios where both strength and conductivity need to be taken into account.

3.1.2 Phase distribution and interface

Tungsten copper alloy are important components of the microstructural characteristics, which directly affect the mechanical properties and functional characteristics of the alloy. Phase distribution refers to the spatial arrangement of tungsten phase and copper phase in the alloy, and the interface refers to the bonding area between the two. Tungsten , as a high melting point phase, is distributed in dispersed particles, and copper, as a low melting point phase, forms a continuous or semi-continuous bonding network. The uniformity of phase distribution determines the consistency of performance, and the quality of the interface affects load transfer and heat diffusion.

The formation of phase distribution depends on the sintering process. Liquid phase sintering is the key step. Copper melts above 1085°C, wets the tungsten particles and fills the gaps by capillary action. When the tungsten content is high (such as W80/Cu20), the copper phase is discontinuously distributed, surrounding isolated tungsten particles; when the copper content is high (such as W60/Cu40), the copper phase forms a continuous network in which the tungsten particles are embedded. The uniformity of phase distribution is controlled by high-energy ball milling and powder mixing processes . Too short ball milling time may cause tungsten agglomeration, while too long ball milling time may introduce impurities. After sintering, the cooling and solidification of the copper phase fixes the phase distribution structure, and hot isostatic pressing can further optimize the uniformity.

The quality of the interface is key to the correlation between phase distribution and performance. The interface between tungsten and copper is chemically and mechanically bonded by liquid phase sintering, where the copper liquid phase penetrates the surface of the tungsten particles and enhances the adhesion of the interface. The metallurgical bonding at the interface reduces voids and defects and improves the load transfer efficiency. The interface also affects electrical and thermal conductivity, with a continuous network of copper connected to tungsten through the interface to form an efficient electron and heat transfer path. Improved interface strength is achieved by adding trace elements such as nickel, which improves wettability and enhances interfacial bonding. A weak interface can lead to delamination or cracking, especially under arc or thermal stress.

Phase distribution and interface have significant effects on performance. The uniform phase distribution improves the comprehensive properties of the alloy, the tungsten phase provides hardness and high temperature resistance, and the copper phase ensures electrical and thermal conductivity. The interface quality directly affects the arc erosion resistance, and a strong interface reduces the concentrated ablation of arc energy at the phase boundary. Alloys with high copper content (such as W70/Cu30) are suitable for heat dissipation substrates because of their good copper phase continuity , excellent electrical conductivity and thermal conductivity; alloys with high tungsten content (such as W90/Cu10) are suitable for electrode applications because of their dominant tungsten phase , strong hardness and wear resistance. Interfacial defects such as voids or non-wetted areas can degrade performance and need to be eliminated through process optimization.

Improvement in the preparation process is the key to optimizing phase distribution and interface. Vacuum sintering reduces oxidation and keeps the interface pure; staged heating controls the flow of copper liquid phase and improves phase distribution. The application of nanoscale powders enhances the interface contact area and improves the bonding strength. Optimization directions include developing functional gradient materials, gradually transitioning the distribution of tungsten and copper phases , or using intelligent monitoring technology to evaluate interface quality in real time. In short, the phase distribution and interface of tungsten-copper alloys provide important support for their performance, especially in scenarios where conductivity, high temperature resistance and mechanical strength need to be taken into account.

3.1.3 Porosity and defect manifestation

Tungsten copper alloy are key features in the microstructure, which directly affect the mechanical properties, conductivity and durability of the alloy. Porosity refers to the tiny gaps that are not completely filled by the copper liquid phase during the sintering process, and defects include cracks, unwetted particles or impurity agglomerations. These structural defects are usually identified by microscopic observation or density testing (such as the Archimedes method). The porosity is closely related to the preparation process. Excessive porosity may reduce density and affect performance consistency.

The formation mechanism of pores is mainly related to powder properties, powder mixing uniformity and sintering conditions. The uneven particle size or agglomeration of the initial tungsten powder may lead to insufficient local copper liquid phase, leaving micropores. Insufficient pressure or poor powder fluidity during pressing may introduce initial voids, and sintering at too low a temperature (e.g., below 1100°C) or for insufficient time may fail to completely eliminate these voids. The wettability of the copper liquid phase also plays a key role. The wetting angle between copper and tungsten is relatively high (about 30°-40°). If impurities are introduced into the sintering atmosphere (such as an oxidizing environment), the wetting effect is weakened and the porosity increases. Typical pore sizes are in the range of 1-10 microns, and uneven distribution may result in the formation of macropores (>20 microns), significantly reducing performance.

Defects can manifest themselves in various forms. Cracks may be caused by thermal stress or phase change stress during pressing or cooling. Especially when the tungsten content is high, uneven shrinkage of the copper phase can easily cause interface cracks. Unwetted particles refer to tungsten particles whose surface is not fully penetrated by the copper liquid phase, which is usually caused by insufficient sintering temperature or too low copper content, and appears as isolated tungsten particles. Impurity agglomerations (such as oxides or carbides) may come from the raw materials or the processing process, and concentrate at grain boundaries or interfaces, affecting load transfer and heat diffusion. The density of pores and defects can be significantly reduced by hot isostatic pressing (HIP) or spark plasma sintering (SPS), and the density can reach more than 98%.

Porosity and defects have a significant impact on performance. High porosity reduces the flexural strength and hardness of the alloy because the voids become stress concentration points that can easily cause fracture, especially in high wear applications such as electrodes. Electrical and thermal conductivity are also impaired, with the pores increasing electrical and thermal resistance, reducing the efficiency of current and heat transfer. The arc erosion resistance is also reduced, and the pores tend to become arc energy concentration points, accelerating surface melting. Defects such as cracks can propagate under thermal cycling or mechanical shock, shortening service life. Optimization directions include using nano-scale powders to improve particle uniformity, optimizing sintering parameters (such as staged heating) to reduce porosity, or filling defects through surface coatings. In short, the control of pores and defects is the key to improving the performance of tungsten copper alloy .

3.1.4 Structural differences under different preparation processes

Tungsten copper alloys varies significantly due to different preparation processes. Common processes include traditional powder metallurgy, copper infiltration , spark plasma sintering (SPS) and additive manufacturing (3D printing). Each method has a unique effect on grain morphology, phase distribution, porosity and interface quality. Process selection directly determines the performance of the alloy and needs to be optimized according to application requirements.

Conventional powder metallurgy is a widely used process involving powder mixing, pressing and sintering. Tungsten powder and copper powder are mixed by high-energy ball milling, pressed into shape and then sintered. The structural features include polyhedral distribution of tungsten particles, a discontinuous network of copper phases, and a porosity typically between 5% and 10%. The interface bonding depends on the wetting of copper liquid phase, and the quality is controlled by the sintering temperature and time. Higher temperature may lead to grain growth and reduce uniformity. Suitable for heat dissipation substrates with high requirements for electrical conductivity and thermal conductivity.

The copper infiltration method prepares the alloy by first sintering the tungsten skeleton and then infiltrating liquid copper. The tungsten skeleton forms a porous structure at a higher temperature, and copper infiltrates and fills it. The structural characteristics are that the tungsten phase is a continuous skeleton, the copper phase is evenly distributed, and the porosity can be reduced to 2%-5%. The interface bonding is strong, which reduces the number of unwetted particles, but the process is complicated and the energy consumption is high. It is suitable for electrode applications that require high density.

Spark plasma sintering (SPS) uses pulsed current and mechanical pressure, and the sintering time is short (several minutes). The structural characteristics are fine tungsten particles, uniform copper phase distribution , porosity less than 2%, and clear grain boundaries. Rapid heating inhibits grain growth, and the interface bonding force is strong, which is suitable for high hardness and arc erosion resistance applications such as contacts. The disadvantage is that the equipment cost is high and the scope of application is limited.

Additive manufacturing (such as selective laser melting SLM) prepares alloys by depositing powder layer by layer. The structural characteristics are a gradient distribution of tungsten and copper phases , controllable grain size, and porosity that depends on laser parameters and can be less than 3% under optimized conditions. The interface quality is high and complex geometries are supported, but thermal stress may introduce microcracks. Suitable for customized aerospace parts. Process differences affect performance. Traditional powder metallurgy is economical but has high porosity and is suitable for large-scale production; copper infiltration has good density but high cost; SPS provides high performance but is suitable for small batches; additive manufacturing is flexible but requires optimization of thermal stress. Optimization directions include combining multiple processes (such as SPS+copper infiltration) to improve density, or using intelligent monitoring technology to adjust parameters in real time. In short, structural differences in preparation processes provide diverse options for performance optimization.

3.2 The intrinsic relationship between the microstructure and performance of tungsten copper alloy

There is an intrinsic relationship between the microstructure of tungsten copper alloy and its performance. The grain morphology, phase distribution, porosity and defects and preparation process jointly determine its electrical conductivity, thermal conductivity, mechanical strength and durability. The optimization of microstructure is achieved by enhancing interface bonding, reducing defects and controlling phase ratio to meet different application requirements.

The effect of grain size on performance is reflected through the Hall-Page effect. Fine grains increase grain boundary density, enhance strength and hardness, but may increase resistance and reduce conductivity. The phase distribution determines the electrical and thermal conduction paths, the continuous network of the copper phase improves performance, and the tungsten phase enhances high temperature resistance. Porosity and defects reduce density, affecting flexural strength and arc erosion resistance, and dense structures significantly improve performance. Interface quality affects load transfer and heat diffusion, and a strong interface improves overall performance.

Optimizing the microstructure needs to be combined with the application scenario. The heat dissipation substrate requires high copper phase continuity, and the electrode requires high tungsten phase density. Future research can explore nanocomposite structures or functional gradient designs to further reveal the intrinsic connection between microstructure and performance.

3.2.1 Mechanism of effect of grain structure on strength

Grain structure on the strength of tungsten copper alloy is mainly reflected in the barrier effect of grain boundaries and the stress dispersion ability. Strength is the ability of an alloy to resist deformation or fracture and is directly related to grain size and morphology. Smaller grains restrict the movement of dislocations, a key strengthening mechanism, by increasing the density of grain boundaries. Grain boundaries act as barriers to dislocations, forcing them to pile up or tangle, consuming more energy to continue moving, thus significantly improving the alloy's resistance to deformation. The uniform distribution of grains further optimizes this effect, reduces local stress concentration points, and enhances the bearing capacity of the overall structure.

Grain morphology also has an important influence on strength. Regular polyhedral or nearly spherical grains can more effectively disperse the applied load and avoid excessive accumulation of stress in a specific direction. In contrast, irregular or flat grains may lead to uneven stress distribution and increase the risk of fracture. During the sintering process, the rearrangement and growth of grains are regulated by temperature and pressure, and the formation of fine grains depends on rapid cooling or short-time sintering processes, which maintain the dense distribution of grain boundaries. The tungsten phase serves as a high-hardness skeleton, and its grain structure provides rigid support for the alloy, while the bonding effect of the copper phase further enhances the connection strength between grains.

This mechanism of action enables tungsten copper alloys to perform well in applications that require high strength. For example, in mechanical shock or high-load environments, the fine grain structure can effectively resist deformation and extend the service life of components. The effect of grain boundary strengthening is also related to the density of the microstructure, and the reduction of pores or defects further improves the strength. Optimizing the grain structure requires stabilizing the grain boundaries by controlling sintering parameters or introducing trace elements to enhance the comprehensive mechanical properties of the alloy, thereby exerting greater potential in high-reliability scenarios.

3.2.2 Mechanism of the effect of grain structure on toughness

Grain structure on the toughness of tungsten copper alloy is mainly reflected in the energy absorption capacity of grain boundaries and the coordination of plastic deformation. Toughness is the ability of an alloy to absorb energy and resist fracture, which is closely related to grain size and interface characteristics. Larger grains generally have higher plasticity and can absorb energy through dislocation sliding and twin deformation, thereby improving toughness. However, overly large grains may reduce strength and lead to performance imbalance. Smaller grains increase the material's resistance to crack growth by increasing the grain boundary density, but may sacrifice some plasticity, and a balance must be sought between strength and toughness.

The effect of grain morphology on toughness is also significant. Regular grain morphology helps to uniformly transfer stress and reduce the risk of crack initiation and propagation. The copper phase acts as a low-melting-point bonding phase, and its ductility provides an additional energy absorption pathway between grains. When an external load is applied, the copper phase can undergo plastic deformation, buffering the brittle effect of the tungsten phase. The micro-deformation at the grain boundaries also relieves local stress concentration through dislocation absorption and redistribution mechanisms. During the sintering process, the fluidity of the copper liquid phase promotes the close bonding between the grains and enhances the toughness foundation, while the rapid cooling process helps to maintain the plastic characteristics of the fine grains.

This mechanism of action enables tungsten copper alloy to show excellent toughness in dynamic load or impact environment. For example, in arc action or mechanical vibration scenarios, the coordinated deformation ability of the grain structure can effectively prevent brittle fracture and extend the life of components. The improvement of toughness also depends on the uniformity of the microstructure. The reduction of pores or unwetted areas enhances the efficiency of load transfer.

3.2.3 Correlation between phase distribution and conductivity

The relationship between phase distribution and electrical conductivity of tungsten-copper alloy is mainly reflected in the continuity of copper phase and the dispersion of tungsten phase . Electrical conductivity is a measure of an alloy's ability to carry electrical current and is directly related to the uniformity of the phase distribution. Copper is a highly conductive phase, and its continuous network is the basis of electrical conductivity. When the copper phase forms a through path, electrons can be transferred efficiently, significantly improving the conductive properties of the alloy. The dispersed distribution of tungsten phase as a low conductivity enhancement phase will not significantly hinder the flow of current, but too high tungsten content may increase resistance and reduce the overall conductivity.

The uniformity of phase distribution is critical to electrical conductivity. The continuity of the copper phase depends on the full wetting and filling of copper during the liquid phase sintering process. If the tungsten particles agglomerate or the copper liquid phase is insufficient, discontinuous areas may be formed, increasing the contact resistance. The uniform dispersion of the tungsten phase is controlled by the powder mixing process . The ball milling time and mixing uniformity directly affect the quality of the phase distribution. The appropriate increase in sintering temperature promotes the flow of the copper liquid phase, enhances the connection between the phases, and optimizes the electrical conductivity. The interface quality also plays an auxiliary role. The good combination between tungsten and copper reduces electron scattering and maintains high conductivity.

This association makes tungsten copper alloys excel in applications that require high conductivity. For example, in electrical contacts or heat dissipation substrates, the continuous network of copper phases ensures efficient current transmission and meets the needs of high current density. The optimization of phase distribution also affects the arc erosion resistance. The uniform copper phase distribution reduces the arc energy concentration points and indirectly supports the stability of conductive properties. Optimizing phase distribution requires adjusting the copper content or using a multi-step sintering process to enhance the network structure of the copper phase to improve conductivity and meet the requirements of high-performance electrical applications.

3.2.4 Correlation between phase distribution and thermal conductivity

Phase distribution and thermal conductivity of tungsten-copper alloy is mainly reflected in the connectivity of copper phase and the dispersion of tungsten phase . Thermal conductivity is the ability of an alloy to transfer heat and is directly related to the uniformity of phase distribution. Copper is a highly thermally conductive phase, and its continuous network is the basis for heat conduction. When the copper phase forms a through path, heat can be transferred efficiently, significantly improving the heat dissipation performance of the alloy. As a low thermal conductivity enhancement phase, the dispersed distribution of tungsten phase will not significantly hinder the heat flow, but too high tungsten content may reduce the overall thermal conductivity because its thermal conductivity is inferior to that of copper. The uniformity of phase distribution is critical to thermal conductivity. The continuity of the copper phase depends on the full flow and penetration of copper during the liquid phase sintering process . If the tungsten particles agglomerate or the copper liquid phase is unevenly distributed, thermal resistance points may be formed, hindering heat transfer. The uniform dispersion of the tungsten phase is achieved through the powder mixing process. Good mixing ensures seamless connection between phases and optimizes the heat conduction path. Proper regulation of the sintering temperature promotes the wetting and filling of the copper liquid phase and enhances the heat transfer efficiency between phases. Interface quality also plays a role in this. The good combination between tungsten and copper reduces heat scattering and maintains efficient heat diffusion.

This relationship enables tungsten copper alloys to excel in applications that require high heat dissipation performance. For example, in power electronics or high-temperature equipment, the continuous network of copper phases can quickly disperse heat to prevent performance degradation caused by overheating. The optimization of phase distribution also affects arc erosion resistance. Uniform copper phase distribution helps to evenly diffuse heat and reduce local high-temperature damage caused by arcs. Adjustment of phase distribution requires optimizing copper content or using a multi-step sintering process to ensure that the copper phase forms an effective heat conduction network, thereby improving thermal conductivity and meeting high-performance thermal management requirements.

3.2.5 Effect of pores and defects on hardness

Pores and defects on the hardness of tungsten copper alloy are mainly reflected in the structural density and stress distribution. Hardness is the ability of an alloy to resist surface indentation or wear, which is

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directly related to the integrity of the microstructure. Porosity, as tiny gaps, reduces the overall density of the material and weakens its ability to resist deformation. Defects such as cracks or unwetted particles become stress concentration points, which can easily cause local failures and thus reduce hardness. The uniformity of the microstructure plays a key role in the performance of hardness, and the presence of pores and defects directly weakens the mechanical strength of the alloy.

The formation of pores is usually related to insufficient filling or material shrinkage during sintering. When the copper liquid phase fails to completely penetrate the gaps between tungsten particles, the residual voids will be dispersed inside the alloy. These pores are prone to cause stress concentration under external loads, causing the material to deform or break at lower pressures. Defects such as cracks may be generated by thermal stress during pressing or cooling, especially in areas of phase change or large temperature gradients. The expansion of cracks further reduces the hardness. Unwetted particles exist in isolation due to the lack of effective bonding with the copper phase , weakening the bearing capacity of the overall structure. These factors work together to reduce the surface resistance of the alloy.

The influence of pores and defects on hardness is also reflected in the stability of mechanical properties. Higher porosity leads to uneven hardness distribution, and obvious softening may occur in local areas. Especially in high-wear environments, pores can easily become the starting point of wear. The presence of defects exacerbates this effect, and cracks may propagate under repeated loading, accelerating material failure. Microstructure optimization can enhance hardness by eliminating pores and repairing defects, for example by improving the sintering process or using post-processing technology to enhance the density of the material. Optimizing the microstructure can significantly improve the durability of the alloy in mechanical impact or surface contact scenarios, making it more suitable for applications with high hardness requirements, such as electrodes or cutting tools.

3.2.6 Effect of pores and defects on corrosion resistance

Pores and defects on the corrosion resistance of tungsten copper alloy is mainly reflected in surface protection and medium penetration. Corrosion resistance is the ability of an alloy to resist erosion by environmental media (such as oxygen, moisture or chemicals), which is directly related to the integrity of the microstructure. Pores, as open or closed gaps, provide a channel for corrosive media to enter the interior, accelerating material degradation. Defects such as cracks or impurities become the starting point of corrosion, which can easily cause local corrosion or stress corrosion cracking, thereby reducing corrosion resistance. The compactness of the microstructure plays a decisive role in corrosion resistance.

The presence of pores allows the corrosive medium to penetrate into the alloy, especially in a humid or acidic environment, where the accumulated liquid in the pores may cause electrochemical corrosion. The copper phase, as a bonding phase, is susceptible to the corrosive medium, and the presence of pores intensifies the oxidation or dissolution of copper, weakening the overall stability of the alloy. Defects such as cracks provide an expansion path for corrosion, and the high stress state at the crack tip accelerates the corrosion reaction, especially under high temperature or arc action, where defects may quickly evolve into severe damage. Impurity agglomeration may also introduce additional electrochemically active sites, further reducing corrosion resistance.

The impact of pores and defects on corrosion resistance is also reflected in the performance during long-term use. Higher porosity leads to reduced surface protection capabilities, especially when exposed to corrosive gases or liquids. The corrosion products in the pores may block the channels but cannot prevent further erosion. The presence of defects makes the corrosion rate in local areas higher than the overall rate. Especially in stress corrosion or fatigue corrosion scenarios, defects may cause material cracking. Microstructure optimization enhances corrosion resistance by reducing pores and defects, such as reducing oxidation through vacuum sintering or using surface coatings to isolate corrosive media. The optimized alloy can maintain long-term stability in harsh environments and is suitable for applications requiring high corrosion resistance , such as marine equipment or chemical processing components.

3.3 Evolution of the microstructure of tungsten-copper alloy

Tungsten copper alloy will undergo dynamic evolution during the preparation and use process. Its change law is driven by multiple factors and directly affects the performance of the alloy. The evolution of the microstructure reflects the adaptability and stability of the material under different conditions, involving the adjustment of grain morphology, phase distribution and defect characteristics. The following will discuss in detail the evolution caused by changes in component ratios, structural transformations during heat treatment, and feedback from the use environment on the structure. Text descriptions are used to highlight the evolution mechanism, process characteristics and performance impact, emphasizing its importance in optimizing alloy applications.

3.3.1 Evolution caused by changes in composition ratios

The change in the composition ratio is an important driving factor in the evolution of the microstructure of tungsten-copper alloys . The grain distribution, phase interface and pore characteristics are affected by adjusting the ratio of tungsten to copper . When the tungsten content increases, its particles dominate the alloy and present a denser skeleton structure, while the copper phase gradually changes from a continuous network to a dispersed filling phase. This change causes the grain morphology to become regular, the interface area to decrease, and the porosity to increase due to insufficient copper liquid phase. On the contrary, when the copper content increases, the fluidity of the copper liquid phase increases, wetting the tungsten particles and filling the gaps, making the phase distribution more uniform, the grain boundaries gradually blurred, and the porosity decreased due to the filling effect of copper.

Adjustment of the composition ratio also triggers the evolution of the phase interface. When the tungsten content is high, the interface is mainly manifested as direct contact between tungsten particles, and the bonding strength depends on the sintering conditions; when the copper content increases, the interface is dominated by the copper phase , the wetting effect is enhanced, and the interfacial bonding force is improved, but thermal stress may be introduced. The grain size also adjusts with the change of the ratio . When the tungsten ratio is high, the grains remain larger in size, and when the copper ratio is high, the grains are refined due to liquid phase rearrangement. This evolution directly affects the density of the

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microstructure, and then adjusts the mechanical and electrical properties of the alloy.

This evolution law enables tungsten-copper alloys to adapt to different application requirements. For example, increasing the tungsten ratio enhances high temperature resistance and arc erosion resistance, making it suitable for high wear environments; increasing the copper ratio improves electrical conductivity and thermal conductivity, making it suitable for heat dissipation substrates. The control of evolution requires optimizing the powder mixing process and sintering parameters to ensure the coordinated development between the composition ratio and the microstructure.

3.3.2 Structural transformation during heat treatment

The heat treatment process is an important stage in the evolution of the microstructure of tungsten-copper alloys . It triggers changes such as grain growth, phase recombination, and defect elimination through the regulation of temperature, time, and atmosphere. In the early stage of heating, the copper phase melts first due to its lower melting point, wets the tungsten particles and fills the pores , making the phase distribution tend to be uniform. As the temperature rises, the grains begin to rearrange and grow. The tungsten particles may adjust their morphology due to thermal diffusion, and the grain boundaries gradually become clear or fused. Long-term heat treatment may cause the grains to be too large, thermal stress to appear at the interface, and the pores to be reduced or redistributed due to material shrinkage.

Heat treatment also induces a change in phase structure. The fluidity of the copper liquid phase enhances the connection between tungsten particles, and some unwetted areas may be filled, and the interfacial bonding force is improved. However, too high a temperature may cause copper to volatilize or oxidize, affecting the stability of the phase distribution. Defects such as cracks or impurity agglomerations may disappear or migrate during heat treatment, especially under pressure-assisted conditions, and the microstructure tends to be dense. The cooling process fixes these changes. Rapid cooling retains fine grains, and slow cooling promotes grain growth and phase stabilization.

This structural transformation allows the properties of tungsten copper alloys to be adjusted. For example, proper heat treatment enhances the uniformity and strength of the material, making it suitable for contact applications that require high reliability; overheating may reduce toughness, and parameters need to be carefully controlled. The optimization of heat treatment needs to be combined with specific processes, such as staged heating or inert atmosphere protection, to achieve the ideal evolution of the microstructure.

3.3.3 Feedback of the usage environment on the structure

The use environment on the microstructure of tungsten copper alloy is reflected in the structural adjustment and degradation caused by external conditions, involving factors such as temperature, humidity, current and mechanical stress. In a high temperature environment, the copper phase may soften or partially melt, the connection between tungsten particles is affected by thermal stress, and microcracks or peeling may occur at the interface. Long-term exposure to humid or corrosive environments makes the copper phase susceptible to oxidation or erosion, and the pores become the entry channel for corrosive media, accelerating structural degradation. Under the action of the arc, the surface grains may be reshaped due to high-temperature ablation, and the expansion of pores and defects aggravates the destruction of the microstructure.

The mechanical stress environment has significant feedback on the structure. Repeated loading may cause grain deformation or fracture, new cracks to form at the interface, and pores to expand due to stress concentration. When current passes through, local high temperature induces phase recombination, the copper phase may migrate or volatilize, and the tungsten skeleton structure is gradually exposed. Cyclic changes in the use environment, such as thermal cycling or arc switching, cause the microstructure to gradually adapt or deteriorate, and grain boundaries and phase distribution may undergo dynamic adjustments, affecting long-term performance.

This feedback makes the tungsten copper alloy show different durability in different environments. For example, in high-temperature arc scenarios, structural adjustments enhance corrosion resistance; while in humid environments, degradation accelerates life attenuation. Environmental feedback provides a basis for optimizing the design, and structural degradation can be mitigated through surface coatings or environmental control.

3.4 Control strategy of tungsten-copper alloy microstructure

Tungsten copper alloy aims to optimize the grain morphology, phase distribution, pore characteristics and interface quality through a variety of technical means to improve the electrical conductivity, thermal conductivity, mechanical strength and durability of the alloy. The control of microstructure is the key to achieving high-performance applications, covering the refinement of the preparation process, the optimization of the addition of alloy elements, and the in-depth exploration of the relationship between structure and performance. These strategies adapt to the diverse needs of electrical contacts, welding electrodes and high-reliability components through the adjustment of process parameters and the design of material composition.

3.4.1 Control methods based on preparation process

The control method based on the preparation process is the basis for regulating the microstructure of tungsten-copper alloy . The microscopic characteristics can be precisely adjusted by optimizing the mixing, pressing, sintering and post-processing links. The powder mixing process is the starting point of the regulation. The uniform mixing of tungsten powder and copper powder is achieved through high-energy ball milling or mechanical alloying technology. Good powder mixing effect can reduce particle agglomeration, ensure the uniform distribution of tungsten and copper phases , and lay the foundation for subsequent performance. Parameter adjustment during the powder mixing process , such as grinding time and medium selection, affects the powder particle size and morphology. Fine particles help to enhance strength, while larger particles may improve toughness. Selecting the appropriate powder particle size range is the key to controlling grain size, and the process design needs to be customized according to the target performance.

The pressing process forms the powder by applying pressure, preliminarily determining the grain arrangement and pore distribution. The uniformity of pressure directly affects the compactness of the green body. Too low pressure may lead to a loose structure and increase porosity, while too high pressure may cause particle rupture or stress concentration. The design of the pressing die and the optimization of process parameters can effectively control the density and geometric accuracy of the green body , providing a stable foundation for sintering. The microstructure of the green body after pressing preliminarily reflects the distribution characteristics of tungsten and copper , and the copper phase begins to show its wetting potential, preparing for liquid phase sintering. The refinement of the pressing process helps to reduce initial defects and lay a good foundation for the subsequent optimization of the structure.

The sintering process is the core stage of microstructure regulation. High-temperature treatment is used to achieve phase bonding and reduce porosity. Liquid phase sintering is a common method. Copper melts at high temperature, wets tungsten particles and fills gaps, enhancing interfacial bonding. Control of sintering temperature and time is key. Lower temperatures help retain fine grains, while higher temperatures promote full flow of the copper liquid phase and reduce unwetted areas. The choice of sintering atmosphere, such as vacuum or inert gas environment, can prevent the introduction of oxidative impurities, maintain the purity of tungsten and copper , and optimize phase distribution. Staged heating or pressure-assisted sintering technology further improves the microstructure, reduces porosity and enhances density, and is particularly suitable for applications requiring high strength and corrosion resistance. Optimization of the sintering process ensures the uniformity and stability of the microstructure.

Post-treatment processes provide a complementary means for fine-tuning the microstructure. Hot isostatic pressing eliminates residual porosity through omnidirectional pressure, improves the consistency of grain distribution, and enhances the overall performance of the material. Surface treatments such as polishing or coating techniques can repair defects and enhance corrosion resistance and arc erosion resistance. The heat treatment process regulates grain growth and phase stability and balances strength and toughness by adjusting temperature and cooling rate. The choice of different post-treatment methods depends on specific application requirements. For example, high conductivity applications may prioritize surface cleaning, while high wear-resistant applications may require hardening treatment. The control method based on the preparation process enables the microstructure of tungsten copper alloy to adapt to diverse performance requirements, providing solid support for high-reliability components.

3.4.2 Optimization methods of alloying element addition

The type and content of added elements directly affect the grain morphology, phase distribution, interface bonding and defect characteristics, aiming to improve electrical conductivity, thermal conductivity, mechanical strength or corrosion resistance. Common added elements include nickel, iron or cobalt, which can interact with tungsten and copper through chemical affinity or physical action to optimize the microstructure.

Nickel, as a common additive element, can significantly improve the wettability of copper to tungsten.

After adding nickel, the fluidity of the copper liquid phase during liquid phase sintering is enhanced, which makes the interface between tungsten particles closer and reduces the unwetted area and pores. This wetting improvement effect enhances the uniformity of phase distribution, thereby improving the density and strength of the material. Nickel may also form stable compounds at the grain boundaries, inhibiting grain growth, maintaining a fine grain structure, and helping to improve the alloy's resistance to deformation. The addition of iron mainly increases the diffusion rate during sintering, enhances the mutual penetration between tungsten and copper , improves the interface quality, and enhances the load transfer efficiency. Due to its ductility, cobalt can provide additional toughness support in the microstructure and buffer the brittle effect of the tungsten phase . Optimization of added elements also involves controlling their distribution and content. Excessive addition may introduce impurity agglomeration or phase separation, weakening the stability of the microstructure, so a balance must be achieved through precise ratios and process adjustments. The introduction of additive elements is usually completed at the powder mixing stage , by mixing with tungsten and copper powders to ensure their uniform dispersion. During the sintering process, the added elements may form a low-melting-point eutectic phase with copper, accelerate the formation of the liquid phase, and further optimize the microstructure. Subsequent heat treatment or surface treatment can further stabilize the effect of the added elements and enhance their contribution to performance.

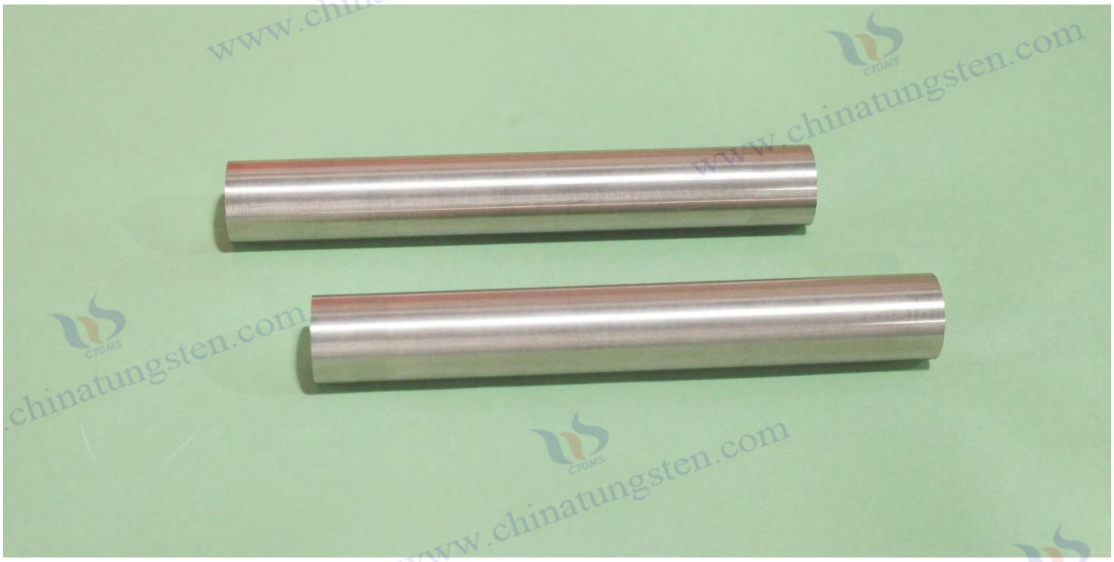
This optimization method enables the microstructure of tungsten copper alloy to adapt to specific application requirements. For example, in electrodes that require high strength, the addition of nickel enhances interface bonding and density; in contacts that require high toughness, the addition of cobalt improves impact resistance. The regulation of added elements also supports the improvement of corrosion resistance and arc erosion resistance, and extends service life by reducing defects and optimizing phase distribution. Future development directions include exploring new added elements or composite phases, combining intelligent design technology, and dynamically optimizing the microstructure to further improve the comprehensive performance of tungsten copper alloys .

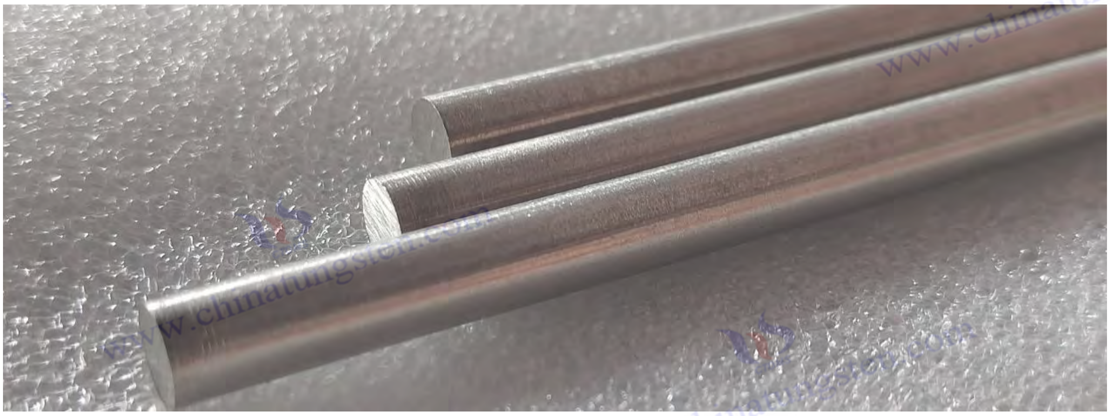
3.4.3 Relationship between structural regulation and performance

Structural regulation and the performance of tungsten-copper alloys is reflected in the fact that the optimization of the microstructure directly affects its electrical conductivity, thermal conductivity, mechanical strength and durability. This relationship is achieved through the adjustment of grain morphology, phase distribution, pore characteristics and interface quality, reflecting the decisive role of microstructure on macroscopic performance. The refinement of the grain structure enhances the material's resistance to deformation by increasing the grain boundary density, thereby improving strength and hardness, and may have a certain effect on toughness. The uniformity of phase distribution determines the efficiency of the electrical and thermal conduction paths. The continuous network of the copper phase optimizes the transfer of electrons and heat, while the dispersion of the tungsten phase provides support for high temperature resistance and wear resistance.

The control of pores and defects is a key link in the relationship between structural regulation and performance. The reduction of pores improves the density of the material, enhances the bending strength and surface resistance, while reducing thermal resistance and electrical resistance, and improving electrical and thermal conductivity. The elimination of defects such as cracks or unwetted particles reduces stress concentration points and improves fatigue resistance and corrosion resistance. The improvement of interface quality indirectly supports mechanical properties and arc erosion resistance by enhancing the bonding force between phases, optimizing load transfer and heat diffusion efficiency. The comprehensiveness of structural regulation lies in its ability to balance the mutual constraints between these properties to meet the needs of diverse applications.

This relationship enables the properties of tungsten copper alloys to be optimized based on microstructural adjustments. For example, in heat dissipation substrates with high conductivity requirements, the continuous distribution of copper phases and the reduction of porosity significantly improve the performance; in electrodes with high wear resistance requirements, fine grains and dense tungsten skeletons enhance durability. The strategy of structural regulation also reveals the limitations of performance. Too fine grains may reduce toughness, and too high tungsten content may increase brittleness. Comprehensive regulation is needed to achieve a balance in performance.





CTIA GROUP LTD Tungsten Copper Alloy

Chapter 4 Preparation Technology of Tungsten Copper Alloy

The preparation process of tungsten-copper alloy is the key to producing high-performance composite materials, involving a variety of technical methods to achieve a uniform combination of tungsten and copper . Tungsten-copper alloy is widely used in electrical, electronic and industrial fields due to its excellent electrical conductivity, thermal conductivity, high temperature resistance and arc corrosion resistance. The goal of the preparation process is to optimize the microstructure and performance of the alloy by controlling raw materials, process parameters and equipment conditions. Different preparation methods such as vacuum infiltration, powder metallurgy and copper infiltration have their own characteristics and are suitable for specific application scenarios.

4.1 Preparation of tungsten-copper alloy by vacuum infiltration

The preparation of tungsten-copper alloy by vacuum infiltration is a preparation method that infiltrates liquid copper into the interior of the tungsten skeleton at high temperature, aiming to form a dense and uniform composite structure. This process uses the high melting point of tungsten and the low melting point of copper to prepare a porous tungsten skeleton by sintering , and then melts copper in a vacuum environment and infiltrates it. The vacuum environment is the core feature of the process, which can remove oxygen and impurities in the air, prevent oxidation reactions, and ensure good bonding between the copper liquid and the tungsten skeleton. The process includes the preparation of the tungsten skeleton, the infiltration of copper, and cooling and solidification. The control of each stage directly affects the microstructure and performance of the alloy. Vacuum infiltration is particularly suitable for components that require high conductivity and high temperature resistance, such as high-voltage circuit breaker contacts and resistance welding electrodes, because it can achieve high density and uniform phase distribution. The optimization of the process focuses on improving the uniformity of penetration, reducing porosity, and enhancing interface bonding to meet diverse application requirements.

4.1.1 Infiltration principle and equipment requirements

Preparing tungsten-copper alloy by vacuum infiltration is based on the permeability characteristics of liquid copper in a vacuum environment. Copper is infiltrated into the interior of the tungsten skeleton by high temperature to form a uniform composite material. The core of the infiltration process is that the low melting point of copper turns it into liquid under heating, and uses capillary action and gravity effect to infiltrate into the tiny pores of the tungsten porous skeleton. As a high melting point material, tungsten remains solid and forms a stable skeleton to provide support for the penetration of copper. The vacuum environment eliminates oxygen and impurities in the air to prevent oxidation reactions and ensure that the copper liquid can fully wet the tungsten surface. The temperature and vacuum degree during the infiltration process regulate the fluidity and penetration depth of the copper liquid, which directly affects the microstructure and properties of the alloy. The key to the success of the process lies in the good interface bonding and penetration uniformity between the copper liquid and the tungsten skeleton. The interface quality and pore distribution become important factors in determining the performance. Specialized equipment is required to achieve this process. The core equipment is a vacuum infiltration furnace equipped with a high-temperature heating system and an efficient vacuum pump to maintain a stable vacuum environment to prevent oxidation and gas residue. The heating system uses resistance heating or induction heating technology, and must have the ability to uniformly heat up and accurately control temperature to ensure that the copper is completely melted and penetrates into every corner of the tungsten skeleton. The vacuum pump must have a high pumping speed and a low leakage rate to achieve a low-pressure state and avoid interference from impurities. The mold or crucible is used to support the tungsten skeleton and contain liquid copper. The material must be resistant to high temperatures and have no chemical reaction with tungsten and copper to prevent contamination or structural damage. Auxiliary equipment such as temperature sensors and pressure monitoring systems are used to monitor process parameters in real time to ensure operational consistency. Together, these devices ensure the efficiency and reliability of the vacuum infiltration process and ensure that the microstructure of the alloy meets the expected performance requirements.

4.1.2 Process steps and parameter optimization

Preparing tungsten copper alloy by vacuum infiltration is a systematic process involving coordinated operations at multiple stages to ensure that the microstructure and properties of the alloy meet the expected goals. The process starts with the preparation and molding of tungsten powder, and a porous tungsten skeleton is formed by pressing or preliminary sintering. At this stage, attention should be paid to the porosity and mechanical strength of the skeleton to provide a suitable channel for the subsequent copper infiltration . Next, the prepared tungsten skeleton is placed in a vacuum infiltration furnace, an appropriate amount of copper material is added, the furnace body is sealed and the vacuum system is started to remove oxygen and impurities in the air to create a pure environment for infiltration. The heating stage is the core of the process. The temperature needs to be gradually increased to above the melting point of copper, allowing the copper liquid to melt and naturally infiltrate in a vacuum environment. The insulation stage ensures that the copper liquid fully fills the pores of the tungsten skeleton by extending the processing time, optimizing the phase distribution and interface bonding. The cooling stage controls the cooling rate to fix the microstructure and prevent defects or inhomogeneities caused by thermal stress. The smooth progress of each step depends on the precise control of process parameters to ensure the quality of the final product.

The focus of parameter optimization is on the coordination of temperature, vacuum and time. Temperature control needs to be carried out in stages. The low-temperature preheating stage reduces thermal shock, the high-temperature stage ensures complete melting of copper, and the intermediate transition stage balances heat distribution to avoid local overheating. The adjustment of vacuum directly affects the wetting effect and impurity content of the copper liquid. Too low vacuum may cause residual gas to affect penetration. Too high vacuum requires a balance between equipment complexity and process efficiency, and needs to be dynamically adjusted according to actual needs. Time optimization involves the allocation of time for each stage of heating, insulation and cooling. Too short may lead to insufficient penetration or residual pores, and too long may cause excessive grain size or copper volatilization, affecting performance. The process flow also needs to consider the pretreatment of the tungsten skeleton, such as surface cleaning or pore adjustment, to enhance the penetration ability of copper. The dynamic adjustment of parameters is achieved through process simulation and experimental verification to ensure the density and uniformity of the microstructure and provide support for performance improvement.

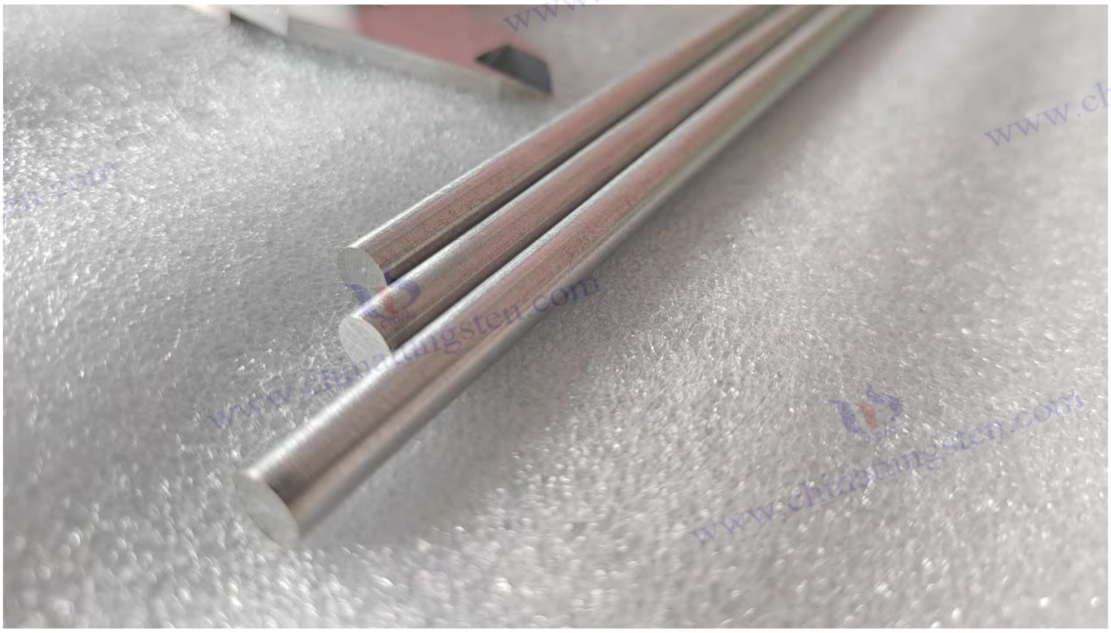
The optimization of the process steps significantly affects the performance of the alloy. Uniform temperature distribution and sufficient penetration time can improve electrical and thermal conductivity, making it suitable for heat dissipation substrate applications; stable vacuum environment and appropriate cooling rate enhance mechanical strength and corrosion resistance, making it suitable for electrode components. Each step in the process needs to be closely linked to the previous stage. Loss of control in any link may lead to increased defects or uneven phase distribution. Future development directions include the introduction of intelligent monitoring systems to dynamically optimize parameters by real-time tracking of temperature, vacuum level and penetration depth to improve process efficiency and product quality. This method provides a reliable guarantee for the industrial production of tungsten-copper alloy .

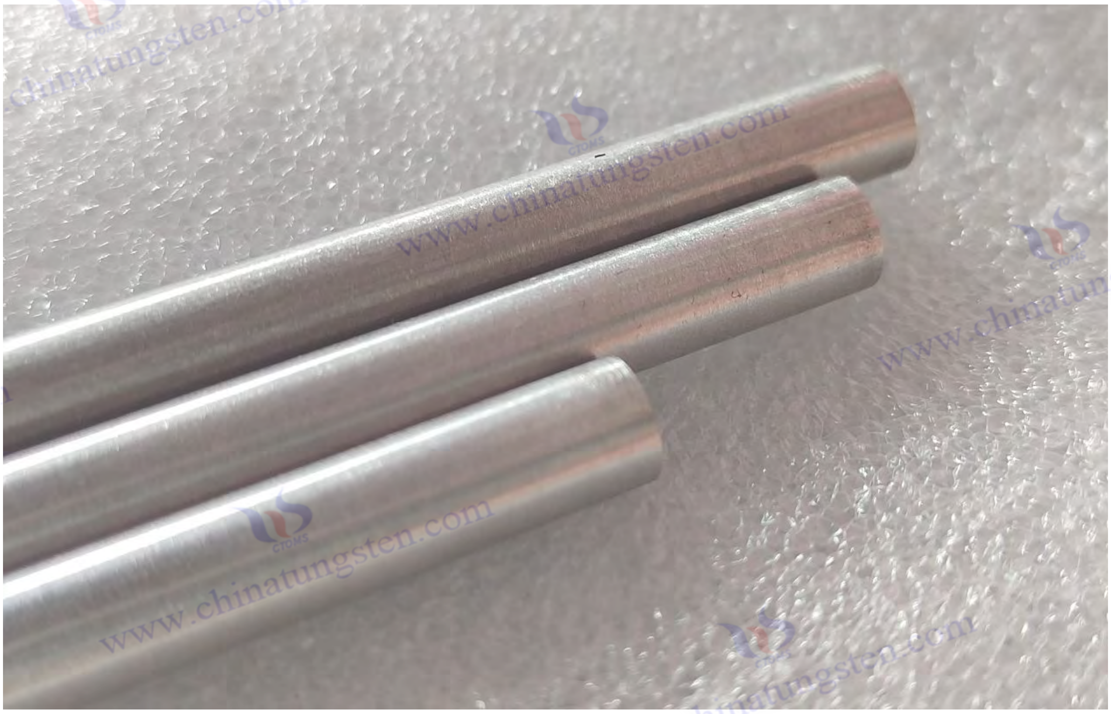
4.1.3 Advantages and limitations of the process

Preparing tungsten-copper alloy by vacuum infiltration shows significant advantages due to its unique process characteristics, but it also has certain limitations. These characteristics jointly determine its scope of application and optimization direction. One of the advantages is its high density. The full penetration of copper liquid in a vacuum environment can significantly reduce porosity and enhance the overall strength and stability of the material. This dense structure provides the alloy with excellent mechanical properties and durability, making it particularly suitable for applications subject to high loads. Another advantage is the uniform phase distribution. The good combination of tungsten skeleton and copper phase optimizes electrical and thermal conductivity, making the alloy perform well in high current and high temperature environments. The protection of the vacuum environment reduces the introduction of oxidative impurities, maintains the purity of the material, and lays a reliable foundation for long-term use. In addition, the controllability of the process enables it to produce complex shapes or large-sized parts, meeting diverse processing needs and demonstrating its flexibility.

However, the process also has some limitations. The equipment complexity and operating costs are high, and the maintenance requirements of the vacuum furnace and related auxiliary equipment are strict, which increases the production input and limits its application in cost-sensitive scenarios. The process cycle is long and involves multi-stage operations. It takes a lot of time from tungsten skeleton preparation to copper infiltration, which may affect the efficiency of mass production. The risk of copper volatilization or uneven infiltration may exist under certain conditions, especially when the porosity of the tungsten skeleton is mismatched or the vacuum degree is insufficient, affecting the stability of product quality. In addition, the process is highly dependent on raw material purity and pretreatment. Any raw material defects or inhomogeneities may be transmitted to the final product, requiring additional quality control and process adjustments.

These advantages and limitations together shape the application scenarios of tungsten copper alloys prepared by vacuum infiltration. The advantages give it an advantage in fields that require high performance, such as high-voltage circuit breaker contacts, where the high density and conductivity of the alloy ensure reliable switching performance; in resistance welding electrodes, uniform phase distribution and high temperature resistance support long-term use. In the aerospace field, complex-shaped tungsten copper parts such as heat sinks and electrical contacts also benefit from this process. Limitations suggest that it needs to be supplemented with other methods such as powder metallurgy to reduce costs or improve efficiency.





CTIA GROUP LTD Tungsten Copper Alloy

CTIA GROUP LTD

Tungsten Copper Alloy Introduction

1. Overview of Tungsten Copper Alloy

Tungsten Copper Alloy is a composite material made from tungsten and copper, typically containing 10% to 50% copper by weight. This alloy combines the outstanding properties of both metals—retaining tungsten's high-temperature resistance and excellent arc erosion resistance, while benefiting from copper's superior thermal and electrical conductivity. It delivers exceptional comprehensive performance in high-end fields such as electrical engineering, power systems, electronics, and aerospace. CTIA GROUP LTD offers a wide range of customized tungsten copper alloy solutions, featuring high density, stable performance, and precise processing tailored to customer requirements for components such as electrodes, thermal management parts, and vacuum system elements.

2. Typical Properties of Tungsten Copper Alloy

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm³)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten Copper Alloys

Power Equipment: Contacts for high-voltage vacuum switches; Conductive parts for circuit breakers; Components for high-power relays and arc-fault interrupters

Electronics and Semiconductor Industry: Heat-dissipating substrates for IGBT modules; Cooling plates for microwave components; Package lids and electronic base plate

Electrical Discharge Machining (EDM): Electrode materials for EDM, especially suitable for machining hard alloy molds; High-precision forming electrodes for fine EDM processes

Aerospace and Defense: High-temperature structural parts such as rocket nozzles and tail cones

4. Purchasing Information

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Chapter 5 Performance Testing and Characterization Methods of Tungsten Copper Alloy

Tungsten copper alloy is an important means to evaluate its electrical conductivity, thermal conductivity, mechanical strength and durability, which directly determine its application effect in electrical, electronic and industrial fields. The test method covers the measurement of physical properties, mechanical properties and electrical properties, and reveals the relationship between the microstructure and macroscopic properties of the alloy through standardized operations and advanced characterization techniques.

5.1 Physical properties test of tungsten copper alloy

Tungsten copper alloy is aimed at evaluating its basic physical properties, such as density, electrical conductivity and thermal conductivity, which are closely related to its microstructure and preparation process. Density test reflects the compactness of the alloy, which directly affects the electrical conductivity and mechanical strength; electrical conductivity test evaluates the electron transmission ability, which is suitable for electrical contacts; thermal conductivity test measures the heat dispersion efficiency, which is key to heat dissipation applications. Physical property tests are carried out by non-destructive or minimally destructive methods to ensure the integrity of the sample while providing reliable data support. The test results provide a basis for process optimization and performance improvement. This section will focus on the density test method and hardness test standards and operations.

5.1.1 Density test method

The density test method is used to measure the unit volume mass of tungsten copper alloy , which reflects the compactness and porosity content of its microstructure and is an important indicator for evaluating the preparation quality. The test principle is based on the Archimedean principle. By measuring the weight difference of the sample in the air and the liquid, its true density is calculated. The operation process first requires the preparation of samples with regular shapes or no obvious defects, and then cleaning and drying to remove surface impurities. Next, the sample is suspended on a precision balance, its weight in the air is recorded, and then it is immersed in a liquid of known density (such as distilled water) to measure its buoyant weight in the liquid. The weight difference is combined with the density of the liquid to obtain the volume of the sample, and finally the density is calculated by dividing the mass by the volume.

The test method requires strict experimental conditions to ensure accuracy. The liquid temperature must be kept constant to avoid the influence of thermal expansion on the density value; the accuracy of the balance must be sufficient to detect small weight changes and reduce measurement errors. There must be no bubbles attached to the surface of the sample, which can be achieved by vacuum degassing or surface treatment. During the test, multiple measurements are taken and the average is taken to eliminate accidental errors. The density test is suitable for detecting porosity and uniformity in the preparation process. A lower density may indicate a higher porosity content, while a higher density reflects better

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compactness. The test results provide a direct basis for optimizing the sintering process and reducing defects, and are widely used in quality control and performance evaluation.

5.1.2 Hardness test standards and operations

Hardness test standards and operations are used to evaluate the ability of tungsten copper alloy to resist surface indentation or wear, reflecting its mechanical properties and durability. The test principle is based on applying a specific load to the sample surface with a standardized indenter, measuring the depth or area of the indentation, and indirectly indicating the material's ability to resist deformation. Common test standards include Brinell hardness, Rockwell hardness, and Vickers hardness, which are suitable for different hardness ranges and sample characteristics. Brinell hardness applies a large load through a steel ball indenter, which is suitable for softer or uniform materials; Rockwell hardness uses a diamond cone or steel ball to quickly measure thin samples or surface hardness; Vickers hardness uses a diamond quadrangular pyramid indenter, which is suitable for small areas or complex structures.

The operation process first requires the preparation of a flat sample surface, removing roughness by grinding or polishing, and ensuring that the indenter is in full contact with the surface. Select the appropriate test standard and indenter type, and determine the load and indentation time according to the sample size and expected hardness range. After applying the load, remove the indenter, measure the geometric characteristics of the indentation, such as the diameter or diagonal length, and use a microscope or special instrument for accurate reading. The test needs to be repeated at multiple points to eliminate the influence of surface inhomogeneity , and calculate the average value to obtain representative results. During the operation, attention should be paid to the ambient temperature and humidity to avoid external factors interfering with the measurement accuracy. Hardness testing is of great significance in performance evaluation. High hardness is usually associated with fine grains and dense structure, reflecting the wear resistance of the alloy, which is suitable for electrode or cutting tool applications. The test results can also be used to detect defects in the preparation process, such as pores or unwetted areas, which may lead to local hardness reduction. Standardized operations ensure the comparability of test results and provide a scientific basis for material selection and process improvement.

5.1.3 Conductivity test method

The conductivity test method is used to evaluate the ability of tungsten copper alloy to transmit current. It reflects the connectivity of the copper phase in its microstructure and the effectiveness of the conductive path. It is a key indicator for measuring the electrical properties of the alloy. The test principle is based on Ohm's law. By measuring the current of the sample at a specific voltage, its conductivity is calculated. The operation process first requires the preparation of a sample of regular shape, and the surface needs to be polished to reduce the influence of contact resistance. Use the four-probe method or the two-probe method for measurement. The four-probe method places four electrodes on the surface of the sample, applies current and measures voltage respectively, and eliminates contact resistance interference; the two-probe method directly measures the voltage and current at both ends, which is suitable for longer samples. The test equipment includes a precision power supply, an ammeter, and a

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voltmeter to ensure measurement accuracy.

The test process needs to be carried out under a constant temperature and humidity environment to avoid environmental factors affecting conductivity. The sample needs to be firmly in contact with the electrode, and a good connection can be achieved by clamping or conductive paste . After applying a stable current, record the voltage and current values, calculate the resistivity, and convert it into conductivity based on the sample geometry. The average value of different points is measured multiple times to ensure the representativeness of the results and exclude local inhomogeneities. The conductivity test is suitable for detecting the influence of the preparation process on the distribution of copper phases . Higher conductivity is usually associated with a continuous network of copper phases, reflecting a good microstructure.

5.1.4 Thermal conductivity test method

The thermal conductivity test method is used to evaluate the ability of tungsten copper alloy to transfer heat. It reflects the influence of phase distribution and interface quality in its microstructure on heat conduction and is an important indicator for measuring heat dissipation performance. The test principle is based on Fourier's law. The thermal conductivity is calculated by measuring the heat transfer rate in the sample. The operation process first prepares a sample of regular shape. The surface must be flat to ensure good thermal contact . Commonly used methods include steady-state method and transient method. The steady-state method measures the temperature gradient by applying a constant heat flux at both ends of the sample; the transient method briefly heats the sample surface, records the temperature change over time, and infers the thermal diffusivity.

The test process needs to be carried out in a controlled temperature environment, using a heat source and thermocouples or infrared sensors to measure the temperature distribution. The steady-state method requires stable temperatures at both ends of the sample and uniform heat flow, and thermal insulation materials are required to reduce lateral heat dissipation; the transient law requires fast- response equipment, such as a laser flash meter, to capture temperature changes. The geometric dimensions and contact surfaces of the sample need to match the test equipment to ensure a clear heat transfer path. Take the average value of multiple tests to eliminate experimental errors. Thermal conductivity testing is suitable for evaluating the impact of preparation processes on the connectivity of copper interconnects. Higher thermal conductivity is usually associated with uniform phase distribution and low porosity, which is suitable for heat dissipation substrate applications. The test results provide a scientific basis for optimizing thermal management performance, and in the future, thermal imaging technology can be combined to improve measurement accuracy.

5.2 Chemical property evaluation of tungsten copper alloy

Tungsten copper alloy aims to study its corrosion resistance and chemical stability in different environments, reflecting the influence of microstructure on environmental adaptability, which is the key to ensure long-term reliability. The evaluation methods include immersion test, corrosion rate measurement and surface analysis, which simulate the use environment to observe the chemical reaction and degradation behavior of the alloy. The operation process first prepares the sample, the surface needs to be cleaned to remove impurities, and then placed in an acid, salt or humid environment to simulate the use conditions. The immersion test observes surface changes by exposing the sample for a long time; the corrosion rate measurement calculates the reaction rate by weight loss or thickness reduction; surface analysis such as scanning electron microscopy or X-ray photoelectron spectroscopy is used to detect the composition and distribution of corrosion products.

The evaluation process needs to control environmental parameters such as temperature, humidity and medium concentration to avoid external interference. Take samples regularly, clean and dry them, observe the weight or surface, and record the trend of changes. Take the average value of multiple tests to eliminate accidental factors. Chemical performance evaluation is suitable for detecting the sensitivity of copper to corrosion. Porosity and defects may accelerate medium penetration and reduce stability. The evaluation results provide a basis for optimizing surface treatment and selecting corrosion-resistant coatings, which are widely used in marine equipment and chemical processing components.

5.2.1 Corrosion resistance test environment and methods

The corrosion resistance test environment and method are used to evaluate the corrosion resistance of tungsten copper alloy in different media, reflecting the adaptability of its microstructure and composition to the chemical environment, and are the key to ensuring long-term stability. The test environment needs to simulate actual use conditions, such as humid, acidic or salty environments, to reproduce possible corrosion scenarios. The operation process first prepares a flat sample, cleans the surface to remove impurities, and ensures that the test results are not affected by contamination. Commonly used test environments include salt spray chambers, acid solution immersion tanks or wet heat chambers. Salt spray chambers simulate marine or industrial environments, acidic solutions such as sulfuric acid or hydrochloric acid simulate chemical processing conditions, and wet heat chambers simulate the combined effects of high humidity and temperature. The samples are placed in these environments, exposed for a certain period of time, and surface changes are observed regularly.

The test methods include weight loss method and electrochemical method. The weight loss method calculates the corrosion rate by the change in sample weight before and after immersion, and requires accurate weighing and recording of time; the electrochemical method measures corrosion potential and current density through a potentiometer to evaluate the dynamic behavior of the corrosion process. Environmental parameters such as temperature, medium concentration and exposure time need to be controlled during the test to avoid interference from external factors. The average value is taken from multiple tests to eliminate accidental errors, and the corrosion morphology is observed under a microscope. The corrosion resistance test is suitable for detecting the sensitivity of copper to relative corrosion. Porosity and defects may accelerate medium penetration and affect stability. The test results provide basis for optimizing surface protection and selecting corrosion-resistant applications. In the future, multi-factor coupling environment can be developed to enhance the practical significance of the test.

5.2.2 Antioxidant performance test method

The oxidation resistance test method is used to evaluate the oxidation resistance of tungsten copper alloy in high temperature or oxygen-containing environment, reflecting the resistance of its microstructure to oxidation, and is an important indicator for high reliability applications. The test principle is based on exposing the sample to an oxidizing atmosphere to observe the formation of the surface oxide layer and the degree of material degradation. The operation process first prepares the sample, polishes the surface to remove the oxide, and ensures that the initial state is consistent. Common methods include high-temperature oxidation test and cyclic oxidation test. The high-temperature oxidation test places the sample in a high-temperature furnace, passes air or oxygen, and continuously heats to observe the oxidation behavior; the cyclic oxidation test simulates thermal cycle conditions, alternately heats and cools, and evaluates the oxidation resistance stability. The test equipment must have precise temperature control and gas supply capabilities.

During the test, it is necessary to record the heating time, temperature and thickness of the oxide layer, take out samples regularly, clean and weigh them, and calculate the mass increment or surface change. Microscope or X-ray diffraction analysis can be used to detect the composition and distribution of oxidation products. The test environment needs to maintain a stable oxygen concentration to avoid interference from other gases. Take the average value of multiple tests to eliminate experimental errors. The antioxidant performance test is suitable for detecting the oxidation tendency of the copper phase at high temperature. The stability of the tungsten phase plays a protective role, and the pores may aggravate oxidation. The test results provide guidance for optimizing high-temperature processes and selecting antioxidant coatings. In the future, real-time monitoring technology can be combined to improve test accuracy and application value.

5.3 Characterization technology of tungsten copper alloy microstructure

Characterization techniques include optical microscope, scanning electron microscope and transmission electron microscope. Optical microscope is used to observe macroscopic surface features, scanning electron microscope provides high-resolution morphology and composition analysis, and transmission electron microscope deeply studies grain boundaries and phase interfaces. The operation process first prepares the sample, which needs to be cut, ground and polished. Some technologies require thinning or etching to enhance contrast.

The testing process requires the selection of appropriate conditions according to the technology. Optical microscopy observation requires appropriate staining, scanning electron microscopy requires a vacuum environment and electron beam adjustment, and transmission electron microscopy requires high-precision sample preparation. The analysis results quantify the grain size and pore distribution through image processing software, and determine the phase composition in combination with energy spectrum analysis. Characterization technology is suitable for detecting the influence of preparation process on microstructure, and grain refinement and phase distribution uniformity improve performance. The results provide a scientific basis for process optimization and defect control, and in the future, it can be combined with three-dimensional imaging technology to fully characterize the microstructure.

5.3.1 Metallographic microscope observation method

The metallographic microscope observation method is used to observe the microstructural characteristics of tungsten-copper alloys , such as grain morphology, phase distribution and porosity, and reveal the influence of the preparation process on the microstructure. The test principle is based on the reflection or transmission of visible light through the sample surface to magnify and observe microscopic details. The operation process first requires sample preparation, which involves cutting, grinding and polishing to obtain a flat surface, followed by chemical etching or electrolytic polishing to enhance the contrast between tungsten and copper phases and make grain boundaries and phase boundaries more visible. The sample is fixed on the stage, and the focus and light source of the microscope are adjusted to observe the microstructure at different magnifications. During the test, it is necessary to select an appropriate lighting mode, such as bright field or dark field, to enhance the visibility of specific features. The operator records the image through the eyepiece or digital imaging system to analyze the grain size, phase distribution uniformity and defects. Observe different areas multiple times to ensure representativeness and exclude the influence of local inhomogeneity . Metallographic microscope observation is suitable for preliminary evaluation of the effect of the preparation process. Grain refinement or phase distribution optimization is usually associated with performance improvement.

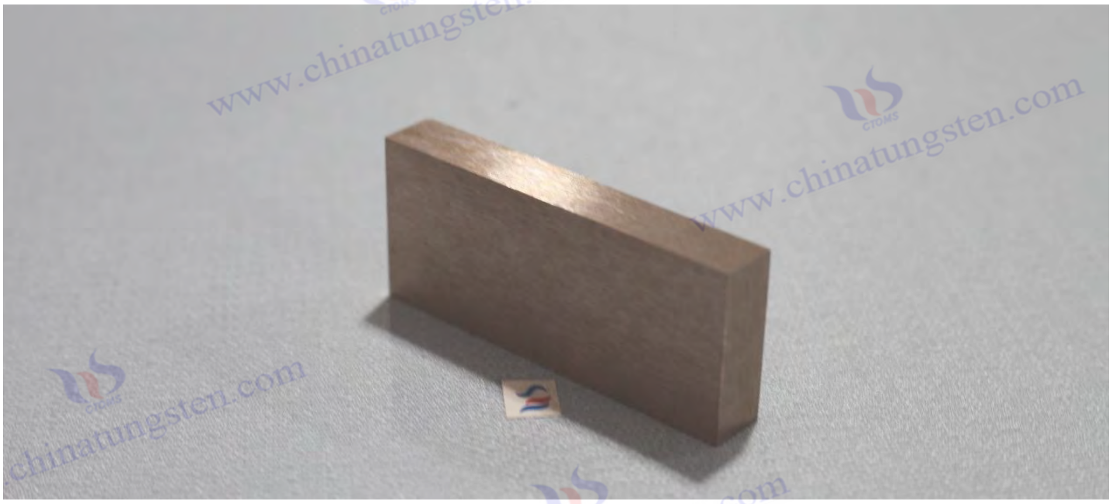
5.3.2 Scanning electron microscope analysis application

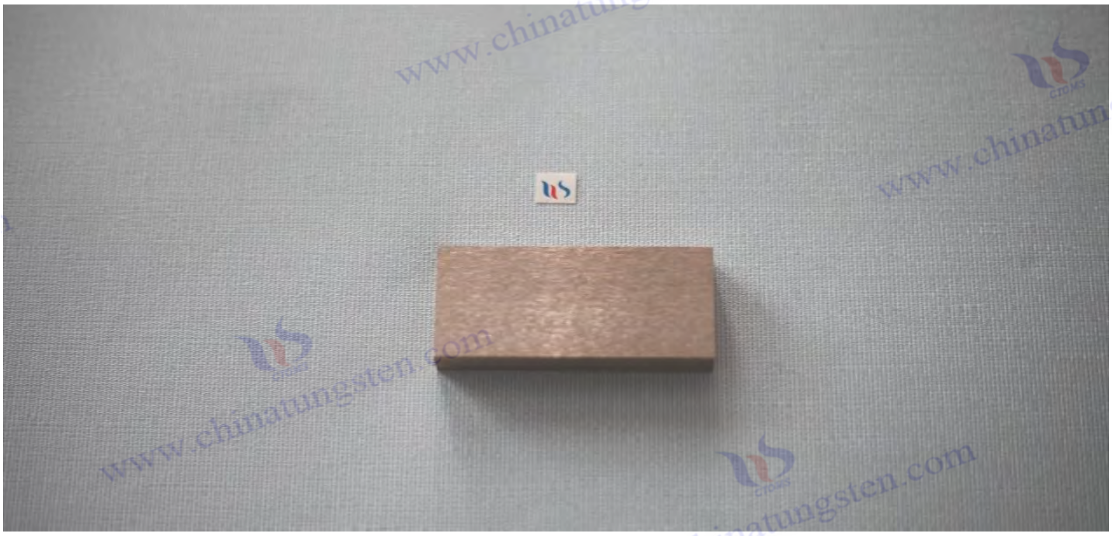
Scanning electron microscopy analysis is used to characterize the microstructure and composition distribution of tungsten copper alloys with high resolution, revealing subtle features of grain morphology, phase interfaces and defects. The test principle is based on the electron beam bombarding the sample surface, generating secondary electrons and backscattered electrons to generate morphological and compositional information. The operation process first prepares the sample, which needs to be cut, ground, polished and subjected to conductive treatment, such as gold spraying or carbon coating, to prevent charging effects. The sample is placed in a vacuum chamber, and the electron beam parameters, such as acceleration voltage and working distance, are adjusted to scan the sample surface. During the test, the secondary electron image provides surface morphological details, the backscattered electron image highlights the contrast of different phases, and the energy dispersive spectrum (EDS) analysis determines the element distribution. The operator can adjust the magnification and detector mode to observe the grain boundaries, pores and phase distribution. Scan different areas multiple times to ensure comprehensiveness, and combine software to process the data. Scanning electron microscopy analysis is suitable for detecting microscopic changes caused by the preparation process, such as reduced pores or improved interfaces, and the relevant results guide performance optimization.

5.3.3 X-ray diffraction structure analysis

X-ray diffraction structure analysis is used to determine the crystal structure, phase composition and lattice parameters of tungsten copper alloys , and to explore the relationship between microstructure and performance. The test principle is based on the Bragg diffraction of X-rays with the sample crystal plane to produce characteristic spectral lines that reflect the atomic arrangement inside the material. Operation process Prepare powder or flat samples, grind to an appropriate particle size or polish the surface to avoid texture effects. Place the sample in the X-ray diffractometer, adjust the X-ray source and detector angles, and scan a certain range of 2θ angles.

During the test, the position and intensity of the diffraction peaks are recorded, the crystal phase characteristics of tungsten and copper are analyzed, and possible impurities or oxides are detected. The operator can use the software to fit the peak shape and determine the grain size and strain. Multiple measurements are averaged to eliminate instrument errors. X-ray diffraction analysis is suitable for evaluating the impact of sintering process on the crystal phase . The sharpness of the peak reflects the grain size, and the peak offset indicates the stress state. The results provide a basis for microstructure optimization and performance prediction, and in the future, synchrotron radiation technology can be combined to improve accuracy.





CTIA GROUP LTD Tungsten Copper Alloy

Chapter 6 Multiple Application Fields of Tungsten Copper Alloy

Tungsten copper alloys benefit from their unique physical and chemical properties, covering multiple industries such as electrical, aviation, electronics and industrial manufacturing. Its excellent electrical conductivity, thermal conductivity, high temperature resistance and arc erosion resistance make it an ideal choice for high-performance components. The application areas are constantly expanding, involving low-voltage power switches, high-voltage circuit breakers, heat sinks and EDM electrodes. Tungsten copper alloys meet diverse performance requirements through different preparation processes and structural designs.

6.1 Application of tungsten copper alloy in electrical field

Tungsten copper alloy is widely used in the electrical field, especially in scenes requiring high conductivity and resistance to arc erosion. The electrical field includes low-voltage power switches, high-voltage circuit breakers and electrical contacts. Tungsten-copper alloy meets the requirements of high current, high voltage and frequent switching due to its high melting point of tungsten and high conductivity of copper . The microstructure of the alloy is optimized through powder metallurgy or vacuum infiltration process, and the phase distribution and density directly affect its performance. In low-voltage power switches, tungsten copper alloy is a key component that significantly improves the reliability and durability of the equipment.

6.1.1 Application in low voltage power switch

Tungsten copper alloy in low-voltage power switches is an important manifestation of tungsten copper alloy in the electrical field, especially in contact components. Low-voltage power switches are used to control the on and off of circuits. Frequent switching actions and arc generation place strict requirements on materials. Tungsten copper alloy meets these requirements through its high resistance to arc erosion and conductivity, and is widely used in household appliances, industrial control and power distribution systems. There are various application forms, including moving and static contacts and electrode components, and process optimization ensures performance stability. This section will discuss in detail the performance requirements of core components, application forms, and the effect of improving service life.

6.1.1.1 Performance requirements for materials of core components of low-voltage power switches

The performance requirements of materials for the core components of low-voltage power switches, such as contacts and electrodes, cover multiple aspects to ensure the safety and reliability of the equipment. First, the material must have excellent electrical conductivity to efficiently transmit current and reduce energy loss and heat generation. Good thermal conductivity is another key requirement, which can quickly disperse the heat generated by arcs or high currents to prevent local overheating. Secondly, the material must have high resistance to arc erosion to resist surface ablation caused by arcs during switching to ensure stability in long-term use. In addition, high temperature resistance is crucial, and the core components must withstand extreme temperatures without deformation or melting when high currents are disconnected. Mechanical strength and wear resistance are also necessary to support frequent mechanical switching actions and prevent wear or breakage. Corrosion resistance helps maintain performance in humid or industrial environments. Finally, the material needs to have appropriate hardness to withstand contact pressure while maintaining sufficient toughness to avoid brittle fracture. These requirements jointly determine the material selection of low-voltage power switch components, and tungsten copper alloy is the first choice due to its comprehensive performance.

6.1.1.2 Application of tungsten copper alloy in contact components

Tungsten copper alloy in low-voltage power switch contact assemblies vary, depending on the design requirements and usage conditions. One common form is to make tungsten copper alloy into contact material, which is directly used for the moving and static contacts of the switch, and withstands frequent on-off operations with its high conductivity and arc erosion resistance. The alloy is usually prepared with a higher tungsten content ratio (such as WCu 70/30 or WCu 80/20). Tungsten provides high temperature resistance and anti-wear support, and copper ensures the continuity of the conductive path. Another form is a composite structure, which uses tungsten copper alloy as the contact surface layer, combined with other substrates such as copper or steel, and integrated by welding or press- fitting to optimize the balance between cost and performance.

In applications, tungsten copper alloys can also be made into specific shapes, such as round or rectangular contacts, through powder metallurgy or vacuum infiltration processes to adapt to the design of different switches. Surface treatments such as polishing or coating can further enhance corrosion resistance and arc tolerance. In some high-demand scenarios, tungsten copper alloys are processed into multi-layer structures with a high tungsten content layer inside to enhance durability and a high copper content layer outside to improve conductivity. The installation form of the contact assembly is usually bolted or embedded to ensure stable contact with the switch body. These application forms make full use of the characteristics of tungsten copper alloys to meet the diverse needs of low-voltage power switches.

6.1.1.3 Effect of application on the service life of low voltage power switches

Tungsten copper alloy in low-voltage power switch contact components significantly improves the service life of the equipment due to its excellent performance. First, the alloy's high resistance to arc erosion reduces ablation and material loss on the contact surface, extending the switch's on-off cycles. High temperature resistance ensures the stability of the contacts when disconnecting at high currents, reducing mechanical failure or performance degradation caused by overheating. Secondly, good electrical conductivity and thermal conductivity reduce the resistance thermal effect, reduce the aging speed of contacts, and enhance the reliability of long-term operation. Mechanical strength and wear resistance support frequent switching actions, reducing the risk of contact wear or breakage, further extending service life. In addition, the uniform phase distribution and low porosity of the tungsten-copper alloy improve the overall structural integrity of the contact and reduce early failure caused by microscopic defects. Corrosion resistance also plays a protective role, especially in humid or industrial environments, reducing the negative effects of surface oxidation or erosion on life. After application, the maintenance interval of low-voltage power switches is extended, the failure rate is reduced, and the overall operating efficiency is improved. In practice, the replacement cycle of contact components is significantly extended, especially in high-frequency usage scenarios such as industrial control systems or household appliances. The application of tungsten copper alloy provides equipment with longer service life and higher economic benefits. In the future, the life-extending effect can be further enhanced by optimizing alloy ratios and surface treatment.

6.1.2 Application in high voltage switch

The application in high-voltage switches is an important manifestation of tungsten copper alloy in the electrical field, especially playing a key role in scenarios that require handling high voltage and strong arcs. High-voltage switches are used for circuit control and protection in power systems, involving equipment such as high-voltage circuit breakers, disconnectors and grounding switches. These devices will generate strong arcs when switching high-voltage currents, which places extremely high demands on material performance. Tungsten copper alloy has become an ideal material for core components of high-voltage switches due to its excellent conductivity, high temperature resistance and arc erosion resistance. Its microstructure is optimized through powder metallurgy or vacuum infiltration processes to ensure stable performance under extreme working conditions. In applications, tungsten copper alloy is mainly used for contacts, moving and static electrodes, and arc extinguishing devices, which significantly improves the reliability and service life of switches. This section will discuss in detail the working environment of high-voltage switches and the material tolerance standards of core components, the performance of tungsten-copper alloy in adapting to the needs of high-voltage switches, and the application differences of tungsten-copper alloy in high-voltage switches of different voltage levels .

6.1.2.1 High-voltage switch working environment and material tolerance standards for core components

The working environment of high-voltage switches is extremely harsh, involving the combined effects of high temperature, high pressure, strong arcs and mechanical stress, which puts forward many requirements on the material tolerance standards of core components. First of all, the high temperature in the working environment is mainly generated by arcs. The energy released instantly when the current is disconnected may cause the local temperature to rise sharply. The material must have excellent high temperature resistance and be able to not melt or lose its shape at high temperatures of thousands of degrees. Core components such as contacts and electrodes need to withstand this extreme heat load while maintaining structural integrity. Secondly, the high-voltage environment is accompanied by high voltage. The continuity and strength of the arc require the material to have extremely high resistance to arc erosion to prevent surface ablation or material loss and extend the service life. In addition, frequent mechanical switching actions bring shocks and vibrations. The material must have sufficient mechanical strength and wear resistance to resist the risk of wear and fracture to ensure long-term operation stability. Corrosion resistance is another key tolerance standard, especially in outdoor or industrial environments, where high-voltage switches may be exposed to moisture, salt spray or chemicals. The material must be able to resist oxidation and corrosion and maintain electrical performance. Electrical conductivity and thermal conductivity are equally important. Efficient current transmission and heat dissipation can reduce the effect of resistive heating, reduce the risk of local overheating, and protect surrounding components. The hardness of the material must be moderate, so that it can withstand contact pressure without cracking due to excessive brittleness. At the same time, the toughness must be sufficient to absorb impact energy. In response to these requirements, international and industry standards such as IEC 62271 and ANSI/IEEE C37.04 have established performance benchmarks for high-voltage switch materials, covering arc resistance tests, thermal stability tests, and mechanical durability assessments. Materials need to be verified by these strict standards to ensure excellent performance in the complex environment of high-voltage switches. Tungsten copper alloys meet these requirements because of their comprehensive performance and become the preferred material.

6.1.2.2 Performance of Tungsten Copper Alloy in Meeting High Voltage Switch Requirements

First of all, the high melting point and hardness of tungsten give the alloy excellent resistance to high temperatures and arc erosion. When the high-voltage switch disconnects the high-voltage current, the extreme heat generated by the arc is effectively absorbed and dispersed by the tungsten phase, preventing the contact from melting or severe ablation. The high conductivity of copper ensures the efficient transmission of current, reduces the resistive thermal effect, and provides a stable conductive path for the arc extinguishing device. The microstructure of the alloy is optimized through powder metallurgy or vacuum infiltration process.

Tungsten copper alloy is particularly important in high-voltage switches. The efficient heat dissipation ability can quickly transfer arc heat to the surrounding area, reduce the local temperature of the contact, and extend the service life. Mechanical strength and wear resistance support frequent switching actions. The toughness of the alloy is enhanced by the ductility of the copper phase , reducing the risk of cracks caused by impact or vibration. In terms of corrosion resistance, the chemical stability of tungsten protects the alloy from moisture or industrial pollution, and the surface treatment of the copper phase can further improve the corrosion resistance. In the actual application of high-voltage switches, tungsten copper alloy also exhibits excellent electrical contact stability, reduces contact resistance and heat generation, and enhances the overall reliability of the equipment. For different ratios, such as WCu 70/30 or WCu 80/20, the alloy can adjust its performance according to specific needs. WCu 80/20 is more suitable for high arc scenarios, while WCu 70/30 is superior in situations where higher conductivity is required. These performance characteristics make tungsten copper alloy an ideal choice for core components of high-voltage switches.

6.1.2.3 Application Differences of Tungsten-Copper Alloy in High Voltage Switches of Different Voltage Levels

Tungsten-copper alloys in high-voltage switches of different voltage levels are mainly reflected in the different requirements of voltage, current and arc intensity, which affects the alloy ratio, preparation process and component design. The voltage levels of high-voltage switches are generally divided into medium voltage (1kV to 35kV), high voltage (35kV to 230kV) and ultra-high voltage (above 230kV). Each level has significantly different application forms and performance requirements for tungsten copper alloys . In medium voltage switches, the arc intensity is relatively low, and tungsten copper alloy is usually prepared by powder metallurgy process with WCu 70/30 ratio, focusing on optimizing conductivity and wear resistance. The contact components are mostly simple geometric shapes, emphasizing cost-effectiveness and long-term stability. The alloy's resistance to arc erosion is sufficient to cope with switching operations in medium voltage environments.

High-voltage switches (such as 110kV to 230kV) face stronger arcs and heat loads. Tungsten-copper alloys tend to use WCu 80/20 or higher tungsten content ratios to enhance high temperature resistance and arc erosion resistance. The preparation process may be combined with vacuum infiltration to ensure higher density and uniformity. The contact design often adopts a multi-layer structure or composite form, with an internal high tungsten layer to resist arcs and an external high copper layer to optimize conductivity. As the size and weight of the components increase, mechanical strength and thermal management need to be considered. Surface coating or heat treatment is often used to improve durability. Ultra-high voltage switches have peak material performance requirements. The arc energy is extremely large. Tungsten-copper alloys may use WCu 90/10 ratios to prepare complex-shaped contacts and arc extinguishing devices through additive manufacturing or plasma spraying technology. The alloy needs to have extremely high resistance to arc erosion and thermal conductivity.

These differences reflect the impact of voltage levels on the application of tungsten copper alloys . Low-voltage scenarios focus on cost and conductivity, medium- and high-voltage scenarios emphasize arc resistance and thermal management, and ultra-high-voltage scenarios pursue extreme performance and complex structures. The preparation process and post-processing need to be adjusted according to the voltage level. In the future, intelligent design and multi-technology combination can be used to adapt to the needs of higher voltage levels and further expand the scope of application.

6.1.3 Application of relays and air circuit breakers

Tungsten copper alloy in relays and air circuit breakers is an important manifestation of tungsten copper alloy in the electrical field, especially in scenarios that require high-reliability electrical control and protection. As a low-power signal control device, relays rely on contacts to realize the on and off of circuits, and frequent mechanical actions place requirements on the durability of materials. Air circuit breakers are used to protect circuits from overload or short circuit damage. Their arc extinguishing systems need to withstand high currents and strong arcs, requiring high-performance materials. Tungsten copper alloy has become the core material for relay contacts and air circuit breaker arc extinguishing chambers due to its excellent conductivity, wear resistance and arc erosion resistance .

6.1.3.1 Relay material wear resistance requirements and suitability of tungsten copper alloy

The wear resistance requirements of relays for materials are due to their frequent mechanical switching actions and contact pressure, which directly affect the service life and reliability of the contacts. Wear resistance is a core requirement because when relays switch low-power signals, the contacts must withstand repeated physical contact and separation. Long-term operation may cause surface wear, material transfer or adhesion, which in turn causes increased contact resistance or failure. The material must also have sufficient hardness to resist indentation while maintaining appropriate toughness to prevent brittle fracture caused by excessive hardening. Electrical conductivity is another key requirement, ensuring a low-resistance path to support signal transmission; high temperature resistance and arc erosion resistance help handle occasional high current or arc conditions. In addition, corrosion resistance is particularly important in humid or industrial environments to prevent oxidation or contamination from affecting performance.

Tungsten copper alloy shows extremely high adaptability and meets the wear resistance requirements of relays. Its tungsten phase provides high hardness and wear resistance, resisting surface wear caused by frequent contact and extending contact life. The copper phase contributes excellent conductivity, ensuring the stability of signal transmission and reducing the thermal effect of resistance. The microstructure of the alloy is optimized through powder metallurgy process, grain refinement enhances wear resistance, while low porosity reduces material spalling during wear. The vacuum infiltration process further improves the density, improves the interface bonding between tungsten and copper , and reduces mechanical stress concentration points. Arc erosion resistance supports occasional high-energy switching, while corrosion resistance is ensured by the chemical stability of tungsten. In practical applications, the use of tungsten copper alloys (such as WCu 70/30) in relay contacts significantly reduces the wear rate and extends the service life of the equipment, especially in high-frequency operation or harsh environments. In the future, its anti-wear properties can be further enhanced by surface hardening or adding trace elements.

6.1.3.2 Installation location and function realization of tungsten copper alloy in relay

tungsten copper alloy in the relay is mainly concentrated in the contact assembly, and the specific position and function realization are closely related to its design requirements. The contact is the core component of the relay, responsible for realizing the on and off of the circuit . Tungsten copper alloy is usually made into a moving contact or a static contact, which is installed between the mechanical drive mechanism and the base of the relay. The moving contact is driven by an electromagnetic coil or a mechanical lever to contact or separate with the static contact to complete the signal control. The installation form is mostly welding or pressing to fix the tungsten copper alloy contact on the copper or steel substrate to ensure electrical connection and mechanical stability. The choice of installation position needs to consider the contact pressure and arc distribution. The contact surface is usually polished to optimize the contact area and reduce resistance.

In terms of functional realization, tungsten copper alloy contacts use their high conductivity to ensure the reliable transmission of low-power signals, and the copper phase provides a continuous conductive path. The high hardness and wear resistance of the tungsten phase support frequent mechanical switching, prevent wear or adhesion, and maintain long-term contact stability. The ability to resist arc erosion plays a role in high voltage or overload conditions, reducing arc damage to the contacts and protecting the internal structure of the relay. The installation location may also include auxiliary electrodes or arc isolation parts. Tungsten copper alloy assists in arc extinguishing or dissipating heat through its high temperature resistance. In some high-demand relays, tungsten copper alloy is designed as a multi-layer structure, with an internal high tungsten layer to enhance durability and an external high copper layer to optimize conductivity. The effectiveness of functional realization depends on the control of installation accuracy and process optimization, such as welding quality and surface treatment. In the future, installation consistency can be improved through automated assembly technology.

6.1.3.3 Material performance requirements for arc extinguishing systems of air circuit breakers

Arc extinguishing system of air circuit breakers are derived from the extreme working conditions when high current is disconnected, and they need to meet strict requirements in many aspects. First, the arc extinguishing system needs to have excellent resistance to arc erosion, because the strong arc generated when high current is disconnected will burn the surface of the material, and the material must be able to withstand multiple arc shocks without failure. High temperature resistance is the key. The arc temperature may reach thousands of degrees. The material must maintain structural integrity at high temperatures to prevent melting or deformation. Secondly, electrical conductivity and thermal conductivity are crucial. Efficient current transmission and heat dissipation can reduce resistive thermal effects, reduce local overheating, and protect surrounding components. Mechanical strength and wear resistance support the frequent movement of arc extinguishing grids or contacts, and resist mechanical stress and wear.

Corrosion resistance is particularly important in outdoor or industrial environments to prevent moisture or chemicals from corroding the material and maintain long-term performance. The hardness of the material must be moderate, so that it can withstand arcs and mechanical pressure without cracking due to excessive brittleness. The toughness must absorb impact energy . The design of the arc extinguishing system also requires the material to have the ability to extinguish arcs quickly, and cooperate with the arc blowing effect of the air medium to quickly interrupt the arc. International standards such as IEC 60947 and ANSI/IEEE C37.13 have established performance benchmarks for arc extinguishing materials, including arc resistance tests and thermal stability tests. Materials need to be verified by these standards to ensure excellent performance in the complex environment of air circuit breakers. Tungsten copper alloy meets these requirements because of its comprehensive performance and has become the main choice for arc extinguishing systems.

6.1.3.4 Application principle of tungsten copper alloy in arc extinguishing chamber of air circuit breaker

Tungsten copper alloy in the arc extinguishing chamber of air circuit breakers is based on its excellent performance when disconnecting at high current, especially in arc control and thermal management . In application, tungsten copper alloy is mainly used for arc extinguishing grids, contacts and disconnector components. With its high resistance to arc erosion and high temperature resistance, it can withstand the extreme conditions of disconnection. The principle is that when the air circuit breaker disconnects high current, the arc is generated in the contact gap, and the high melting point and hardness of the tungsten phase effectively absorb the arc energy to prevent surface ablation or material loss. The high electrical conductivity and thermal conductivity of the copper phase quickly transmits current and disperses heat, reduces local temperature, and cooperates with the air blowing to accelerate arc extinction.

Microstructure optimization is the key to the application principle. The uniform distribution of tungsten and copper is achieved through powder metallurgy or vacuum infiltration process, which reduces porosity and enhances density to ensure uniform distribution of arc energy. The tungsten-copper alloy components in the arc extinguishing chamber are designed as segmented structures. The arc splits between the grids , increasing the cooling surface area and enhancing the arc extinguishing efficiency. The mechanical strength of the alloy supports frequent opening and closing actions, while the toughness absorbs mechanical stress and prevents crack propagation. Corrosion resistance protects components from environmental influences and extends service life. The application principle also includes synergy with the air medium. The surface of the tungsten-copper alloy forms a protective oxide layer under the action of the arc to assist in arc interruption. In high-current scenarios, such as industrial power distribution or power systems, the performance of tungsten-copper alloy ensures the reliable operation of the arc extinguishing chamber . In the future, thermal management and arc extinguishing effects can be optimized through functional gradient design .

6.1.4 Application in isolating switches and earthing switches

Tungsten copper alloy in disconnectors and earthing switches is an important manifestation of tungsten copper alloy in the electrical field, especially in the scenarios of isolation and grounding operations in power systems. Disconnectors are used to isolate circuits under no-load conditions to prevent accidental power-on, while earthing switches provide safe grounding during maintenance or failures and need to withstand the impact of short-circuit currents. Tungsten copper alloy has become the core material of these switches due to its excellent conductivity, high temperature resistance and mechanical strength. The microstructure of the alloy is optimized through powder metallurgy or vacuum infiltration process to ensure stable performance under long-term exposure and extreme current conditions. This section will discuss in detail the material weather resistance requirements of disconnectors under long-term exposure, the application design of tungsten copper alloy in the conductive contact part of disconnectors, the material strength and conductivity requirements of earthing switches when they are subjected to short-circuit currents, the mechanism of tungsten copper alloy to ensure the safe operation of earthing switches, and the selection criteria of tungsten copper alloy in disconnectors and earthing switches .

6.1.4.1 Weather resistance requirements for materials of disconnectors exposed to long-term environments

The weather resistance requirements of materials in long-term exposure environments for disconnectors stem from the fact that they are usually installed outdoors or in industrial environments and must withstand the influence of various natural and human factors. First of all, weather resistance must include corrosion resistance. Disconnectors are often exposed to rain, salt spray or industrial exhaust gas. The materials must resist oxidation, rust or chemical erosion and maintain electrical conductivity and mechanical integrity. Secondly, resistance to UV aging is an important requirement. Long-term sunlight exposure may cause surface degradation of the material, and it must have anti-photodegradation properties to prevent performance degradation. In addition, high and low temperature resistance is crucial. Changes in ambient temperature may induce thermal stress. The material must remain stable under extreme weather conditions, such as high temperatures in summer or severe cold in winter. Moisture resistance must also be considered. A humid environment may cause failure of the surface insulation layer or electrical corrosion, affecting safe operation.

Mechanical durability is another key requirement. Frequent operation or wind loads of disconnectors may cause vibration and wear. The material must have sufficient hardness and fatigue resistance to prevent cracking or deformation. Electrical conductivity and thermal conductivity must still be maintained during long-term exposure to ensure the reliability of isolation operation. International standards such as IEC 62271-102 have established weathering test requirements for disconnector materials, including salt spray tests, UV exposure tests, and temperature cycle tests. The material must pass these tests to prove its long-term stability in outdoor environments.

6.1.4.2 Application design of tungsten copper alloy in the conductive contact part of the disconnector

Tungsten copper alloy in the conductive contact part of the disconnector focuses on its performance in no-load isolation operation. The conductive contact part includes the moving contact, the static contact and the connection terminal. The tungsten copper alloy is usually prepared in a WCu 70/30 or WCu 80/20 ratio, and a high-density structure is formed by powder metallurgy. In the design, the alloy is processed into a specific shape, such as a cylindrical or plate-shaped contact, and the surface is polished to optimize the contact area, reduce resistance and heat. The installation form is mostly bolted or welded to ensure a stable electrical connection with the main body of the disconnector. Some designs also include a spring loading mechanism to maintain a constant contact pressure.

The application design also takes into account the optimization of the microstructure. The tungsten phase provides high hardness and wear resistance to support long-term mechanical contact, while the copper phase ensures efficient current transmission. The alloy's resistance to arc erosion plays a role in occasional high-voltage operations to prevent surface ablation. A composite structure may be used in the design, using tungsten-copper alloy as a contact layer combined with a copper or aluminum substrate to reduce costs and enhance overall conductivity. Surface treatments such as silver plating or coating can improve corrosion resistance and conductivity and adapt to outdoor environments. The design also needs to consider thermal expansion matching.

6.1.4.3 Material strength and conductivity requirements for earthing switches when subjected to short-circuit current

The material strength and conductivity requirements of the grounding switch when subjected to short-circuit currents stem from its critical protection role under fault conditions. Short-circuit currents can reach thousands of amperes, and the energy released instantly places extremely high demands on the material. First, the material must have excellent mechanical strength to resist the electromagnetic force and impact force caused by the short-circuit current and prevent the contact from deforming or breaking. The strength must also support the mechanical action of the grounding operation to ensure stable contact. Conductivity is the core requirement, and efficient current transmission can quickly conduct short-circuit energy to the ground, reducing equipment damage and personnel risks. The material must also have high thermal conductivity to quickly disperse the short-circuit heat and prevent local overheating from causing melting or failure.

High temperature resistance is critical. Short-circuit currents may cause high-temperature arcs, and materials must maintain structural integrity under extreme thermal conditions. Arc erosion resistance supports multiple short-circuit operations and reduces surface erosion that affects service life. Corrosion resistance is particularly important in outdoor grounding switches to prevent moisture or salt spray from affecting conductivity. Hardness and toughness need to be balanced, with hardness resisting contact pressure and toughness absorbing impact energy. International standards such as IEC 62271-102 and IEEE C37.41 set strength and conductivity test requirements for grounding switch materials, including short-circuit withstand tests and thermal stability assessments. Tungsten copper alloy meets these requirements due to its high strength and conductivity, and performance can be improved in the future through alloy ratio optimization.

6.1.4.4 Mechanism of tungsten copper alloy to ensure safe operation of grounding switch

Tungsten copper alloy to ensure the safe operation of grounding switches is based on its comprehensive performance under short-circuit conditions. The mechanism is first reflected in high conductivity. The copper phase provides a continuous current path, quickly conducts short-circuit energy into the earth, reduces system voltage and protects equipment. The high melting point and arc erosion resistance of the tungsten phase absorb energy under the action of the short-circuit arc, prevents the contact from melting or severe ablation, and ensures the reliability of grounding contact. The microstructure of the alloy is optimized through vacuum infiltration or powder metallurgy process. The density reduces porosity, enhances impact resistance and thermal stability, and supports the instantaneous load of short-circuit current.

The mechanical strength and toughness mechanism supports the mechanical action of the grounding operation. The tungsten phase provides hardness to resist electromagnetic forces, and the copper phase enhances ductility, absorbs impact energy, and prevents crack propagation. The thermal conductivity mechanism quickly disperses short-circuit heat, reduces local temperature, and protects surrounding components. The corrosion resistance mechanism resists environmental erosion through the chemical stability of tungsten, and the surface treatment of the copper phase further improves weather resistance. In applications, tungsten-copper alloys are often made into contacts or connectors, designed as multi-layer structures. The high tungsten layer resists arcs, and the high copper layer optimizes conductivity . Combined with the arc blowing or segmented structure of the grounding switch, the arc is extinguished faster. In the future, intelligent monitoring can be used to evaluate alloy performance in real time and enhance safety.

6.1.4.5 Selection criteria for tungsten copper alloy in disconnectors and earthing switches

Tungsten copper alloys in disconnectors and earthing switches are based on a comprehensive assessment of application requirements and environmental conditions. First, conductivity is the core criterion. The alloy needs to ensure efficient current transmission. The copper content is usually between 20% and 40%. WCu 70/30 or WCu 80/20 are common choices. High temperature resistance and arc erosion resistance are another criterion. High voltage and short circuit scenarios require higher tungsten content, such as WCu 90/10, and the preparation process needs to optimize density. Mechanical strength and wear resistance require the alloy to have fine grains and low porosity to support mechanical operation and long-term use.

Corrosion resistance and weather resistance are important considerations in selection. Alloys with surface treatment or coating enhancement should be selected for outdoor environments. The coefficient of thermal expansion needs to match the substrate to reduce thermal stress. Cost and processability also affect selection. Complex parts may give priority to powder metallurgy, and composite structures can be used in cost-sensitive scenarios. International standards such as IEC 62271-102 and industry specifications provide performance benchmarks, and selection must be verified through weather resistance, short-circuit tolerance and conductivity tests.

6.2 Application of tungsten copper alloy in the field of electronics

Tungsten copper alloy is widely used in the electronics field, especially in scenarios that require high-precision processing and efficient thermal management . The electronics field covers electrospark machining (EDM) electrodes, electronic packaging heat sinks, and high-frequency circuit connectors. Tungsten copper alloy meets the needs of precision manufacturing and thermal management with its high wear resistance of tungsten and high conductivity of copper . In EDM, the alloy is used as an electrode material to efficiently remove workpiece materials while maintaining a long service life. In electronic packaging, its low thermal expansion coefficient and thermal conductivity support the heat dissipation of high-density integrated circuits. In high-frequency applications, the conductivity of the alloy ensures the stability of signal transmission. This section will deeply analyze the performance requirements of EDM electrodes and the advantages of tungsten copper alloy .

6.2.1 Performance requirements of EDM electrodes and advantages of tungsten-copper alloy

The performance requirements of EDM electrodes are closely related to the advantages of tungsten copper alloys . The comprehensive performance of the alloy makes it occupy an important position in high-precision machining. EDM removes workpiece materials through electric spark discharge, which places strict requirements on the conductivity, wear resistance and high temperature resistance of electrode materials. Tungsten copper alloy perfectly adapts to these requirements through the high

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hardness of tungsten and the high conductivity of copper . WCu 70/30 and WCu 80/20 ratios are common choices, achieving a balance between conductivity and wear resistance respectively. The microstructure of the alloy is optimized through powder metallurgy or vacuum infiltration process to ensure low porosity and uniform phase distribution, improve machining accuracy and service life. This section will discuss in detail the performance index requirements of EDM process for electrode materials, the requirements for electrode performance differences in different machining scenarios, the adaptability analysis of tungsten copper alloy in terms of conductivity and wear resistance, the comparison of performance advantages compared with traditional electrode materials, and the selection criteria of tungsten copper alloy electrodes in common EDM equipment .

6.2.1.1 Performance index requirements of electrode materials for EDM process

The performance requirements of the electrode material in the EDM process are derived from its unique principle of removing workpiece material through electric spark discharge, which involves multiple key properties. First of all, the material needs to have excellent conductivity to ensure efficient current transmission, generate stable spark discharge, and reduce energy loss and unevenness during processing. Electrical conductivity directly affects discharge efficiency, especially in fine machining, where electrodes are required to provide a low resistance path. Thermal conductivity is another core indicator. Good heat dissipation capability can quickly transfer the heat generated by discharge to the outside of the electrode, preventing local overheating from causing electrode deformation or burns on the workpiece surface. Wear resistance is a key requirement. The discharge between the electrode and the workpiece during EDM will cause material loss.

Arc erosion resistance is equally important. Frequent discharges may cause ablation or material transfer on the electrode surface. The material needs to withstand high-energy arcs without rapid deterioration. High temperature resistance is essential. The local high temperature at the moment of discharge may reach thousands of degrees. The material needs to maintain structural integrity under extreme thermal conditions to prevent melting or cracking. Mechanical strength and processability also need to be considered. The electrode needs to withstand mechanical clamping and processing pressure, while facilitating precision cutting into complex shapes, such as deep holes or fine structures. Corrosion resistance is particularly important when processing certain chemically active workpieces to prevent damage to the electrode surface or contamination of the workpiece surface. Processing accuracy requires the electrode to have low porosity and uniform microstructure to ensure discharge uniformity and avoid processing defects. International standards such as ISO 14132 and JIS B 6402 have established performance benchmarks for EDM electrode materials, including conductivity testing, wear resistance testing, and thermal stability evaluation. Tungsten copper alloys meet these requirements because of their comprehensive properties and become the preferred material for EDM.

6.2.1.2 Different electrode performance requirements in different processing scenarios

The different demands for electrode performance in different processing scenarios reflect the diverse requirements of workpiece materials, processing accuracy and efficiency, and directly affect the ratio and application form of tungsten copper alloy . In precision cutting scenarios, such as processing molds, micro gears or precision electronic components, the electrode must have extremely high processing accuracy and surface quality, and require low porosity and fine grain structure to ensure discharge uniformity. The conductivity needs to be stable to support fine current control, and the wear resistance needs to be excellent to reduce electrode loss and extend service life. The commonly used WCu 70/30 ratio has a moderate proportion of copper phase , which ensures conductivity and maintains a certain wear resistance. In rough processing scenarios, such as removing large volumes of material or opening rough mold cavities , efficient discharge and rapid material removal are emphasized. Conductivity and high temperature resistance are more important, and wear resistance requirements are relatively low. The WCu 60/40 ratio can be selected to enhance conductivity and speed up processing.

When processing high melting point or high hardness materials (such as tungsten steel, tungsten carbide or titanium alloy), the electrode needs to have higher resistance to high temperature and arc erosion. WCu 80/20 or alloys with higher tungsten content are more suitable. Thermal conductivity also needs to be improved to disperse high-energy heat and reduce the heat-affected zone of the workpiece. In deep hole or complex geometry processing scenarios, the electrode needs to have good mechanical strength and processability, support slender structures or complex shapes, and wear resistance and corrosion resistance support multiple uses. WCu 70/30 ratio combined with surface polishing process is often used. When processing non-conductive materials (such as ceramics), auxiliary electrode design is required, and the conductivity requirements are matched with auxiliary materials. WCu 60/40 with high copper content may be selected. Different scenarios also involve processing speed and cost. Precision cutting tends to be high-precision and high-durability materials, and rough processing tends to be cost-optimized and efficient. In the future, the alloy ratio and process parameters can be dynamically adjusted to adapt to diversified processing needs and further improve electrode performance.

6.2.1.3 Analysis on the compatibility of tungsten copper alloy in terms of conductivity and wear resistance

The compatibility analysis of tungsten copper alloy in terms of conductivity and wear resistance reflects its unique advantages as an EDM electrode. The conductivity is mainly provided by the copper phase . The high conductivity of copper ensures efficient current transmission, produces stable electric spark discharge, and reduces energy loss and unevenness during processing. The microstructure of the alloy is optimized by powder metallurgy or vacuum infiltration process. The continuous network of copper phase reduces resistance and enhances discharge uniformity. The WCu 70/30 and WCu 60/40 ratios perform well in conductivity and are suitable for scenarios requiring high-efficiency processing. Thermal conductivity and electrical conductivity complement each other. The high thermal conductivity of the copper phase quickly transfers the discharge heat to the outside of the electrode, reduces the local temperature, and prevents deformation or cracking, especially in precision cutting.

The wear resistance is mainly contributed by the tungsten phase , whose high hardness and anti-wear properties resist the material loss caused by spark discharge. The fine grains and low porosity structure enhance surface stability and reduce electrode wear and erosion, especially in high energy machining.

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The high temperature resistance of the tungsten phase supports high energy discharge. WCu 80/20 performs better in wear resistance and arc erosion resistance, and is suitable for processing high hardness materials. The interface bonding between tungsten and copper is achieved through process optimization, reducing the risk of peeling and maintaining long-term wear resistance. Compatibility analysis shows that tungsten-copper alloy can achieve a balance between conductivity and wear resistance by adjusting the tungsten-copper ratio . WCu 70/30 is a general choice that takes both performances into consideration, while WCu 80/20 is more suitable for high wear resistance requirements.

6.2.1.4 Performance advantages compared with traditional electrode materials

Compared with traditional electrode materials such as pure copper, pure tungsten and graphite, tungsten-copper alloy shows significant superiority in performance advantage comparison. First, compared with pure copper, tungsten-copper alloy has stronger resistance to high temperature and arc erosion. Pure copper is easy to melt or deform in high-energy discharge, while the tungsten phase of tungsten-copper alloy improves thermal stability and extends the life of the electrode. In terms of conductivity, pure copper is slightly better, but tungsten-copper alloy approaches its level by optimizing the copper phase distribution . It also has wear resistance and reduces loss, which is particularly evident in long-term processing. Compared with pure tungsten, the electrical conductivity and thermal conductivity of tungsten copper alloy are greatly improved. The low electrical conductivity of pure tungsten limits the discharge efficiency, while the copper phase of tungsten copper alloy makes up for this deficiency and is suitable for efficient processing.

Compared with graphite electrodes, tungsten-copper alloy has better mechanical strength and wear resistance. Graphite is easy to break or wear during complex shape processing, while tungsten-copper alloy supports precision cutting and deep hole processing, and has higher processing accuracy. Graphite has high conductivity, but its resistance to high temperature and arc erosion is not as good as tungsten-copper alloy . It has large losses when processing high-hardness materials and poor surface roughness. The low porosity and uniform microstructure of tungsten-copper alloy ensure processing consistency, while graphite may cause uneven discharge due to its porosity. Comprehensive comparison, tungsten-copper alloy has advantages in durability, precision and adaptability to multiple scenarios, especially in the requirements of high precision, long life and complex processing, traditional materials such as pure copper, pure tungsten and graphite are difficult to match.

6.2.1.5 Selection criteria for tungsten-copper alloy electrodes in common EDM equipment

tungsten-copper alloy electrodes in common EDM equipment are based on a comprehensive evaluation of equipment characteristics and processing requirements, which directly affects processing quality and efficiency. First of all, conductivity is the core standard. The alloy needs to match the discharge parameters of the equipment. The ratio of WCu 60/40 to WCu 80/20 is selected according to the current intensity and processing accuracy. The conductivity needs to be compatible with the power system to ensure stable discharge. Wear resistance and arc erosion resistance are key. Processing high-hardness materials or high-energy scenarios requires a higher tungsten content. WCu 80/20 or WCu 90/10 is more suitable. The preparation process needs to ensure low porosity to reduce losses. High temperature resistance supports high-energy discharge, and the selection needs to consider the maximum discharge power and pulse parameters of the equipment.

Mechanical strength and processability affect electrode forming. Complex shapes or slender structures require easy-to-cut alloys, and surface roughness must match processing accuracy. WCu 70/30 ratio is often used to balance these two aspects. Corrosion resistance is important when processing chemically active workpieces, and selection can include surface plating or coating enhancement. Cost and availability also need to be considered. WCu 70/30 is an economical choice and suitable for general processing. High-end equipment can use high tungsten ratios to meet high durability requirements. Equipment manufacturers provide technical guidelines, and selection must be confirmed through wear resistance testing, conductivity verification and processing tests. International standards such as ISO 14132 provide performance references.

6.2.2 Role in the field of microelectronics

The microelectronics field has extremely stringent requirements on the performance of materials. It requires good electrical and thermal conductivity to ensure efficient transmission of electronic signals and heat, and a suitable thermal expansion coefficient to match core components such as chips. It also needs to have a certain structural strength to meet the needs of precision packaging. With its unique combination of properties, tungsten copper alloy plays an important role in this field and has become a key material for connecting core devices with external circuits and solving heat dissipation problems.

6.2.2.1 Requirements for precision and stability of materials for microelectronic devices

The precision and stability requirements of microelectronic devices for materials stem from their high integration and tiny size, which directly affects the performance and reliability of the devices. First of all, precision requires that the material have extremely high dimensional accuracy and surface flatness. Microelectronic devices such as chips and sensors are usually at the micron or nanometer level. The material needs to achieve low roughness and consistency through precision processing to ensure uniformity of electrical connection and thermal conduction. Electrical conductivity is a key indicator. The material needs to provide a low resistance path to support high-speed signal transmission and avoid signal attenuation or interference. Thermal conductivity is equally important. Efficient heat dissipation can reduce the operating temperature of the chip and prevent performance degradation or failure due to overheating.

Stability requires that the material maintains consistent performance in long-term operation, and high temperature resistance is the core. The operating temperature of the chip may reach above 150°C, and the material must not lose shape or oxidize at high temperatures. Fatigue resistance and mechanical stability support frequent thermal cycles and mechanical stresses to prevent microcracks or interlayer delamination. Low thermal expansion coefficient is an important requirement, matching the thermal expansion of silicon-based materials (such as chip substrates) to reduce warping or fracture caused by thermal stress. Corrosion resistance and chemical stability are particularly important in humid or acidic environments to prevent material degradation from affecting device life. International standards such as JEDEC JESD22 and IPC-6012 have established performance benchmarks for microelectronic materials, including thermal cycle testing and reliability evaluation. Tungsten copper alloys meet these requirements because of their comprehensive performance and have become the preferred material in the field of microelectronics.

6.2.2.2 Application of tungsten copper alloy in microelectronic packaging

Tungsten copper alloy in microelectronic packaging takes various forms, depending on the package type and thermal management requirements. One common form is to make tungsten copper alloy into a heat sink substrate, which is directly used for chip packaging. WCu 85/15 or WCu 90/10 ratio is prepared by powder metallurgy process, the thickness is usually between 0.5mm and 2mm, and the surface is polished to optimize thermal contact. Another form is a composite structure, which uses tungsten copper alloy as a heat sink layer, combined with a ceramic (such as AlN) or metal (such as Cu-Mo) substrate, and integrated by diffusion welding or press fitting to balance thermal expansion and thermal conductivity. In application, the alloy can also be processed into complex shapes, such as heat sinks with microchannels, to meet the needs of high-density packaging.

The installation form is mostly fixed by bonding or bolting to ensure close contact with the chip or package shell. Surface treatment such as nickel or gold plating can improve corrosion resistance and weldability, and adapt to a variety of packaging processes. In some high-performance applications, tungsten copper alloy is designed as a functional gradient material, and the tungsten content decreases from the substrate to the surface to optimize the thermal matching and conductivity with the chip. In packaging, the alloy is also used for lead frames or interconnects, and the WCu 70/30 ratio supports signal transmission and heat dissipation. The application form makes full use of the low thermal expansion and thermal conductivity of tungsten copper alloy to meet the high precision and reliability requirements of microelectronic packaging. In the future, more complex application forms can be developed through 3D printing technology.

6.2.2.3 Mechanisms for improving heat dissipation efficiency and service life of microelectronic devices

Tungsten copper alloy improves the heat dissipation efficiency and service life of microelectronic devices is based on its excellent thermal management and structural stability. First, the high thermal conductivity of the alloy quickly transfers the heat generated by the chip to the heat dissipation surface, reducing the operating temperature and preventing performance degradation caused by thermal stress accumulation. The low thermal expansion coefficient matches the silicon-based material, reducing warping or cracking during thermal cycles and enhancing the mechanical stability of the packaging structure. The high melting point and high temperature resistance of the tungsten phase support the chip in an operating environment above 150°C and prevent material degradation.

Microstructure optimization reduces pores and defects, enhances the continuity of the heat conduction path, and the WCu 85/15 ratio performs outstandingly in heat dissipation efficiency. Uniform phase distribution reduces thermal resistance, the copper phase provides efficient heat spreading, and the tungsten phase supports structural integrity. Corrosion and oxidation resistance protect the alloy from moisture or chemicals, extending service life. In applications, the heat dissipation efficiency of tungsten copper alloy reduces heat localization, slows down chip aging, and increases service life from thousands of hours for traditional materials to more than 10,000 hours, especially in high-performance computing and 5G devices.

6.2.2.4 Design of mounting structure in chip packaging module

The design of the mounting structure in the chip packaging module needs to make full use of the performance of tungsten copper alloy to optimize thermal management and electrical connections. In the design, tungsten copper alloy is often used as a heat dissipation substrate, placed under the chip, and in contact with the bottom of the chip through thermal interface materials (such as thermal grease) to ensure efficient heat conduction. The installation form is mostly bolted or bonded. The thickness of the substrate is selected according to the chip power, and 0.5mm to 1.5mm is a common range. The design also includes microchannel or fin structure to increase the heat dissipation area. The WCu 90/10 ratio supports high-power chips, and the surface coating improves weldability.

The electrical connection design uses tungsten copper alloy for lead frames or interconnects. The WCu 70/30 ratio is integrated by press-fitting or welding, and docked with the chip pad to ensure a low resistance path. The structural design considers thermal expansion matching, and the low thermal stress design of tungsten copper alloy and ceramic or silicon substrate prevents package warping. The installation location also includes an auxiliary heat dissipation layer, combined with an air cooling or liquid cooling system to optimize the heat flow path. The design needs to verify thermal stress and mechanical stability through finite element analysis, and international standards such as JEDEC JESD51 provide thermal management guidelines.

6.2.2.5 Requirements for purity and microstructure of tungsten copper alloy in the field of microelectronics

The requirements for the purity and microstructure of tungsten copper alloys in the field of microelectronics stem from the need for high precision and reliability. First of all, the purity requirements are extremely high, and the impurity content of tungsten and copper must be less than 0.1% to avoid reduced conductivity or obstruction of heat conduction. The oxygen content must be controlled at a low level to prevent the formation of oxides that affect the microstructure. Purity also involves the control of trace elements. For example, the doping of iron or silicon may cause grain boundary weakening, which must be ensured by high-purity raw materials and vacuum processes. International standards such as ASTM B702 specify the composition requirements for high- purity tungsten copper alloys . The microstructure requires uniform phase distribution. The particle size of tungsten and copper needs to be in the range of 5-20 microns. Fine grains enhance mechanical strength and thermal conductivity. The porosity needs to be less than 1% to ensure the continuity of thermal conduction and electrical properties. The interface bonding needs to be tight to reduce the risk of peeling. The microstructure optimization of WCu 85/15 ratio is often used in high-demand scenarios. Micro defects such as cracks or unwetted areas need to be verified by scanning electron microscopy. Preparation processes such as hot isostatic pressing (HIP) can improve structural uniformity. In the future, purity and micro quality can be further improved through nanotechnology or phased array processes.

6.2.3 Application in the field of sensors

As the core device for obtaining environmental information, sensors often work in complex environments, such as high-temperature industrial scenes, humid outdoor environments, or mechanical systems with vibration and shock, which puts forward many requirements on the stability, adaptability and functionality of sensor materials. Tungsten copper alloy has gradually shown its application value in the field of sensors due to its high temperature resistance, vibration resistance, good thermal conductivity and structural stability, and has become an important material choice for improving sensor reliability.

6.2.3.1 Material performance requirements for sensor working environment

The performance requirements of the material in the working environment of the sensor vary due to its diverse application scenarios, which directly affects the accuracy and life of the sensor. First of all, high temperature resistance is a key requirement. Many sensors, such as high-temperature pressure sensors or thermocouples, need to operate in environments above 200°C to 1000°C. The material must maintain structural stability and conductivity to prevent performance degradation due to thermal deformation or oxidation. Corrosion resistance is another core requirement. Sensors are often exposed to acidic, alkaline or humid environments, such as chemical or marine applications. The material needs to resist chemical erosion to prevent surface degradation from affecting measurement accuracy. Mechanical strength and wear resistance support the long-term use of sensors under vibration or mechanical stress, preventing component wear or breakage, especially in industrial equipment.

Electrical conductivity is critical for electrical signal sensors (such as resistive or capacitive sensors). The material needs to provide a low resistance path to ensure the accuracy and stability of signal transmission. Thermal conductivity is important in high-temperature or high-power sensors. Efficient heat dissipation reduces operating temperatures and protects sensitive components. Low thermal expansion coefficient matches the substrate, reduces stress concentration during thermal cycles, and enhances structural integrity. Arc erosion resistance is required in high-voltage sensors to prevent spark damage. Processability and dimensional accuracy require that the material is easy to cut precisely to meet the micron- level structure requirements of micro sensors (such as MEMS). International standards such as IEC 60751 and ASTM E1137 have established performance benchmarks for sensor materials, including temperature resistance testing and reliability evaluation. Tungsten copper alloy has become the preferred material in the sensor field because of its comprehensive performance to meet these requirements.

6.2.3.2 Potential Applications of Tungsten-Copper Alloy in Sensor Sensing Elements

Tungsten copper alloy in sensor sensitive elements varies, depending on the type of sensor and functional requirements. One potential form is to make tungsten copper alloy into a sensitive element of a resistive temperature sensor. The WCu 70/30 ratio is prepared by powder metallurgy and processed into a thin film or filament structure, using the high conductivity of the copper phase and the stability of the tungsten phase to accurately measure temperature changes. Another form is to use it for the diaphragm or contact of a pressure sensor. The WCu 85/15 ratio is optimized by vacuum infiltration process, with a thickness between 0.1mm and 0.5mm, and the surface polishing ensures high contact, supporting deformation detection under high pressure environment.

In displacement or acceleration sensors, tungsten copper alloy can be used as electrodes or connectors. The WCu 60/40 ratio is integrated by pressing or welding, combining high conductivity and mechanical strength to meet dynamic measurement needs. Potential applications also include heating elements for gas sensors. The alloy is processed into micro-heating plates. The WCu 80/20 ratio supports high temperature stability and the surface coating enhances corrosion resistance. The installation form mostly adopts bonding or micro-welding, which is closely integrated with the sensor substrate. The design may adopt a multi-layer structure, with an internal high tungsten layer to enhance durability and an external high copper layer to optimize conductivity. These application forms make full use of the performance of tungsten copper alloys to meet the high precision and reliability requirements of sensitive components. In the future, more complex application structures can be developed through 3D printing technology.

6.2.3.3 Application design of sensor heat dissipation components based on high thermal conductivity

The application design of sensor heat dissipation components based on high thermal conductivity aims to utilize the thermal management capabilities of tungsten copper alloy to improve the performance and life of sensors in high temperature environments. In the design, tungsten copper alloy is often used as a heat dissipation substrate and placed under the sensor sensitive element. WCu 85/15 or WCu 90/10 ratio is prepared by powder metallurgy process, with a thickness between 1mm and 3mm and a surface flatness better than 5μm to ensure close contact with the sensitive element. The design also includes microchannel or fin structure to increase the heat dissipation area, quickly transfer heat to the external radiator or ambient air, and reduce the temperature of the sensitive element.

The mounting method is bolt fixing or thermal conductive bonding, integrated with the sensor housing or air cooling system, and the thermal interface material (such as thermal conductive pad) optimizes the contact thermal resistance. The low coefficient of thermal expansion (about 7 ppm/°C) is designed to match the silicon or ceramic substrate, reducing stress during thermal cycling and preventing package cracking. The heat dissipation component may be combined with an active cooling system (such as a micro fan). The WCu 70/30 ratio is advantageous in lightweight scenarios, and the surface nickel plating improves corrosion resistance. In applications, the heat dissipation efficiency significantly reduces the operating temperature of sensitive components and prolongs their service life, especially in high-temperature pressure sensors or infrared sensors. The design needs to verify the heat flow distribution through thermal simulation, and international standards such as JEDEC JESD51 provide thermal management guidelines. In the future, functional gradient design can be used to optimize heat dissipation and structural balance.

6.3 Application of tungsten copper alloy in aerospace field

The aerospace field has almost stringent requirements on the tolerance of materials. It needs to cope with the impact of extreme high temperature, high pressure and high-speed airflow, while ensuring structural stability and reliable functions. Tungsten copper alloy has become the core material for many key components in this field due to its high melting point and high strength of tungsten and high thermal conductivity and thermal shock resistance of copper. In scenes such as solid rockets, spacecraft thermal protection, and satellite components, its characteristics of "balance between high temperature resistance and thermal conductivity" and "combination of strength and impact resistance" are fully utilized. Among them, the solid rocket nozzle throat liner is one of its most representative applications .

6.3.1 Application of solid rocket nozzle throat lining

The throat liner of the solid rocket nozzle is the "throat" part of the rocket engine nozzle, which is responsible for guiding the high-temperature gas to eject at high speed to generate thrust. Its performance directly determines the propulsion efficiency and launch safety of the rocket. Due to the extremely complex working environment, the comprehensive performance requirements of the material are extremely high. Tungsten copper alloy has become the ideal material choice for this component through performance optimization and process adaptation .

6.3.1.1 Working environment of solid rocket nozzle throat liner

The working environment of the throat liner of a solid rocket nozzle can be described as "material purgatory", and it needs to withstand the superposition of multiple extreme conditions at the same time. After the rocket is ignited, the high-temperature combustion gas generated by the combustion of the solid propellant flows through the throat liner at a supersonic speed. The temperature of the gas can reach thousands of degrees Celsius, which is enough to melt most metals instantly; the solid particles carried by the high-speed airflow impact the surface of the throat liner at an extremely high speed, forming a continuous "sandblasting" effect, constantly wearing away the surface of the material; the oxidizing gas and corrosive particles contained in the combustion gas will react chemically with the surface of the throat liner, further exacerbating material loss; what is more serious is that in the short period of time from the ignition to the shutdown of the engine, the temperature of the throat liner will rise sharply from room temperature to high temperature, and then cool rapidly. The huge temperature fluctuation will produce strong thermal stress, which can easily cause the material to crack. This composite environment of "high-temperature burning + high-speed scouring + chemical corrosion + thermal shock" poses an extreme challenge to the tolerance of the material .

6.3.1.2 Requirements for material properties of nozzle throat lining

The working environment of the nozzle throat liner determines that its performance requirements for the material must be comprehensive and strict. First of all, the material must have extremely high temperature resistance, not melt or deform at high temperatures of thousands of degrees Celsius, and be able to maintain structural integrity; secondly, it must have excellent resistance to erosion and wear, be able to resist the continuous impact of high-speed airflow and particles, and reduce surface loss; thirdly, the thermal conductivity must be excellent, and the heat absorbed by the surface can be quickly discharged to avoid local excessive temperature and ablation; at the same time, thermal shock resistance is indispensable-when the temperature rises and falls suddenly, it can reduce the generation of thermal stress and avoid the appearance of cracks; finally, the material must have sufficient structural strength and will not break or collapse under the action of high-pressure gas. Only by meeting these requirements at the same time can the throat liner be guaranteed to function stably during the operation of the rocket .

6.3.1.3 Performance of tungsten copper alloy to meet the requirements of nozzle throat lining

tungsten-copper alloy is precisely matched with the requirements of nozzle throat lining, and its core advantage lies in the "synergistic complementarity of tungsten and copper". The high melting point of tungsten allows the alloy to remain stable in high-temperature gas. Even if the surface is exposed to extremely high temperatures, the skeleton formed by the tungsten phase will not melt, directly resisting "high-temperature burning"; the high strength and hardness of tungsten give the alloy excellent anti-erosion ability, which can withstand the impact of high-speed particles, reduce surface wear, and cope with "high-speed erosion"; the high thermal conductivity of copper plays a key role - it can quickly conduct heat from the surface of the throat lining to the interior or cooling system, avoid ablation caused by local heat accumulation, and solve the problem of "heat accumulation"; at the same time, the plasticity of copper can alleviate the thermal stress caused by sudden temperature changes, reduce the risk of brittle cracking of the tungsten skeleton, and improve thermal shock resistance; in addition, after the tungsten-copper alloy is processed by the densification process, the structural strength is sufficient to resist the impact of high-pressure gas and ensure the stability of the throat lining shape.

6.3.1.4 Forming process and structural design of tungsten copper alloy in nozzle throat lining

tungsten copper alloy in nozzle throat lining requires precise molding process and structural design to maximize performance. The molding process is based on powder metallurgy: first, tungsten powder and copper powder are mixed in a specific ratio, and pressed into the initial shape of the throat lining (green billet) through a mold; then, tungsten particles are combined through high-temperature sintering to form a continuous skeleton, and then the copper is used to fill the skeleton pores through the infiltration process to ensure the density of the material; finally, the curved surface shape is trimmed through precision machining to ensure the assembly accuracy with other parts of the nozzle .

The structural design focuses on "functional adaptation": the surface of the throat liner adopts an arc-shaped curved surface design to fit the gas flow trajectory and reduce local wear caused by airflow impact;

some throat liners are reserved with tiny cooling channels inside , combined with the high thermal conductivity of copper, which can quickly remove heat through the cooling medium; at the connection with other parts of the nozzle, a stepped sealing structure is adopted to avoid high-temperature gas leakage; at the same time, the thickness of the throat liner is adjusted according to the force distribution - the area with the most severe gas impact is appropriately thickened to ensure strength while reducing material waste. This design of "process to ensure density + structure to optimize force and heat dissipation" allows the performance of tungsten copper alloy to be fully utilized .

6.3.1.5 Improvement of nozzle throat lining service life after using tungsten copper alloy

Compared with traditional materials (such as pure tungsten, ceramics, etc.), tungsten copper alloy significantly extends the service life of the nozzle throat liner, upgrading it from "one-time use" to "capable of withstanding multiple impacts". Although traditional pure tungsten is resistant to high temperatures , it is brittle and has poor thermal shock resistance. It is prone to cracking when the temperature changes suddenly, and often fails due to cracks after one ignition. Although ceramic materials are wear-resistant, they have poor thermal conductivity and the surface is prone to local ablation due to heat accumulation, and their service life is extremely short.

Tungsten copper alloy solves these pain points through synergistic performance: the tungsten phase resists high temperature and erosion, reducing the surface wear rate; the copper phase conducts heat efficiently to avoid local overheating and ablation; the improvement of thermal shock resistance reduces the possibility of cracks; coupled with the dense molding process and optimized structural design, the throat liner can withstand the impact of multiple ignition-shutdown cycles. In practical applications, the nozzle throat liner made of tungsten copper alloy can not only complete a single launch mission, but some models can also be used for multiple tests or reused rockets, which greatly reduces the replacement frequency and failure risk, while improving the economy and reliability of rocket launches .

6.3.2 Potential applications in aircraft engine components

The aircraft engine is the "heart" of the aircraft, and its performance directly determines the power, efficiency and safety of the aircraft. As the aviation industry's requirements for engine thrust-to-weight ratio and fuel efficiency increase, the working environment of core components has become increasingly harsh, posing higher challenges to the comprehensive performance of materials. Tungsten copper alloy , with its balanced characteristics of high temperature resistance, thermal conductivity and structural strength, has shown great potential application value in key locations such as the hot end components of aircraft engines, and is expected to solve the performance bottleneck of traditional materials under extreme working conditions .

6.3.2.1 Characteristics of the working environment of key aircraft engine components

The working environment of key aircraft engine components (especially hot end components, such as combustion chambers, turbine blades, nozzles, etc.) has four core characteristics: "high temperature, high pressure, high frequency vibration, and corrosion". The fuel combustion temperature inside the combustion chamber can reach thousands of degrees Celsius, and the turbine blades need to rotate at high speed (the speed can reach thousands of revolutions per minute) under the flushing of high-temperature combustion gas, and withstand huge centrifugal force and thermal stress; the gap components between the high-pressure compressor and the turbine need to remain sealed in a high-pressure gas environment, while resisting the local high temperature generated by air flow friction; in addition, the sulfides, nitrogen oxides and other components contained in the combustion gas will cause continuous corrosion to the surface of the components; the temperature and pressure fluctuations during the engine start-up, acceleration, and deceleration process will also cause high-frequency thermal fatigue and mechanical vibration of the components. This composite environment of "continuous high temperature + alternating stress + corrosion erosion + vibration impact" poses a severe test to the stability and durability of the material .

6.3.2.2 Requirements for material properties of aircraft engine components

Due to the extreme working environment, the performance requirements of aviation engine components for materials present an "all-round" feature. First, the material must have excellent high temperature resistance, and maintain mechanical properties (strength, hardness) without a significant decrease under long-term high temperature to avoid deformation or fracture due to softening; secondly, the thermal conductivity must be outstanding, and it can quickly export heat from the surface of the component to reduce the generation of local hot spots and reduce the risk of thermal fatigue; thirdly, it must have good thermal shock resistance and mechanical toughness to reduce cracks when temperature and pressure change, and resist vibration shock; at the same time, corrosion resistance is indispensable, and it can resist the erosion of corrosive components in the gas to avoid surface peeling or structural weakening; finally, the material must have a certain degree of processability, and can be made into complex structures (such as the curved surface of the blade, cooling channels, etc.) through the molding process to meet the precision design requirements of the components. These performances need to be achieved in a coordinated manner, and none of them can be missing .

6.3.2.3 Application of tungsten copper alloy in hot end parts of aircraft engines

of tungsten copper alloy in the hot end components of aircraft engines mainly focuses on the core position of "needing to take into account both heat conduction and high temperature resistance", and the application form is adjusted according to the different functions of the components. In the field of combustion chamber liners, tungsten copper alloys with high tungsten content can be used to make thin-walled liners, using the high temperature resistance of tungsten to resist direct flame burning, while the thermal conductivity of copper can quickly transfer heat to the cooling system to avoid local overheating of the liners; at the edge or tip sealing part of the turbine blade, tungsten copper alloy can be used as a wear-resistant heat-conducting insert and embedded in the blade matrix - its high hardness can resist friction and wear with the casing, and its thermal conductivity can assist the blade in heat dissipation and reduce thermal stress concentration; in fuel nozzles or igniter components, tungsten copper alloy can be made into nozzle cores, relying on high temperature resistance to ensure the stability of fuel atomization, while thermal conductivity prevents nozzles from being blocked due to overheating due to carbon deposits. In addition, in auxiliary components such as the engine's thermal protection gaskets and high-temperature sensor housings, tungsten copper alloys can also play a role through customized structures (such as composite structures with cooling channels) .

6.3.2.4 Performance optimization direction of tungsten copper alloy for aero-engine applications

In order to better adapt to the needs of aircraft engines, the performance optimization of tungsten-copper alloys needs to focus on "improving shortcomings" and "strengthening advantages". In terms of high temperature resistance, a small amount of high-melting-point alloying elements (such as molybdenum and niobium) can be added to refine tungsten particles, improve the high-temperature stability of the tungsten skeleton, and reduce the softening phenomenon under long-term high temperatures; in terms of corrosion resistance, surface modification technology (such as plasma permeation layer and anti-oxidation coating) can be used to form a dense protective layer on the surface of the alloy to resist gas corrosion without affecting thermal conductivity; in terms of mechanical toughness, the bonding strength of the tungsten-copper interface can be enhanced by adjusting the tungsten-copper ratio (such as moderately increasing the copper content) or optimizing the sintering process, reducing the risk of brittle fracture; for processability, precision processes such as powder injection molding can be developed to achieve near-net forming of complex structures (such as micro-cooling channels and special-shaped surfaces) to reduce the difficulty of subsequent processing; in addition, "gradient structure tungsten-copper alloys" can also be developed-high tungsten content on the surface of the component to enhance high temperature resistance and wear resistance, high copper content in the inner layer to enhance thermal conductivity and toughness, and adapt to the different position requirements of the component through performance zoning. These optimization directions are aimed at moving tungsten copper alloy from "potential application" to "actual adaptation" to meet the stringent standards of aircraft engines .

6.3.3 Application in spacecraft electrical systems

The spacecraft electrical system is the "nerve center" that maintains the normal operation of the spacecraft. It is responsible for power transmission, command control and equipment power supply. Its reliability is directly related to the success or failure of the mission. In space, the electrical system faces extreme environmental tests, and tungsten copper alloy has become an ideal material for core components such as contactors and circuit breakers due to its "excellent electrical and thermal conductivity + strong resistance to arc erosion", providing key support for the stable operation of the electrical system .

6.3.3.1 Working environment and reliability requirements of spacecraft electrical systems

The working environment of the spacecraft electrical system has two major characteristics: "extreme" and "unmaintainable". When operating in orbit, the system needs to withstand a vacuum, high and low temperature alternating environment - there is no air heat dissipation in a vacuum state, which easily leads to heat accumulation in the components; sudden temperature changes will cause the material to expand and contract, resulting in stress fatigue. At the same time, there is high-energy particle radiation in space, which may interfere with the transmission of electrical signals; and the severe vibration and impact during the launch phase will test the structural integrity of the components .

Based on these environmental characteristics, the system's reliability requirements are close to "zero failure": core components need to work stably within a mission cycle of several days to several years without problems such as poor contact and arc erosion; electrical connections need to maintain conductivity under extreme temperatures and vibrations, and arc extinguishing components need to reliably disconnect current; even in the event of particle radiation or micro-meteorite impacts, sudden failures must be avoided. Once a failure occurs, it may directly lead to mission failure because it cannot be repaired on orbit .

6.3.3.2 Requirements for material properties of core components of spacecraft electrical systems

The performance requirements of materials for core components of spacecraft electrical systems (such as contactor contacts and circuit breaker arc extinguishing chambers) are highly focused on "electrical stability" and "environmental adaptability". First, the material must have excellent conductivity to ensure efficient current transmission and reduce heat caused by contact resistance; second, arc erosion resistance is the key - the arc generated when the contacts are on and off will burn the surface, and the material must resist the melting and splashing of high-temperature arcs; at the same time, the thermal conductivity must be outstanding, and the heat generated by the arc can be quickly discharged to avoid overheating of components; in addition, the material must have good thermal shock resistance and mechanical strength, and will not crack or deform under high and low temperature alternation and vibration shock; finally, in a vacuum environment, the material must not release volatiles (to avoid contaminating optical equipment), and must have strong chemical stability and not react with the surrounding medium .

6.3.3.3 Application of tungsten copper alloy in spacecraft contactor contacts

The contactor is the "switch" that controls the on and off of the circuit in the electrical system of the spacecraft. Its contacts are the core executive components, and the application of tungsten-copper alloy in the contacts accurately matches the functional requirements. The contactor contacts will generate a short arc when they are on and off. The tungsten phase in the tungsten-copper alloy can resist the high temperature of the arc and prevent the contacts from melting and deforming; the copper phase ensures excellent conductivity, reduces contact resistance, and reduces heat generation during conduction. In terms of structural design, the contacts often adopt the form of a "tungsten-copper composite layer" - the high tungsten content on the surface enhances the arc resistance, and the slightly higher copper content in the bottom layer improves the weldability with the base.

6.3.3.4 Application of tungsten copper alloy in arc extinguishing components of spacecraft circuit breakers

Circuit breakers are the "safety guards" of spacecraft electrical systems. When the circuit is overloaded or short-circuited, the current must be quickly disconnected and the arc must be extinguished . Tungsten-

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copper alloy plays a key role in arc-extinguishing components (such as arc-extinguishing chamber walls and arc contacts). When extinguishing the arc, the high temperature generated by the arc easily melts the surface of the component, and the tungsten phase of the tungsten-copper alloy can withstand high temperatures and reduce surface ablation; the high thermal conductivity of the copper phase can quickly conduct the arc heat to the cooling structure, accelerating the arc extinguishing. In a vacuum arc-extinguishing environment , tungsten-copper alloy releases no volatile components, avoiding the mixing of impurity gases in the arc and ensuring arc-extinguishing efficiency; at the same time, its thermal shock resistance prevents the components from cracking during the sudden change from high temperature to low temperature vacuum, maintaining structural integrity. This performance allows circuit breakers to reliably disconnect current and protect circuit safety in emergency situations .

6.3.3.5 The role of tungsten copper alloy in ensuring the operational stability and life of spacecraft electrical systems

Tungsten copper alloy directly ensures the operational stability and life of the spacecraft electrical system by improving the reliability of core components. In the contactor, its arc erosion resistance reduces contact wear, increases the number of on-off times from thousands to tens of thousands, and extends the component replacement cycle; stable conductivity avoids local overheating caused by contact heating and reduces the risk of circuit failure. In the circuit breaker, the efficient arc extinguishing and ablation resistance of tungsten copper alloy ensure that the current can be quickly cut off when overloaded to avoid the spread of faults; at the same time, the thermal shock resistance and mechanical strength of the material prevent the components from failing in long-term high and low temperatures and vibrations, adapting to the spacecraft's mission cycle of several years. In addition, the low volatility of tungsten copper alloy avoids contamination of other equipment, indirectly ensures the coordinated operation of the entire electrical system, and reduces chain failures caused by material problems .

6.3.3.6 Material selection criteria and quality control requirements for tungsten copper alloys in spacecraft applications

Tungsten copper alloys used in spacecraft must pass strict material selection and quality control to ensure reliability. In terms of material selection criteria, the composition ratio must be clarified first - the contactor contacts must take into account both conductivity and arc resistance, and the W70-Cu30 to W80-Cu20 series are usually selected; arc extinguishing components require a higher tungsten content (W85-Cu15 and above) to enhance high temperature resistance. At the same time, the material density must be above 98% to prevent internal pores from becoming weak points of arc erosion; the conductivity must be ≥40% IACS (International Annealed Copper Standard) to ensure current transmission efficiency .

Quality control runs through the entire process: raw materials must be tested for purity to prevent impurities from affecting conductivity; the molding process uses vacuum sintering + infiltration to reduce oxidation and porosity; the finished product must pass environmental tests such as high and low temperature cycles, vibration and shock to verify performance stability; and finally, arc erosion simulation tests are required to ensure that the function can be maintained after thousands of on and off

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cycles. Only through full-chain control can tungsten copper alloys meet the "zero defect" application requirements of spacecraft.

6.4 Application in other fields

Tungsten copper alloy are not limited to high-end fields such as aerospace. Its characteristics of "high temperature resistance and electrical and thermal conductivity balance" and "controllable density and strength" also show unique value in metallurgy, sports, medical treatment, nuclear energy and other fields. By optimizing the composition and process according to the needs of different scenarios, tungsten copper alloy has gradually expanded from "special materials" to more civil and industrial scenarios, becoming a key choice to solve the performance bottleneck of traditional materials .

6.4.1 Application scenarios in the metallurgical industry

The high-temperature smelting, casting and processing links of the metallurgical industry have outstanding requirements for high-temperature resistance, wear resistance and thermal conductivity of materials . Tungsten-copper alloy plays a role in multiple core scenarios. Among the electrode materials for vacuum smelting, tungsten-copper alloy can be used as an electrode for arc melting due to its high conductivity and high-temperature resistance. The tungsten phase resists the high-temperature arc erosion during smelting, and the copper phase ensures stable current transmission, while quickly dissipating the arc heat to avoid electrode overheating. In the wear-resistant parts of the continuous casting crystallizer, tungsten-copper alloy with high tungsten content can be made into the inner wall insert of the crystallizer. Its wear resistance can resist the erosion of high-temperature molten steel, and its thermal conductivity assists the molten steel to quickly cool and form, reducing the phenomenon of steel sticking . In the local inserts of metal die-casting molds (such as the mold gate, core and other easily worn parts), the high strength and thermal shock resistance of tungsten-copper alloy can extend the life of the mold and avoid cracks caused by repeated heating and cooling. In addition, in the high-temperature sensor housing of metallurgical detection equipment, its high temperature resistance and sealing can also ensure detection accuracy .

6.4.2 Use cases in sports equipment

In the field of sports equipment, the application of tungsten copper alloy focuses on the core demand of "combining high density with shock absorption", and the use cases are concentrated in precision sports equipment. In the balance weight of archery equipment, tungsten copper alloy with high tungsten content can provide enough weight in a small volume due to its high density, helping archers adjust the center of gravity of the arrow shaft and improve shooting stability; at the same time, the presence of copper phase gives the weight block a certain toughness to avoid breaking in collision. In the weighted core of billiard cues, tungsten copper alloy can replace traditional lead blocks. By adjusting the tungsten-copper ratio to control the weight distribution, it can not only meet the power transmission requirements when hitting the ball, but also avoid the toxic pollution of lead. In the handle weight component of high-end fishing rods, its density and corrosion resistance are combined - it can not only improve the grip feel through weight, but also resist rust in the water environment and extend the service life of the equipment. These use cases all take advantage of the advantages of tungsten copper alloy "controllable density + non-toxicity + good formability" to replace traditional heavy metal materials .

6.4.3 Exploration in the field of medical devices

The medical device field has strict requirements on the biosafety, precision and functionality of materials. The exploration and application of tungsten-copper alloys focus on scenarios that require "a combination of high density and radiation shielding". In the dose calibration equipment for radiotherapy, tungsten-copper alloys with high tungsten content can be used as radiation attenuators - tungsten has strong shielding capabilities for X-rays and gamma rays, and can accurately control the radiation penetration dose. The presence of copper improves the processing accuracy of the material and can be made into complex attenuation channels to ensure calibration accuracy; at the same time, its non-toxicity and chemical stability avoid contamination of the equipment. In the positioning components of interventional medical devices (such as the development marks of vascular stents), the high density of tungsten-copper alloys can be clearly developed under X-rays to help doctors locate the stent, and the processability of the copper phase allows the marks to be made into microstructures without affecting the flexibility of the stent. At present, these applications are still in the exploratory stage. The core is to further improve biocompatibility through surface passivation treatment to lay the foundation for clinical applications .

6.4.4 Application prospects in the field of nuclear energy

The extreme environment (high temperature, radiation, high pressure) in the nuclear energy field requires extremely high tolerance of materials . Tungsten-copper alloys have shown broad application prospects with their characteristics of "high temperature radiation resistance + stable thermal conductivity". In the control rod guide components of nuclear reactors, tungsten-copper alloys can be used as guide tubes - tungsten has strong radiation resistance and can maintain structural stability in a neutron radiation environment. The thermal conductivity of copper can conduct heat out of the reactor to prevent the guide tube from deforming due to overheating and ensure the smooth movement of the control rods; at the same time, its corrosion resistance can resist the erosion of reactor coolants. In the shielding components of nuclear waste treatment equipment, tungsten-copper alloys with high tungsten content can be made into shielding containers, using tungsten's radiation shielding ability to isolate nuclear waste, and the copper phase improves the sealing and processability of the container, making it easier to make complex sealing structures. In the future, with the optimization of radiation-resistant coating technology and powder metallurgy processes, tungsten-copper alloys are expected to achieve breakthroughs in scenarios such as heat exchange components and radiation detector housings of small modular reactors, becoming one of the key materials for the safe operation of nuclear energy .

CTIA GROUP LTD

Tungsten Copper Alloy Introduction

1. Overview of Tungsten Copper Alloy

Tungsten Copper Alloy is a composite material made from tungsten and copper, typically containing 10% to 50% copper by weight. This alloy combines the outstanding properties of both metals—retaining tungsten's high-temperature resistance and excellent arc erosion resistance, while benefiting from copper's superior thermal and electrical conductivity. It delivers exceptional comprehensive performance in high-end fields such as electrical engineering, power systems, electronics, and aerospace. CTIA GROUP LTD offers a wide range of customized tungsten copper alloy solutions, featuring high density, stable performance, and precise processing tailored to customer requirements for components such as electrodes, thermal management parts, and vacuum system elements.

2. Typical Properties of Tungsten Copper Alloy

Product Name	Chemical Composition (%)			Physical and Mechanical Properties			
	Cu	Total Impurities ≤	W	Density (g/cm^3)	Hardness (HB)	Resistivity (MΩ·cm)	Tensile Strength (MPa)
Tungsten Copper (50)	50±2.0	0.5	Balance	11.85	115	3.2	—
Tungsten Copper (60)	40±2.0	0.5	Balance	12.75	140	3.7	—
Tungsten Copper (70)	30±2.0	0.5	Balance	13.8	175	4.1	790
Tungsten Copper (80)	20±2.0	0.5	Balance	15.15	220	5	980
Tungsten Copper (90)	10±2.0	0.5	Balance	16.75	260	6.5	1160

3. Applications of Tungsten Copper Alloys

Power Equipment: Contacts for high-voltage vacuum switches; Conductive parts for circuit breakers; Components for high-power relays and arc-fault interrupters

Electronics and Semiconductor Industry: Heat-dissipating substrates for IGBT modules; Cooling plates for microwave components; Package lids and electronic base plate

Electrical Discharge Machining (EDM): Electrode materials for EDM, especially suitable for machining hard alloy molds; High-precision forming electrodes for fine EDM processes

Aerospace and Defense: High-temperature structural parts such as rocket nozzles and tail cones

4. Purchasing Information

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Chapter 7 Future Development Trend of Tungsten Copper Alloy

Tungsten copper alloy focuses on its continuous optimization and innovation in high-performance applications, and combines emerging technologies to promote its performance improvement and application expansion. Future development will focus on new preparation technologies, performance enhancement strategies and sustainable design to meet the growing needs of electrical, aerospace and new energy fields.

7.1 Exploration of new preparation technology of tungsten copper alloy

Tungsten-copper alloys aims to break through the limitations of traditional processes and introduce advanced manufacturing methods to improve microstructure control and performance. These technologies optimize the distribution of tungsten and copper , reduce defects and enhance functionality through innovative material processing and forming methods. The development of new preparation technologies will promote the widespread use of alloys in complex geometries, high-precision components and customized applications.

7.1.1 Potential Applications of Additive Manufacturing Technology

Additive manufacturing technology , as a potential application for the preparation of tungsten-copper alloys , provides the possibility of achieving complex structures by depositing materials layer by layer. Driven by computer-aided design, the technology uses powder bed fusion or directed energy deposition methods to melt and solidify tungsten and copper powders layer by layer to form alloy parts with customized microstructures. The potential application lies in its ability to precisely control the local distribution of tungsten and copper , create functional gradient materials, and achieve a dynamic balance between conductivity and high temperature resistance in different areas of the component. The process allows the design of complex geometries, such as internal cooling channels or lightweight structures, to meet the high requirements of aerospace and electronic equipment.

Additive manufacturing technology also include reducing material waste and shortening production cycles, and directly forming through digital models to meet small batch or personalized production needs. In tungsten copper alloys , this technology can optimize grain morphology and phase distribution, enhance interface bonding, and reduce porosity and unwetted areas in traditional processes. Potential application scenarios include high-performance heat sinks, precision electrical contacts, and customized welding electrodes, especially in components that require complex internal structures. Future development needs to solve problems such as powder mixing uniformity, thermal stress control, and post-processing optimization to improve the reliability and consistency of components.

7.1.2 Outlook of other cutting-edge preparation technologies

In addition to additive manufacturing technology, the prospects of other cutting-edge preparation technologies provide diverse paths for the future development of tungsten-copper alloys . These

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technologies include nanotechnology, plasma spraying and self-assembly methods, which aim to improve the performance of alloys through innovative material design and processing methods. Nanotechnology uses ultrafine tungsten and copper powders to enhance the uniformity and density of the microstructure, potentially improving conductivity and mechanical strength. Plasma spraying technology melts and deposits tungsten and copper particles through high-speed plasma , which is suitable for rapid preparation of coatings or complex surfaces, and is suitable for wear-resistant and corrosion-resistant applications. The self-assembly method uses the chemical or physical properties of the material itself to regulate the phase distribution at the molecular level and explore new composite structures.

The prospect of these cutting-edge technologies lies in their ability to break through the limitations of traditional powder metallurgy or melt infiltration methods and provide greater flexibility and functionality. For example, nanotechnology can achieve finer grain sizes and enhance resistance to arc erosion; plasma spraying can quickly repair or enhance the surface of components; and self-assembly methods may open up new areas of intelligent material design. Future development directions include combining multiple technology integration, such as the combination of nanopowders and additive manufacturing , or the synergy of plasma spraying and surface treatment to optimize microstructure and performance. The challenges lie in process complexity, cost control, and the feasibility of large-scale applications. The advancement of these technologies will open up new application prospects for tungsten copper alloys.

7.2 Research direction of performance optimization of tungsten copper alloy

Tungsten-copper alloy aims to comprehensively improve its electrical conductivity, thermal conductivity, mechanical strength and durability through in-depth exploration of material design and process improvement to meet increasingly complex application requirements. The core of performance optimization lies in balancing the characteristics of tungsten and copper , fine-tuning the microstructure, and developing customized solutions for specific scenarios . The research direction covers the improvement of comprehensive performance and the strengthening of specific application scenarios, emphasizing the role of innovative methods in promoting the development of alloys.

7.2.1 Research directions for improving comprehensive performance

The research direction of comprehensive performance improvement focuses on simultaneously enhancing the multiple properties of tungsten-copper alloys , including electrical conductivity, thermal conductivity, mechanical strength and corrosion resistance, to achieve all-round performance optimization. The core of the research lies in the fine control of the microstructure, reducing defects and improving material density by optimizing grain size, phase distribution and interface bonding. A potential method is to develop a new powder mixing technology to ensure uniform distribution of tungsten and copper , enhance the continuity of the copper phase to improve electrical and thermal conductivity, while maintaining a stable structure of the tungsten phase to support mechanical strength. Interface enhancement techniques, such as the introduction of an intermediate phase or surface modification, can improve the adhesion between tungsten and copper and reduce the risk of debonding.

Another research direction is to explore multiphase composite design, by introducing trace additives or second phase materials to adjust the microstructure to balance strength and toughness. The selection of additives needs to consider their chemical compatibility with tungsten and copper to avoid introducing new weaknesses. In addition, process innovations such as staged sintering or pressure-assisted treatment can further reduce porosity and enhance the overall stability of the material. Improvements in corrosion resistance and oxidation resistance can be achieved through surface treatment or coating technology to protect the copper phase from environmental erosion while retaining the high temperature resistance of tungsten. Future research can also combine simulation technology and artificial intelligence to predict the relationship between microstructure and performance and dynamically optimize preparation parameters. Advances in these directions will promote the comprehensive performance of tungsten-copper alloys in a variety of high-performance applications.

7.2.2 Performance Enhancement in Specific Application Scenarios

The research direction of performance enhancement in specific application scenarios aims to customize and optimize the performance of tungsten-copper alloys in specific fields such as electrical contacts, welding electrodes, and aerospace components. For electrical contact applications, the focus of enhancement is to improve conductivity and resistance to arc erosion. The network structure of the copper phase can be optimized to enhance the efficiency of electron transmission, while high-temperature resistant coatings or surface modifications can be used to reduce arc-induced surface damage. Research can explore methods to dynamically adjust the tungsten content to provide better wear resistance and stability in high current scenarios.

For welding electrode applications, the direction of performance enhancement is to improve high temperature resistance and anti-adhesion ability. The anti-melting performance of the skeleton can be enhanced by increasing the proportion of tungsten phase , while optimizing the sintering process and reducing porosity to improve heat conduction. Strengthening the interface bonding is also crucial to prevent the copper phase from adhering to the workpiece at high temperature. Research can introduce wetting improvers or multilayer structure design. The needs of aerospace components such as heat sinks focus on thermal conductivity and lightweight. Functional gradient design can be used to achieve high thermal conductivity distribution of copper phase on the surface, and tungsten phase provides structural support inside. Research directions include developing new molding technologies to optimize internal porosity distribution. These specific strengthening studies need to be combined with the actual conditions of the application scenario, such as temperature, mechanical stress and use cycle, to develop targeted testing and verification methods. Future developments can explore adaptive material design, enabling alloys to dynamically adjust performance according to environmental changes, or use smart manufacturing technology to monitor and optimize performance in real time.

Appendix

Appendix A China National Standard for Tungsten Copper Alloy

China's national standards for tungsten copper alloys are formulated by the Standardization Administration of China (SAC) to regulate the preparation, performance and application of tungsten copper alloys to ensure product quality and industry consistency. These standards mainly cover tungsten copper alloy powders, finished parts and related test methods. Although there is no single national standard specifically for tungsten copper alloys , relevant standards can be derived from the general specifications of tungsten and copper alloys . China's national standard system includes the GB/T series, some of which, such as GB/T 26055-2022 (reconstituted tungsten carbide powder), involve the preparation requirements of tungsten-based materials and can be used as a reference. GB/T 38470-2023 and GB/T 38471-2023 specify the quality standards for secondary copper alloys and copper raw materials , respectively, and are indirectly applicable to the copper phase quality control of tungsten copper alloys . In addition, GB/T 5242-2006 and GB/T 5243-2006 provide inspection rules and packaging and transportation specifications for cemented carbide products, some of which can be extended to the inspection and transportation of tungsten copper alloys. These standards ensure material homogeneity and performance consistency through chemical analysis, density determination and microstructural evaluation.

The characteristics of Chinese standards are their adaptability to domestic raw materials and processes, and their emphasis on environmental protection and quality supervision. In recent years, with the tightening of scrap import policies, such as the implementation of the new customs standards in 2023, higher requirements have been put forward for the purity and non-metallic impurity content of copper raw materials, which indirectly affects the production of tungsten copper alloys . The content of the standards usually includes requirements for material composition, physical properties and processing technology, aiming to support domestic industrial needs, such as the application of electrical contacts and welding electrodes. In the future, the standards may be further refined to incorporate requirements for new preparation technologies to adapt to technological progress and international competition.

Appendix B International Tungsten Copper Alloy Standards

International tungsten copper alloy standards are mainly developed by the International Organization for Standardization (ISO) and other national or regional standards bodies to provide a unified reference framework for the global supply chain . Although there is no international standard specifically for tungsten copper alloys , relevant specifications can be obtained from the general standards for tungsten alloys and copper alloys . ISO 18119 covers tungsten alloy powders used in cemented carbide production, provides basic requirements for powder preparation and properties, and can be used as the basis for tungsten copper alloy raw materials. Other international standards such as JIS H 3201 (Japanese Industrial Standard) specify the characteristics of tungsten alloy powders, some of which are applicable to tungsten copper composites . Although ASTM international standards and EN standards do not directly target tungsten copper alloys , their metal material test methods (such as density and hardness tests) can be used for performance evaluation.

The characteristics of international standards are their transnational applicability, emphasizing material consistency and trade convenience. Industrial standards (such as ASTM, JIS and DIN) in different countries and regions such as the United States, Japan and Europe have formed a global specification system through mutual assistance and mutual recognition. The international applications of tungsten copper alloys , such as aerospace and electronic packaging, have prompted these standards to focus on high electrical conductivity, high thermal conductivity and high temperature resistance. Some major powder manufacturers have also developed internal specifications to supplement the deficiencies of international standards and ensure high-quality supply. However, international standards do not yet fully support emerging preparation technologies such as additive manufacturing , and may need to be updated in the future to adapt to technological developments. Overall, international standards provide important guidance for the global trade and application of tungsten copper alloys , but their specific implementation needs to be combined with the actual conditions of each country.

Appendix C Tungsten Copper Alloy Standards in Europe, America, Japan, South Korea and other countries

Tungsten copper alloy standards in Europe, America, Japan, South Korea and other countries are formulated by their respective national or regional standardization agencies to standardize material properties, preparation processes and application requirements to support global trade and industrial development. Although there is no unified international standard specifically for tungsten copper alloys , the relevant specifications are usually derived from the general standards of tungsten alloys, copper alloys or composite materials. The following is an overview of the standards in major countries and regions.

In Europe and the United States, the ASTM international standards in the United States and the EN standards in Europe are the main reference frameworks. ASTM standards such as ASTM B702 cover the preparation and performance requirements of tungsten-copper electrical contact materials, involving parameters such as density, conductivity and hardness, but do not provide detailed specifications for all types of tungsten-copper alloys. EN standards mainly focus on copper and its alloys, and are indirectly applicable to the copper phase quality control of tungsten-copper alloys . These standards emphasize the consistency of materials and the repeatability of test methods, and are widely used in electrical contacts and heat sink applications. European and American standards have high requirements for high conductivity and high temperature resistance. Some companies such as American Elements and Plansee have formulated internal specifications to supplement the deficiencies of general standards.

Japan's JIS standards (such as JIS H 3201) specify the characteristics of tungsten alloy powders, some of which are applicable to tungsten-copper composites , focusing on the uniformity of powder particle size and chemical composition. The application of tungsten-copper alloys in Japanese industry is mostly concentrated in electrospark machining (EDM) electrodes and high-voltage switch contacts, and the standards emphasize arc erosion resistance and electrical conductivity. Korean standards are formulated by Korean Industrial Standards (KS). Specifications such as KS D 2101 involve tungsten-based materials and are applicable to powder metallurgy processes for tungsten-copper alloys . South Korea focuses on the production of high-precision components, and the standards have specific requirements for microstructure and thermal conductivity, reflecting its needs in the fields of electronic packaging and aerospace.

There are differences in the standards of these countries. Europe and the United States focus on versatility and trade compatibility, while Japan and South Korea pay more attention to technical details of specific industrial applications. The performance requirements of the ratio of tungsten copper alloys (such as WCu 70/30, WCu 80/20) in different standards may vary, but generally require high density, low thermal expansion and excellent conductivity. The current standards have limited support for emerging technologies such as additive manufacturing , and may need to be updated in the future to adapt to technological advances. Overall, these standards provide important guidance for international cooperation and application of tungsten copper alloys , but their implementation needs to be combined with the industrial characteristics and market needs of each country.

Appendix D Glossary of Tungsten Copper Alloys

the term	definition
Tungsten Copper Alloy	of tungsten and copper by powder metallurgy or infiltration, combining high melting point and electrical conductivity.
Powder Metallurgy	The process of preparing the alloy by mixing, pressing and sintering metal powders is suitable for the uniform distribution of tungsten copper alloy .
Vacuum Infiltration	The process of infiltrating liquid copper into the tungsten skeleton in a vacuum environment is used to prepare a high- density tungsten-copper alloy .
Grain size	The average size of the tungsten or copper particles in the alloy, affecting strength and conductivity.
Phase distribution	tungsten and copper phases in the alloy determines the electrical and thermal conduction paths.
Porosity	The proportion of unfilled voids in an alloy affects density and mechanical properties.
Interface bonding	the tungsten and copper phases affects load transfer and resistance to peeling.
Electrical conductivity	The ability of the alloy to transmit electric current is mainly determined by the continuity of the copper phase .
Thermal conductivity	The ability of the alloy to transfer heat depends on the copper phase distribution and microstructural homogeneity.
Arc erosion resistance	The alloy's ability to resist arc high temperature ablation is affected by the stability of the tungsten phase and the distribution of pores.
Liquid Phase Sintering	The density of the alloy is improved by sintering process at high temperature using copper liquid phase wetting and filling tungsten particles.
Hot Isostatic Pressing	The alloy is treated at high temperature using omnidirectional pressure to reduce porosity and improve the microstructure.

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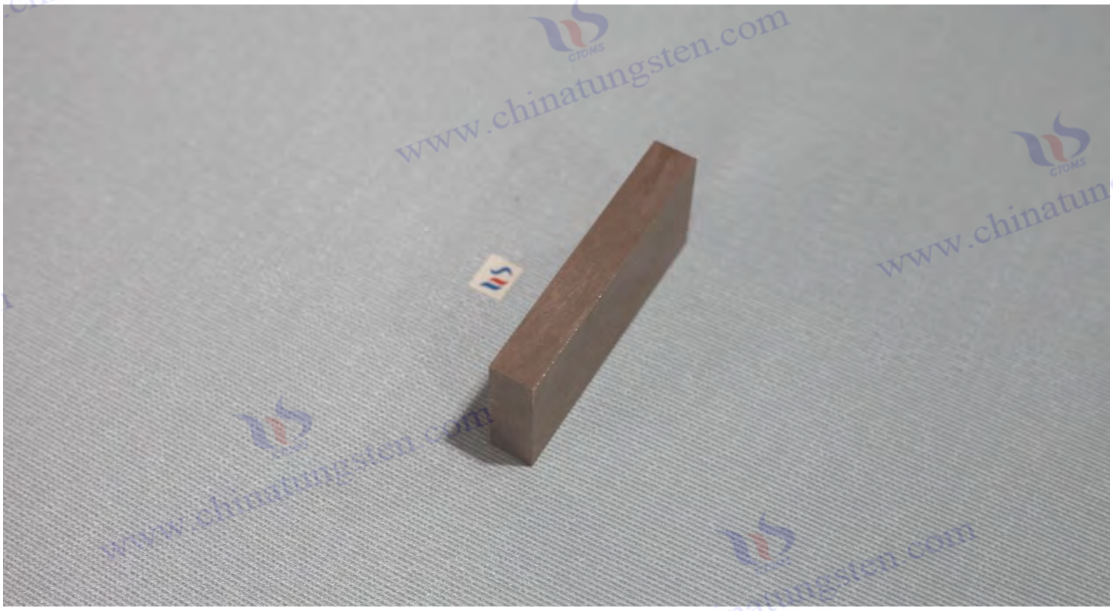

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