Tungsten Alloy Plate Encyclopedia

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CTIA GROUP LTD

CTIA GROUP LTD

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

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INTRODUCTION TO CTIA GROUP

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

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

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

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

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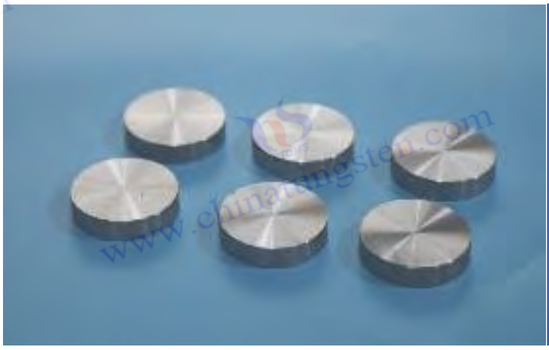
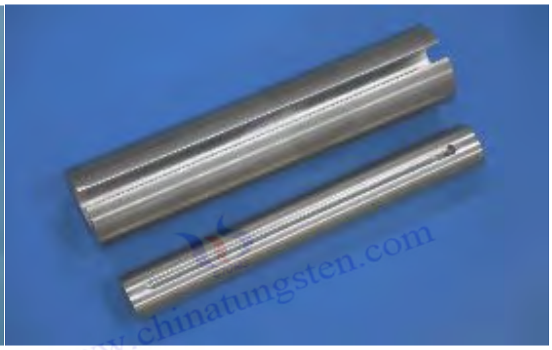

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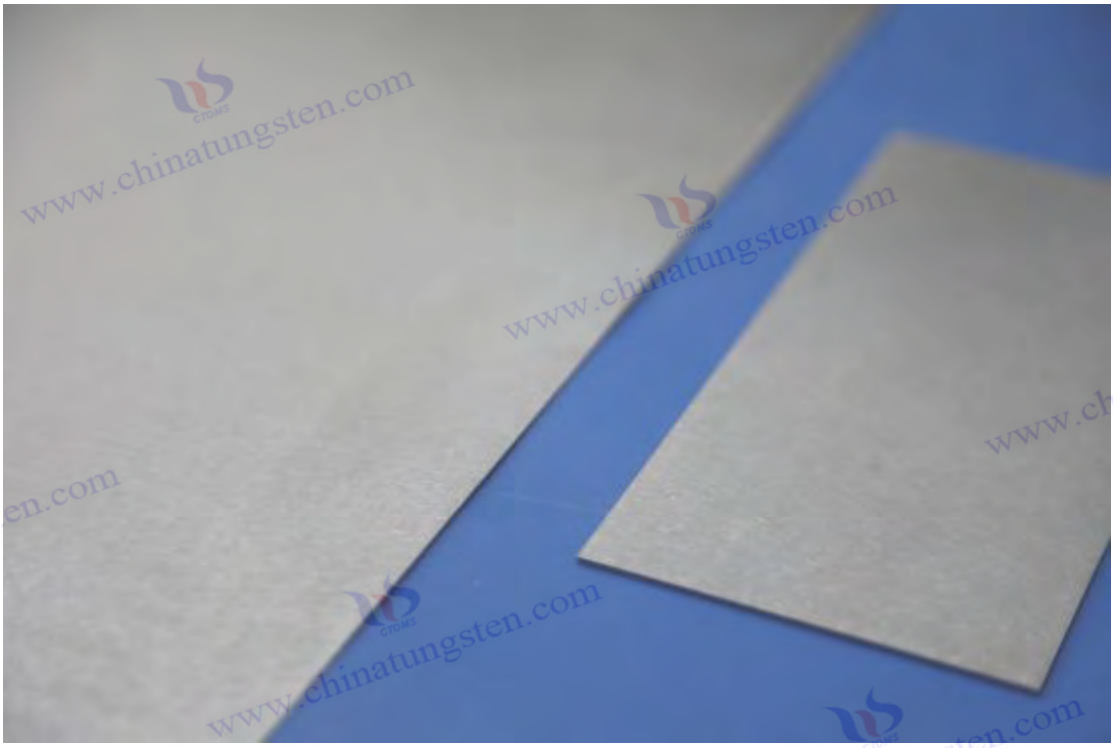

Chapter 1 Basic Concepts and Development History of Tungsten Alloy Plates

1.1 Definition and basic characteristics of tungsten alloy plate

Tungsten alloy plate is a sheet-like alloy material made primarily of tungsten (W) with appropriate amounts of nickel (Ni), iron (Fe), copper (Cu), cobalt (Co), or other elements added through powder metallurgy, hot rolling, cold rolling , or additive manufacturing . Due to tungsten's inherently high melting point (3422°C), excellent density (19.25 g/cm³), good thermal conductivity, and radiation resistance, tungsten alloy plate is widely used in a variety of key applications, including aerospace, nuclear power, protective armor, medical equipment, high-temperature structures, and electronic thermal management .

1. Definition of Tungsten Alloy Plate

From the perspective of materials science, tungsten alloy plates are mainly composed of a high proportion of tungsten powder, supplemented by a small amount of bonding phase metal (usually Ni-Fe, Ni-Cu or Ni-Co system) to form a dense multiphase alloy system. Its form is usually a rectangular or special-shaped flat metal plate with a thickness of 0.1 mm to 50 mm and customizable length and width. Compared with traditional tungsten rods or tungsten wires, tungsten alloy plates have a larger surface area, are easier to cut, and can be used for multifunctional purposes such as covering, shielding, and structural parts manufacturing.

2. Main Composition and Classification of Tungsten Alloy Plates

According to different alloy composition, forming method and application, tungsten alloy plates can be divided into the following categories:

- **Classification by alloy system** :
  - W-Ni-Fe alloy plate (common type, high strength, high density, good mechanical properties)
  - W-Ni-Cu alloy plate (non-magnetic type, used in electronics and medical fields)
  - W-Cu alloy plate (high thermal conductivity, suitable for electronic heat dissipation and electrode applications)
  - W-Co alloy plate (enhanced wear and corrosion resistance)
  - Nano tungsten alloy plate (using nanoparticle strengthening technology to improve toughness and micro stability)
- **Classification by production process** :
  - Powder metallurgy sheet (molding/isostatic pressing + sintering + hot processing)
  - Rolled tungsten alloy plate (hot rolled/cold rolled and then processed)
  - Additive manufacturing of tungsten alloy sheets (new technologies such as laser melting and 3D printing)
  - Composite tungsten alloy plates (such as W-Cu sandwich structures, tungsten-titanium composite plates, etc.)
- **Classification by function** :
  - **Structural tungsten alloy plate** : structural components that bear static loads and impact loads
  - **Functional tungsten alloy plate** : has specific physical functions such as thermal conductivity, anti-magnetic, and anti-radiation
  - **Shielding tungsten alloy plate** : used for radiation protection, medical radiotherapy equipment, etc.

3. Key Performance Characteristics of Tungsten Alloy Plate

1. **High density** : The density of a typical tungsten alloy plate is between 17.0 and 18.5 g/cm³, which is 2.2 times that of steel of the same volume. It is effectively used for inertial loads, dynamic balance and radiation shielding.
2. **Excellent mechanical properties** : It has high tensile strength (usually up to 700-1000 MPa), good impact toughness and processability, and is suitable for manufacturing parts with complex shapes.
3. **High temperature stability** : Tungsten-based alloys can maintain stable structure and performance above 1000°C, and are suitable for vacuum high-temperature furnaces and thermal field systems.
4. **Good thermal and electrical conductivity** : Especially in the W-Cu alloy system, the thermal conductivity can reach 170-220 W/ m·K , and is widely used in heat dissipation structures and electronic substrates.
5. **Excellent radiation resistance** : Tungsten's high atomic number and high density give it excellent X-ray and gamma-ray shielding effects, far superior to traditional lead plates.

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6. **Good chemical stability and corrosion resistance** : Stable in neutral and weakly acidic environments, and outperforms other heavy metals in high temperature or strong oxidizing environments.

4. Overview of the shape and specifications of tungsten alloy plates

Tungsten alloy plates are usually customized in size according to user requirements. Typical specifications are as follows:

- Thickness range: 0.1 mm ~ 50 mm
- Width range: 10 mm to 600 mm
- Length range: 10 mm to 2000 mm
- Surface condition: lathing, grinding, polishing, chemical plating, PVD coating, etc.

Some high-precision applications (such as particle accelerators and nuclear magnetic equipment) also require a surface roughness Ra < 0.2 μm and a thickness tolerance within ± 0.01 mm.

5. Comparative advantages of tungsten alloy plates and traditional metal plates

Performance parameters	Tungsten Alloy Plate	stereotype	Steel Plate	Copper Plate
Density (g/cm³)	17.0～18.5	11.3	7.8	8.9
Melting point (°C)	2700+	327	1500	1083
Shielding capability	Very strong (gamma/neutron)	General (X/γ)	weak	generally
Thermal conductivity	good	Difference	generally	Excellent
High temperature stability	Excellent	Difference	generally	Difference
Environmental protection	High (non-toxic)	Low (toxic)	high	high

Tungsten alloy plates are gradually becoming an alternative material to lead and steel in special functional fields due to their strength, density, thermal properties and environmental protection attributes.

In summary, tungsten alloy plate, as an advanced material with high density, high strength, high temperature stability and excellent shielding ability, shows important value in modern high-end manufacturing and precision applications. With the continuous advancement of preparation technology and the reduction of process costs, its application scope is gradually expanding from the military and nuclear energy fields to a wider industrial system such as electronics, medical, aerospace, etc.

1.2 Brief History of the Formation and Development of Tungsten Alloy Plates

an important high-performance metal material, the development of tungsten alloy plate is closely accompanied by the progress of powder metallurgy technology, the strategic development of tungsten resources and the continuous pursuit of material performance in extreme environments in high-end industrial fields. From early experimental applications to today's widespread deployment in key fields such as nuclear industry, aerospace, and medical protection, the development history of tungsten alloy plate is not only a microcosm of the evolution of metal material technology, but also reflects the global manufacturing industry's leap from conventional metals to ultra-high performance functional materials.

1. Discovery and early research of tungsten materials

Tungsten (W) was first known to humans in the mid-18th century. In 1781, Swedish chemist Carl Wilhelm Scheele first extracted tungsten oxide from sodium tungstate, and a few years later, the Spanish Elhuyar brothers (Juan José and Fausto Elhuyar) successfully separated metallic tungsten. Tungsten is known for its extremely high melting point (3422°C) and density (19.25 g/cm^3), and it was quickly used in incandescent filaments, electrical contacts and high-temperature alloys.

However, due to the inherent brittleness and difficulty in processing tungsten , traditional metallurgical methods have made it difficult to form it into thin sheets or plates. Therefore, early attempts at "tungsten alloy plates" remained largely at the laboratory research stage, and its actual engineering application did not gradually emerge until the mid-20th century.

2. The rise of powder metallurgy technology and the realization of sheet metal forming

In the early 20th century, with the rapid development of **powder metallurgy** technology, scientists began to try to process high-melting-point refractory metals (such as tungsten and molybdenum) into structural parts through pressing and sintering. This technology was studied intensively before and after World War II, especially in the military industrial systems of the United States, Germany, the Soviet Union and other countries, and eventually promoted the actual production of products such as tungsten alloy plates.

1950s to the 1970s , with the development of atomic energy and aerospace technology, the demand for high-density, high-strength, and radiation-proof materials increased sharply, **and high-density tungsten alloy systems such as W-Ni-Fe and W-Ni-Cu** were systematically established. During this period, tungsten alloy plates were mainly prepared by pressing sintering + hot rolling process, and the industrial production of thin plate parts was initially realized, mainly used for:

- Shielding plates and neutron absorbers for atomic reactors;
- Aircraft and missile counterweight systems;
- X-ray/gamma ray shielding components in the medical field.

3. Technology maturity driven by applications (1980s-2000s)

In the 1980s , with the popularization of medical radiotherapy equipment, the rapid development of the electronics industry, and the urgent requirements of environmental regulations for "lead substitutes", the demand for tungsten alloy plates increased sharply. During this period, the development of tungsten alloy plate technology showed the following important trends:

- **Precision rolling and cold processing technology** significantly improves the thickness control accuracy and surface quality of the plate;

- Developed **non-magnetic W-Ni-Cu** alloys to solve the magnetic interference problem in medical magnetic resonance imaging and some aerospace equipment;
- **Composite structural plates** (such as W-Cu sandwich structures) have emerged to achieve multi-performance integration;
- The quality management system is becoming increasingly standardized, and many national and industry standards have been introduced, such as ASTM B777, GB/T 3879, etc.

At this time, tungsten alloy plates have gradually evolved from early structural materials to integrated materials with both structure and function. They are widely used in many high-end fields such as precision instruments, thermal management systems, radiation protection shielding, and high-temperature furnace wall panels.

IV. Modern Development Stage and Frontier Exploration (2000s to Present)

After entering the 21st century, as emerging technology industries put forward more stringent requirements on material performance, the development of tungsten alloy plates has entered a new stage of **high performance, lightweight, intelligent and multifunctional** . The main manifestations are:

1. Material microstructure optimization

- Nano-reinforced W-alloys technology was introduced to give the alloy higher yield strength and fracture toughness;
- Functionally graded panels (FGM) are gradually being designed for use in aerospace thermal control systems and nuclear reactor panels, taking into account multiple physical performance requirements.

2. Innovation in manufacturing methods

- **Additive manufacturing technologies** such as laser selective melting (SLM) and electron beam melting (EBM) have begun to be used for the rapid manufacture of customized tungsten alloy plates;
- Advanced technologies such as vacuum hot isostatic pressing and ultrasonic-assisted rolling are used to prepare high-density plates to improve the consistency and organizational stability of finished products.

3. Accelerated expansion of international applications

- The United States, Japan, Germany and other countries widely use tungsten alloy plates in lunar exploration vehicles, nuclear fusion experimental reactors (such as the ITER project), and advanced accelerator components;
- China's tungsten alloy plate manufacturing technology has also gradually moved from "raw material dependence" to a new pattern of "independent design, mass production, and military-civilian integration", forming a number of leading enterprises and national key laboratories.

V. Outlook for future development trends

With the advancement of new material strategies and the increase in the value of tungsten resources , the future development direction of tungsten alloy plates will focus on the following points:

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- **Functional integration** : a multifunctional alloy plate that integrates heat conduction, electrical conduction and radiation resistance;
- **Extreme service adaptability** : high temperature resistant, impact resistant, high density tungsten plates for complex environments such as space, nuclear fusion, and deep earth;
- **Green manufacturing and sustainable development** : design and large-scale manufacturing of low-energy, recyclable and environmentally friendly alloy systems;
- **Intelligent material integration** : Integrate sensing, self-repair and other functions into the tungsten alloy plate structure to adapt to the development of future intelligent systems.

In summary, the development of tungsten alloy plates fully demonstrates the profound interaction between materials science and industrial needs. From early physics laboratory samples to modern high-performance, high-stability key structural materials, tungsten alloy plates, with their unique comprehensive properties, are playing an increasingly important role in the global materials technology system. In the future, their application potential in new energy, advanced manufacturing, national defense science and technology, and other fields will continue to expand.

1.3 Classification of tungsten alloy plates (by composition, process, and purpose)

tungsten alloy plates are widely used due to their rich variety and diverse performance. To more systematically understand the performance characteristics and applicable scenarios of tungsten alloy plates, it is necessary to classify them based on multiple dimensions, such as material composition, preparation process, and application. The following detailed classification methods for tungsten alloy plates are discussed from three main perspectives: **classification by composition, classification by preparation process, and classification by application** .

1. Classification by alloy composition

tungsten alloy plates is based on their primary alloy systems. In actual production and application, different binder metals significantly affect the physical properties, processability, and functionality of the plates.

1. W-Ni-Fe alloy plate (conventional type)

- **Composition characteristics** : The tungsten content is usually 85%~97%, supplemented by Ni and Fe as bonding phases, with a ratio of approximately Ni:Fe = 7:3.
- **Performance characteristics** : It has excellent strength, toughness and balanced processing performance. It is the most common structural tungsten alloy plate.
- **Application scenarios** : inertial components, counterweight plates, protective structures, etc.

2. W-Ni-Cu alloy plate (non-magnetic type)

- **Composition characteristics** : Mainly tungsten , the bonding phase is mainly Ni and Cu, often used in occasions sensitive to magnetic fields.
- **Performance characteristics** : non-magnetic, good conductivity, strong shielding performance, but the strength is slightly lower than the W-Ni-Fe system.

- **Application scenarios** : medical equipment, magnetic resonance imaging (MRI) components, and protective covers for electronic devices.

3. W-Cu alloy plate (high thermal conductivity)

- **Composition characteristics** : It is composed of tungsten and copper , and is a typical intermetallic composite material.
- **Performance characteristics** : extremely high thermal and electrical conductivity, resistant to thermal shock, suitable for thermal management applications.
- **Application scenarios** : electronic packaging substrates, high-frequency switches, electrodes and heat sinks.

4. W-Co alloy plate (wear-resistant type)

- **Composition characteristics** : tungsten-based, supplemented with cobalt (Co) as bonding metal.
- **Performance characteristics** : Excellent wear resistance and corrosion resistance, and performs well in extreme mechanical wear environments.
- **Application scenarios** : impact-resistant protective plates, mold liners, and armor-piercing protective structures.

5. Nano-enhanced tungsten alloy plate

- **Composition characteristics** : Introducing nanoparticles or second phase reinforcements into the traditional tungsten alloy system .
- **Performance characteristics** : The strength and toughness are significantly improved, suitable for fields with extreme performance requirements.
- **Application scenarios** : nuclear fusion reactor siding, deep space probe casing, etc.

2. Classification by forming and preparation process

Tungsten alloy plates can be manufactured using a variety of process routes, and different processes will significantly affect their microstructure, density, mechanical properties and cost structure.

1. Powder Metallurgy Sheet (PM)

- **Process flow** : tungsten powder + bonding powder → pressing (molding or isostatic pressing) → high temperature sintering → hot processing or rolling.
- **Advantages** : dense structure, uniform performance, strong controllability, suitable for medium and thick specifications of plates.

2. Hot-rolled and cold-rolled plates

- **Process flow** : sintering billet → hot rolling (or cold rolling) into plate → surface treatment.
- **Advantages** : high dimensional accuracy, good surface quality, suitable for mass production.

3. Rapid curing and tape technology

- **Process flow** : After high-temperature melting, it is rapidly cooled and solidified to form thin strips or sheets.
- **Advantages** : refined structure, suitable for high-frequency electronic devices.

4. Additive manufacturing plates (3D printing)

- **Process flow** : laser melting or electron beam melting → layer-by-layer accumulation → finishing.

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- **Advantages** : It can realize customized production of complex-shaped plates, suitable for high-end military and aerospace components.

5. Composite laminated tungsten alloy plate

- **Process flow** : Tungsten alloy layer + other metal layers (such as copper, titanium) hot pressing forming.
- **Advantages** : It can realize multifunctional composite and is suitable for electronic packaging and electrode fields.

3. Classification by purpose and function

Tungsten alloy plates are suitable for many industries due to their high density, radiation resistance, good thermal conductivity, and excellent processing performance. They can be divided into the following categories according to their uses:

1. Structural tungsten alloy plate

- Used for load-bearing structures, mechanical parts or dynamic balancing systems, emphasizing mechanical strength and dimensional stability.
- Typical applications: inertial flywheels, aerospace counterweights, and shaft balance plates.

2. Protective tungsten alloy plate

- Emphasis on protection capabilities, including shielding against gamma rays, X-rays, neutrons, etc.
- Typical applications: protective panels for radiotherapy equipment, shielding layers for nuclear reactors, and bullet-resistant structures for aircraft cabins.

3. Thermal control and heat dissipation tungsten alloy plate

- Emphasis on thermal conductivity and thermal shock stability.
- Typical applications: semiconductor device heat dissipation base plate, heat pipe wall plate, plasma equipment cooling device.

4. Functional/Electronic Tungsten Alloy Plate

- Combining the functions of conductivity, non-magnetism and high strength, it is used in precision electronic systems.
- Typical applications: high-frequency switch packaging, microwave absorbers, and avionics antimagnetic structural parts.

5. Composite tungsten alloy plate

- It adopts multi-layer structure and composite manufacturing of heterogeneous materials to achieve structural and functional integration.
- Typical applications: tungsten-copper composite plates (electronic substrates), tungsten-titanium composite plates (lightweight armor structures).

IV. Classification summary comparison table

Classification	Main Types	Feature Keywords	Application Areas
Element	W-Ni-Fe, W-Ni-Cu, W-Cu, W-Co, nano- tungsten alloy	Density, magnetism, thermal conductivity, wear resistance, enhanced functionality	Military industry, medical treatment, thermal

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			management, nuclear energy
Technology	Powder metallurgy, rolling, additive manufacturing , composite lamination	Density, dimensional accuracy, customization capability, multifunctional integration	High-end manufacturing, mass production, and customization of complex structures
use	Structural type, protective type, heat dissipation type, electronic type, composite type	Mechanical strength, radiation shielding, thermal and electrical conductivity, intelligent integration	Aerospace, nuclear energy, electronics, medical

In summary, as a versatile, high-performance metal material, tungsten alloy plates require a multi-dimensional and systematic classification approach . By clarifying the correspondence between composition, processing, and application, this not only helps industrial users select targeted and suitable products but also provides a clear technical reference path for subsequent research and development and standard setting. With the continuous expansion of material design concepts and processing methods, the classification of tungsten alloy plates will become more diversified and intelligent, adapting to the sophisticated needs of future advanced manufacturing.

1.4 The similarities and differences between tungsten alloy plate, tungsten rod, tungsten wire and tungsten copper plate

Tungsten materials are widely used in various industrial fields due to their high melting point, high density, and excellent thermal and mechanical properties. In practical applications, tungsten products primarily include tungsten alloy plates, tungsten rods, tungsten wire, and tungsten copper plates, depending on their form and function. Although they all belong to the tungsten -based system, they exhibit significant differences in chemical composition, preparation methods, structural properties, and application. This section will provide a horizontal comparison of these four typical tungsten materials to help readers fully understand the unique position of tungsten alloy plates within the material system.

1. Introduction to Tungsten Alloy Plate

Tungsten alloy plate is a high-density alloy plate made of tungsten as the main component, supplemented by nickel, iron, copper, cobalt and other elements. Its main characteristics are high density, high strength, good radiation resistance and thermal conductivity, suitable for high-strength structural parts, shielding protection plates and heat dissipation components.

Basic Features :

- Shape: Flat rectangular plate, thickness ranging from 0.1mm to 50mm;
- Preparation: mainly powder metallurgy, hot rolling, cold rolling, additive manufacturing , etc.
- Application: Widely used in aviation counterweight, radiotherapy protection, thermal control system, inertial components, etc.

2. Introduction of Tungsten Rod

Tungsten rod is one of the most basic tungsten processing materials, usually solid cylindrical, can be made of pure tungsten or tungsten alloy. It has a dense structure and is mainly used in high-temperature structural parts, electron emission sources, high-voltage electrodes and other fields.

Basic Features :

- Shape: cylindrical or square rod, diameter 2mm～100mm;
- Preparation: hot isostatic pressing/forging or turning after sintering and pressing;
- Application: electron tube cathode, support rod, impact tool, electrode, etc.

3. Introduction to Tungsten Filament

Tungsten wire is a thin wire drawn from tungsten ingot . It has excellent high-temperature creep resistance and electrical conductivity. It is an important material for electric light sources, electronic components and electric heating applications.

Basic Features :

- Morphology: Long and thin filaments, with diameters down to micrometers;
- Preparation: Forging, rolling and repeated drawing;
- Application: Filament, vacuum evaporation heating wire, electron beam emission source.

4. Introduction of Tungsten Copper Plate

Tungsten copper plate is a composite material plate composed of tungsten and copper . It is an intermetallic composite material that combines the high melting point of tungsten and the high thermal conductivity of copper . It is an important material for thermal management and electrical contact applications.

Basic Features :

- Form: thin plate or medium plate, thickness 1mm～20mm;
- Preparation: Powder metallurgy pressing and sintering/hot pressing composite;
- Application: heat dissipation base plate, electrode plate, high frequency packaging, etc.

5. Comparative analysis of performance and usage

Compare Projects	Tungsten Alloy Plate	Tungsten Rod	Tungsten Wire	Tungsten Copper Plate
Main ingredients	W + Ni/Fe/Cu/Co etc.	Pure W or tungsten alloy	High purity W	W + Cu (usually 50:50)
Typical form	Rectangular plates	Round or square rods	Filament	flat
density	17.0～18.5 g/cm³	18.5 ～ 19.2 g/cm³ (pure W)	Same as above	14.5～17.0 g/cm³
Mechanical properties	High strength and high toughness	High hardness, high brittleness	Flexible and plastic, high tensile strength	Moderate, combining hardness and thermal conductivity

Thermal performance	Good thermal conductivity, thermal shock resistance	Excellent high temperature stability	Resistance to high temperature evaporation and creep	Excellent thermal conductivity (>200 W/ m·K)
Processing difficulty	Medium, machinable and machinable	Difficult to process, requiring high-strength equipment support	Difficult to process, requiring multiple drawing and annealing	Relatively easy to process
Typical Applications	Radiation protection, counterweight, thermal control components	Electrodes, thermal field brackets, high-temperature components	Filaments, vacuum electronics, heating elements	Radiators, switch electrodes, electronic packaging

6. Summary of similarities and differences

Common points:

1. Material basis: All products use tungsten as the main element, some products are pure tungsten, and some are tungsten-based alloys ;
2. Performance characteristics: high density, high melting point, and good high temperature performance;
3. Production method: Most of them are based on powder metallurgy process, supplemented by thermal processing or post-processing;
4. Key areas: Widely used in high-end industries such as aerospace, electronics, military, energy, and medical.

Differences:

- Different forms and functions: plates are mainly used for covering/structural parts, rods are used for pressure-bearing/supporting parts, wires are used for heating/emitting, and tungsten copper plates are used for thermal conduction/electrical contact.
- Different processing methods: Plates are usually made by rolling and forging, bars are mainly made by sintering and forging, wires rely on multiple drawing processes, and tungsten-copper composite materials require special sintering and pressing technologies.
- Different usage conditions: tungsten filament emphasizes evaporation and resistance characteristics, tungsten copper plate emphasizes heat dissipation and conductivity, and tungsten alloy plate emphasizes structural strength and comprehensive thermal-physical properties.

7. Advantages of Tungsten Alloy Plate

Compared with the above tungsten-based materials , tungsten alloy plates have unique advantages in comprehensive performance and applicable scenarios:

- High functional integration: high density, high strength, radiation resistance and processability;
- Good form stability: the plate-like structure is more suitable for covering protection and thermal control systems;

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- Wide range of applications: It can realize function embedding and integrated design in many fields such as military industry, aerospace, medical treatment, electronics, etc.

In summary, tungsten alloy plate occupies a strategic and core position in the tungsten-based material system. It not only has the mechanical performance advantages of tungsten rods , but also has the thermal performance of tungsten copper plates, and has stronger structural integrity and radiation protection than tungsten wires. With the improvement of manufacturing technology and the expansion of emerging fields, tungsten alloy plates will continue to play a key role in the direction of multifunctional integration in the future.

1.5 Overview of Tungsten Alloy Plate Technology Evolution and Patents at Home and Abroad

As an important branch of high-performance refractory metal materials, tungsten alloy plates are widely used in key fields such as aerospace, nuclear protection, electronic packaging, high-energy physics experiments and medical equipment. With the continuous expansion of downstream applications, the world is paying more and more attention to the technological innovation capabilities, patent protection and industrialization level of tungsten alloy plates. This section will systematically sort out the domestic and foreign technological development and intellectual property layout of tungsten alloy plates from four aspects: **technological evolution process, key technical nodes, representative countries and enterprise layout, and main patent content and trends** .

1. Overview of the development and evolution of global tungsten alloy plate technology

1. Early stage (1950s–1970s) – exploration of protective materials

The initial development of tungsten alloy plate technology stemmed primarily from the military needs of the Cold War, particularly in the areas of **high-density protective materials** and **neutron shielding** . The United States and the Soviet Union pioneered the development of tungsten alloy plates, typically W-Ni-Fe, through powder metallurgy processes. These plates were used in nuclear submarines, missile counterweights, and radiation shielding armor.

Representative technological breakthroughs include:

- Tungsten powder particle size control and low temperature sintering mechanism;
- Densification and microstructure uniformity control of hot rolled plates;
- Establishment of W-Ni-Cu non-magnetic alloy system.

2. Mature development stage (1980s–2000s) – high-precision panels and multifunctional development

During this period, with the rapid development of the electronic information industry and the popularization of radiotherapy equipment, tungsten alloy plate technology gradually shifted to **the integration of structural performance and functional performance** , and formed a standardized production system in developed countries such as the United States, Japan, and Germany.

Key developments include:

- High density plate pressing technology;
- Optimization of multi-element ratio control (such as adding Co, Mo, Re);

- Standardization of high-precision cold rolling and surface treatment processes.

During this period, companies such as General Electric (GE) of the United States, Plansee of Germany , and Mitsubishi Materials (MMC) of Japan were in a leading position in technology and held a large number of patents for key manufacturing processes and application designs.

3. Advanced Manufacturing Stage (2000s to Present) – The Rise of Microstructure Control and Composite Integration Technologies

After entering the 21st century, tungsten alloy plates have made continuous breakthroughs in **intelligent manufacturing, extreme service conditions, and multiple functional integration .** Representative technologies include:

- nano-enhanced tungsten alloy plates (W-ZrO_2 , W-La_2O_3 , etc.);
- Additive manufacturing technologies such as selective laser melting (SLM) are used for tungsten plate customization ;
- Functionally graded materials (FGMs) are integrated into plates of metal/ceramic composite structures.

Currently, tungsten alloy plates are no longer a single "high specific gravity material", but are evolving towards **a structural-functional integration with multiple physical properties** .

2. Development path and achievements of domestic tungsten alloy plate technology

the country with the largest tungsten resource reserves and output in the world, China started late in tungsten alloy material technology, but has developed rapidly and has caught up in many key areas in recent years.

1. Initial reliance on import and imitation (1980s–1990s)

tungsten alloy plates in China was initially concentrated in the fields of national defense and nuclear industry, led by the Chinese Academy of Sciences, China Aerospace Science and Industry Corporation, and military research institutes. Most of the technology came from the Soviet system or was introduced from abroad.

2. System establishment and industrial expansion (2000s–2010s)

With the development of domestic powder metallurgy technology, a number of universities and key enterprises (such as Xiamen Jinlu, China Tungsten High-Tech , AVIC New Materials, and Baoti Group) have gradually formed a complete process system from tungsten powder preparation, alloy proportioning to plate rolling.

Major technological breakthroughs include:

- Pressing and sintering of low porosity and high density alloy plates;
- Optimization of binder phase ratio;
- Hot pressing diffusion bonding technology of tungsten-copper composite plates.

3. Intelligent manufacturing and independent innovation go hand in hand (2015 to present)

At present, China's tungsten alloy plate technology has international competitiveness in the fields of high-precision aviation structural parts, nuclear medicine protection, electronic packaging boards, etc. Many key technologies have won national science and technology awards and have been applied in projects such as the C919 large aircraft, space station cabin, and nuclear radiation targeting structure.

3. Analysis of the distribution of key technology patents of tungsten alloy plates worldwide

1. Patent regional distribution

According to statistics from WIPO and China National Intellectual Property Administration (CNIPA), by the end of 2024, there are more than 4,000 valid patents related to tungsten alloy plates in the world, mainly distributed as follows:

Country/Region	Proportion (%)	Main patent applicants
China	45%	China Tungsten High-Tech , Xiamen Jinlu, Beijing Nonferrous Metals Research Institute, Baoti, etc.
USA	twenty two%	Plansee , GE, Kennametal, etc.
Japan	13%	Mitsubishi Materials, Sumitomo Electric Industries, Ltd., Tokyo Steel, etc.
Germany	8%	HC Starck, Plansee , etc.
South Korea, Russia	5%	POSCO, TRINITY, etc.
Other areas	7%	Switzerland, Israel, India, etc.

2. Distribution of patent technology types

The patent contents can be summarized into five main technical directions:

Technical direction	Representative content
Alloy formula innovation	W-Ni-Co, W-Cu-Re, W-Mo series ratio
Microstructure regulation	Nanocrystalline strengthening mechanism and precipitate distribution control
Plate processing and surface treatment	Multi-pass rolling technology, electrolytic polishing, plasma surface treatment
Composite structure and bonding technology	Tungsten-copper, tungsten-titanium composite plate pressing, brazing/diffusion bonding
Application adaptability design	Radiotherapy protection module structure, heating plate distribution optimization design, etc.

IV. Representative Patent Examples at Home and Abroad

Patent Name	Authorized Country	Patent Number	Brief Description
Preparation method of high-density W-Ni-Fe tungsten alloy plate	China	CN108982173B	Proposed a process to optimize sintering temperature and pressing parameters, density > 99.5%

Non-magnetic tungsten alloy sheet and manufacturing method thereof	USA	US8574432B2	W-Ni-Cu alloy plate, emphasizing non-magnetic properties and ductility control
Tungsten-copper composite plate with gradient structure and preparation method thereof	Japan	JP2018147022A	Developed W/Cu functionally graded plates suitable for high-frequency thermal conductive electrical devices
Tungsten Alloy Protective Plate Module for Radiotherapy Equipment	China	CN110456887A	Modular panel splicing system design improves protection efficiency and facilitates replacement and maintenance
Tungsten alloy plate powder for additive manufacturing and laser sintering method thereof	Germany	DE102018001328A1	A special spherical powder composition and parameter control method suitable for SLM preparation of tungsten plates is proposed

V. Outlook on Technology and Intellectual Property Development Trends

1. Evolution from "single physical performance" to "multi-functional integration"

In the future, tungsten alloy plates will not only meet density or strength requirements, but will also integrate multiple properties such as thermal conductivity, electrical conductivity, corrosion resistance, and radiation resistance.

2. Additive manufacturing technology will lead the development of personalized board making

Laser/electron beam-based tungsten alloy plate 3D printing will be widely used in complex customized structures such as defense and nuclear energy.

3. High-end patents and technology barriers will be further raised

Core formulas, composite structures and plate microstructure control will become the focus of major technology companies, and patent competition is becoming increasingly fierce.

4. China will gradually move from a "country of patent quantity" to a "country of patent quality."

Promote the globalization of intellectual property rights by improving the material database, establishing a process standard system, and strengthening international patent collaboration and layout.

In summary, the global evolution of tungsten alloy plate technology presents the characteristics of "military origin - industrial expansion - multi-functional integration - intelligent manufacturing" in four stages. Its patent system is becoming increasingly complex and key core technologies are mostly oligopolistic. Although China started a little later, it is accelerating the construction of an independent and controllable innovation system with its resource advantages and industrial system. The future competition of tungsten alloy plate technology and intellectual property rights will become an important strategic focus in the field of new materials in the world.

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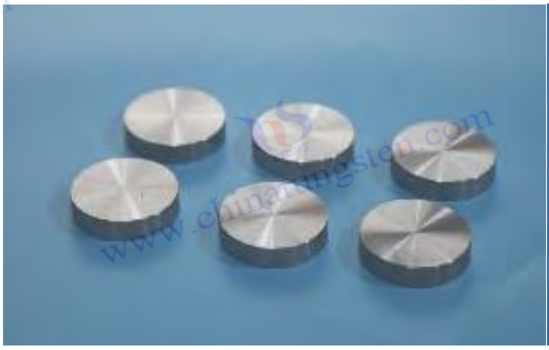
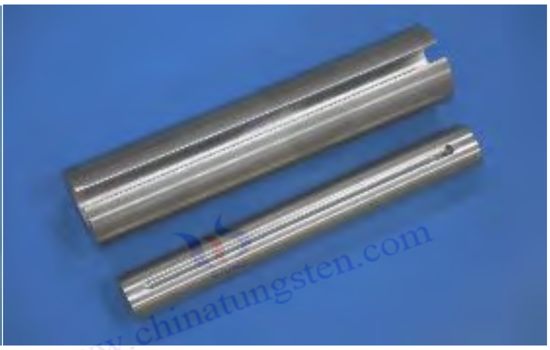

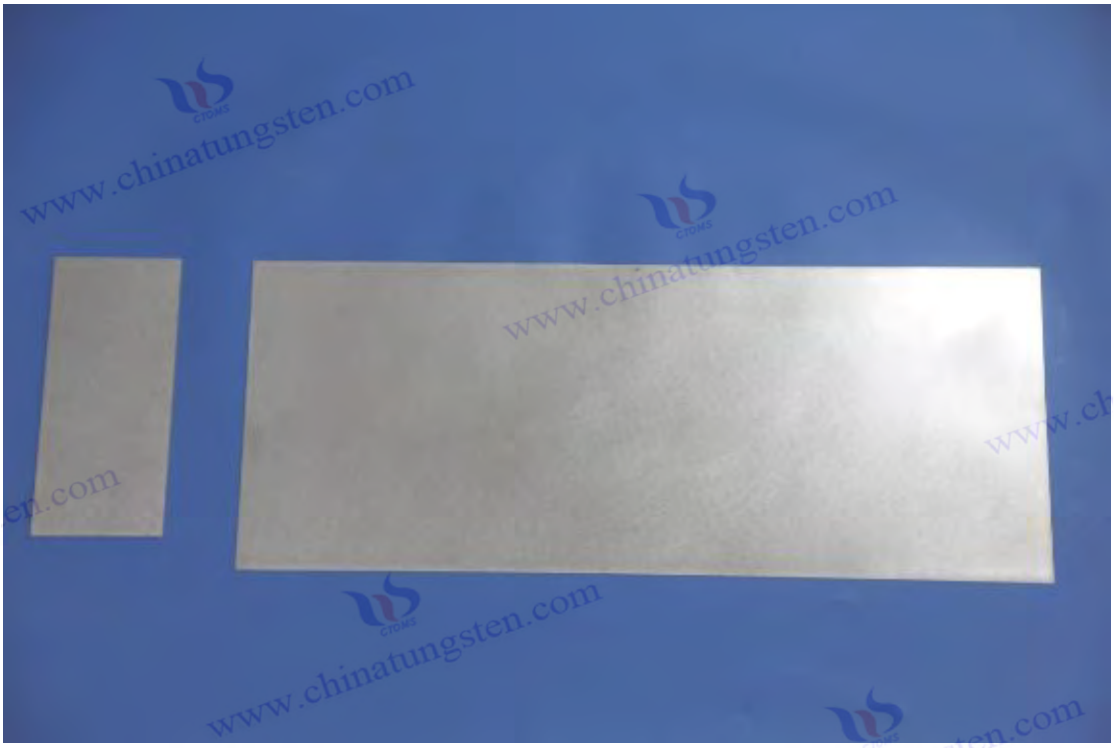

Chapter 2 Physical and Mechanical Properties of Tungsten Alloy Plate

2.1 Density, specific gravity and size control accuracy

a high-performance metal composite material based on tungsten, the physical properties of tungsten alloy plate depend largely on **the uniformity of density control** , **the consistency of specific gravity** , and **the accuracy of plate dimensions** . In fields such as aerospace, the nuclear industry, and precision medical devices, which require extremely high quality and structural accuracy, even slight deviations in these parameters can lead to systematic errors, strength loss, or thermal expansion imbalances. Therefore, this section will systematically explore the basic indicators and technical requirements for the physical properties of tungsten alloy plate from three perspectives: "Density and specific gravity control technology," "Dimensional control accuracy standards," and "Key process influencing factors."

1. Density and specific gravity of tungsten alloy plate

1. Definition of density and specific gravity

- **Density** : refers to the mass per unit volume, usually expressed in g/cm³, and is the core parameter for measuring the density of a material;
- **Gravity** : refers to the ratio of the material density to the density of pure water (4°C, 1 g/cm³), often used as a standard for intuitive classification of high-density alloys.

The theoretical density of tungsten is 19.25 g/cm³, while the density of tungsten alloy plate usually depends on its alloy composition and degree of densification:

Alloy type	Typical density range (g/cm³)
W-Ni-Fe	17.0–18.5
W-Ni-Cu (non-magnetic type)	16.5–18.0
W-Cu (thermal conductive type)	14.5–17.0
Nano-enhanced tungsten alloy	≥18.5 (theoretically >99.9% dense)

2. Technical points of density control

Density control is not just a simple ratio of alloy components, but more importantly, it is necessary to achieve the following points in the entire manufacturing process:

- **Optimization of powder particle size distribution** : Adjusting the ratio of fine powder to coarse powder can effectively reduce porosity;
- **Consistency of pressing process** : Molding/isostatic pressing needs to maintain uniform pressure per unit volume;
- **High temperature sintering densification** : Liquid phase assisted sintering or multi-stage sintering can significantly improve the final density;
- **Heat treatment and densification adjustment after rolling** : Re-homogenization of the structure after rolling can further improve the density of the material.

3. Consistency requirements for specific gravity

In engineering applications, particularly in **counterweights** and **inertial components** , specific gravity consistency directly impacts **the dynamic balance** and **structural response time of the entire machine** . Common international standards such as ASTM B777 and MIL-T-21014 have strict specifications for specific gravity tolerances, generally requiring batch-to-batch specific gravity variations to no more than ±0.1 g/cm³. For some precision components, this limit is even limited to ±0.05 g/cm³.

2. Size Control Accuracy of Tungsten Alloy Plate

1. Overview of size parameters

tungsten alloy plates involves three key dimensions:

- **Thickness** : usually between 0.1 mm and 50 mm, and some special products can reach 0.05 mm;
- **Length and width** : Varies depending on the application , generally in the range of 50 mm–500 mm;
- **Flatness and edge angle** : directly related to the assembly of the board and the integrity of the panel.

2. Dimensional accuracy grade standard

Commonly used international dimensional tolerance reference standards include:

Standard No.	project	Accuracy level	Remark

ASTM B777	Thickness and width tolerance	±0.05–0.2 mm	Classification by plate thickness and rolling state
GB/T 3876	Length, diagonal difference	±0.3 mm	National standard general specifications
ISO 2768-f	Tolerance grade for more precise sheet metal	Fine	For precision applications such as electronics and medical treatment

Some high-end tungsten alloy plates, such as those used in radiotherapy collimation systems or structural plates for nuclear detectors, even require **laser cutting and CNC milling** to achieve geometric accuracy control within ±0.01 mm.

3. Key process factors affecting size control

- **Mold accuracy and pressing uniformity** : directly affect the dimensional consistency of the blank sheet;
- **Prediction and control of sintering shrinkage ratio** : The linear shrinkage during sintering is about 10%–15%, which requires accurate calculation;
- **Rolling deformation and elastic rebound control** : Hot rolling and cold rolling should fully estimate material hardening and deformation compensation;
- **Post -processing control** : including grinding, polishing, trimming and other processes must be coordinated with the dimensional accuracy control target.

3. Synergistic influence of density and dimensional accuracy

tungsten alloy plates do not exist in isolation, but are key physical properties that restrict and optimize each other. For example:

- High density is often accompanied by an increased tendency for plate warping, and its flatness needs to be optimized through a reasonable rolling path;
- When the dimensional tolerance is reduced, the requirements for the uniformity of the internal structure of the plate are also higher;
- Small thickness fluctuations in precision sheet metal can amplify the impact on specific gravity evaluation and the dynamics of functional components.

Therefore, in industrial practice, the " **density-size** dual-dimensional control system" of tungsten alloy plates usually needs to rely on **numerical simulation** (such as finite element thermal deformation analysis), **intelligent measurement equipment** (laser interferometer, three-coordinate measuring machine) and **quality management system** (such as ISO 9001, AS9100) to ensure that the final product meets the high reliability requirements.

IV. Summary

tungsten alloy plate density and specific gravity is one of the core indicators for evaluating its overall physical stability and structural strength, while dimensional control accuracy determines its adaptability and interchangeability in high-end manufacturing systems. Against the backdrop of new materials developing towards high performance, microstructure, and integration, tungsten alloy plate density and dimensional control technology is continuously evolving towards " **high density, high precision, and intelligent manufacturing** ."

2.2 Tensile strength, yield strength and fracture toughness

As a high-performance structural material, tungsten alloy plates' mechanical properties, such **as tensile strength** , yield strength **, and** fracture toughness, directly determine their applicability, safety, and longevity when subjected to external loads and high-temperature stresses. In applications such as aerospace, high-energy physics, and protective armor, the material must not only possess high strength but also maintain structural integrity under extreme conditions such as stress concentration, impact loads, and thermal fatigue. Therefore, a comprehensive understanding of the mechanical response behavior of tungsten alloy plates is a core foundation for their design, manufacturing, and engineering applications.

1. Basic Definition of Tensile Strength and Yield Strength

- **Strength** (UTS): It is the maximum stress that a material can withstand under uniaxial tension. The unit is MPa or ksi , which reflects the ultimate bearing capacity of the material.
- **Strength** (YS): refers to the stress value at which the material begins to produce plastic deformation under the action of external force. It is an important indicator of the safety limit of the designed structure.

For tungsten alloy plates, due to its high density and strong metal bonding, the strength value is much higher than that of general structural alloys. Typical parameters are as follows:

Alloy system	**Tensile strength (MPa)**	**Yield strength (MPa)**	**Remark**
W-Ni-Fe	700–1000	500–750	Under normal temperature conditions
W-Ni-Cu (non-magnetic type)	600–850	450–700	Slightly better ductility
Nano W alloy plate	>1000	>850	Particle size <500 nm, with strengthening mechanism

Note : The actual mechanical properties vary with alloy proportion, heat treatment status, plate thickness, microstructure, and are subject to test standards (such as ASTM E8/E8M, GB/T 228.1).

2. Analysis of the Microscopic Mechanism of Intensity

tungsten alloy plate is mainly controlled by the following factors:

1. **tungsten matrix** : According to the Hall–Petch relationship, the finer the grain, the higher the yield strength. Nanocrystalline tungsten alloys exhibit extraordinary strength due to their ultrafine grain structure;
2. **Multiphase metal bonding phase (Ni, Fe, Cu)** : forms a continuous or network distribution during the sintering process, forms a transition phase interface with tungsten particles, and enhances plasticity;
3. **Porosity and defect control** : High density (>98.5%) can reduce microcrack initiation and improve tensile strength;

4. **Residual stress and heat treatment status** : Residual stress from hot working or rolling will reduce strength uniformity, and annealing treatment helps stabilize strength;
5. **Element strengthening mechanism** : Adding Re, Mo, etc. can form a strengthening phase, inhibit dislocation movement, and increase yield strength.

3. Fracture toughness and fracture behavior

1. Definition and Importance

Fracture toughness (K_IC) refers to the ability of a material to resist fracture in the presence of notches or cracks. It is a core parameter for measuring the structural safety redundancy. The unit is MPa·m^1/2.

tungsten alloy has high strength, its fracture toughness is much lower than that of titanium alloy or aluminum alloy due to the brittleness of the tungsten matrix itself. Therefore, it is particularly necessary to optimize the toughness performance in the fields of protection and structural impact.

2. Typical toughness parameters

Alloy type	**Fracture toughness K_IC (MPa·m^1/2)**	**Remark**
Ordinary W-Ni-Fe plate	15–25	Normal temperature test value
Refined W-Ni-Cu plate	20–30	Non-magnetic type, slightly better ductility
Nano-strengthened W alloy plate	30–45	Ultrafine grain strengthening, significantly improved toughness

3. Crack propagation mechanism

tungsten alloy plate under tensile load has the following characteristics:

- **High brittle-ductile transition temperature** : Most W alloy plates exhibit quasi-brittle fracture at room temperature;
- **Crack deflection mechanism** : The Ni/Cu bonding phase in the multiphase structure can partially absorb the crack propagation energy, resulting in deflection;
- **fine-grained tungsten alloy plate presents a quasi-cleavage plane** : part of it presents a composite mode of dimple-cleavage.

In order to improve fracture toughness, the following methods are often used:

- Control the powder particle size distribution to avoid stress concentration caused by large particles;
- Improve the continuity and toughness of the bonding phase;
- After the plate is heat treated, "directional rolling" is performed to passivate the cracks that extend along the interface.

4. Mechanical properties test methods and standards

1. **Tensile strength test** : using standard dumbbell specimens, according to ASTM E8 or GB/T 228.1 standards;
2. **Fracture toughness test** : Single edge notched beam specimen (SENB) or compact specimen (CT) is usually used, refer to ASTM E399;
3. **Test condition control** :
   - o Temperature: room temperature to high temperature (300°C–800°C);
   - o Directionality: The performance difference between the plate thickness direction and rolling direction is significant;
   - o Crack size/loading rate etc.

5. Comparative analysis with other high-strength materials

Material Type	Tensile strength (MPa)	Fracture toughness (MPa·m^1/2)	App Reviews
Titanium alloy Ti-6Al-4V	~900	~50–60	Excellent comprehensive performance, suitable for aviation structures
High strength aluminum alloy 7075	~600	~25–35	Low density but not as strong as tungsten alloy
Tungsten Alloy Plate (W-Ni-Fe)	800–1000	20–30	High density and high strength, suitable for inertia and protection structures
Tungsten copper composite plate	~600	~15	Good thermal conductivity but slightly lower toughness, suitable for heat dissipation components

Tungsten alloy plates far exceed aluminum alloys and titanium alloys in strength and specific gravity, but have slightly lower toughness. They are suitable for **structural parts with compact size, large loads, and high requirements for instantaneous impact response** , such as aerospace counterweights, nuclear reactor protection, and armor-piercing projectile structures.

VI. Summary

Tungsten alloy plates boast high tensile and yield strength levels, while maintaining high specific gravity and heat resistance while also continuously optimizing their fracture toughness. Through refined grain control , bond phase design, and improved heat treatment processes, modern tungsten alloy plates have gradually developed a comprehensive structural capability that balances high strength with controlled toughness. This makes them irreplaceable material advantages in key areas such as defense, aerospace, medical devices, and electronic cooling.

2.3 Hardness and wear resistance

As an advanced metal material with high density, high strength, heat resistance and corrosion resistance, the **hardness** and **wear resistance of** tungsten alloy plate are key parameters to measure its service life and structural stability, especially in the fields of high-speed moving parts, impact contact surfaces, strong friction conditions, etc. These two properties are not only controlled by the microstructure of the material itself, but also closely related to its composition design, preparation process and surface treatment status.

1. Hardness basis of tungsten alloy plate

1. Hardness definition and common units

Hardness refers to the ability of a material to resist local plastic deformation, indentation or scratching. The hardness of tungsten alloy plates is usually expressed in the following ways:

- **Brinell hardness (HB)** : Applicable to thick tungsten plates, reflecting the overall hardening state;
- **Vickers hardness (HV)** : suitable for precision measurement, especially for microstructure research;
- **Rockwell hardness (HRC/HRB)** : Suitable for on-site rapid testing of medium hardness alloy plates.

2. Common hardness range of tungsten alloy plates

Alloy type	Typical hardness range
W-Ni-Fe Alloy Plate	200–300 HB
W-Ni-Cu alloy plate	180–260 HB
High Strength Tungsten Alloy Plate	320–400 HB
Tungsten copper composite plate (hard surface)	150–200 HB
Nanocrystalline tungsten alloy plate	≥400 HV

Generally speaking, the higher the tungsten content, the greater the density, and the finer the grains, the higher the hardness of the material.

3. Microscopic mechanisms affecting hardness

- **The intrinsic hardness of the tungsten matrix is extremely high** : the Vickers hardness of pure tungsten can reach 350–450 HV, which gives the material overall resistance to deformation;
- **Strengthening effect of multiphase structure** : Ni, Fe, Cu and other bonding phases are dispersed to improve stress dispersion ability;
- **Grain refinement and strengthening** : The Hall-Petch mechanism significantly improves the resistance to microscopic dislocation movement;
- **Heat treatment effects** : Annealing reduces hardness and increases ductility; solution strengthening and aging treatments increase overall hardness.

2. Wear resistance of tungsten alloy plate

1. Definition and importance of wear resistance

physical wear, surface peeling, or micro-cutting damage during contact motion . Tungsten alloy plates, due to their high hardness, high melting point, and strong metallic bonding, are often used in friction components, mold templates, rotating bearing rings, and other applications where they are required **to maintain a low wear rate despite dry friction, high loads, and corrosive media** .

2. Analysis of wear resistance mechanism

tungsten alloy plates is mainly dominated by the following mechanisms:

- **High hard phase dominates wear resistance** : Tungsten grains themselves have high hardness, which can effectively prevent cutting by foreign particles or tool edges;
- **Wear control function of bonding phase** : Although metal phases such as Ni and Cu are relatively soft, they can buffer impact loads and improve impact wear resistance;
- **Porosity and defect control is critical** : the more micropores there are, the more susceptible the surface is to fatigue peeling;
- **Surface treatment improvement mechanism** : If the tungsten alloy plate is treated with plasma nitriding, electroplating nickel, and spraying ceramic layer, the wear resistance can be significantly enhanced.

3. Typical wear resistance tests and data

Common tests include:

- **Dry friction test (pin-on-disk)** : Determination of wear volume rate and friction coefficient;
- **Grinding wheel wear test (ASTM G65)** : used to evaluate erosion and scratch resistance;
- **High-speed impact wear test** : simulates ballistic erosion environment (such as friction heat of armor-piercing projectile core).

Some examples of test results are as follows:

Material Type	Wear rate (mm³/ N·m)	Friction coefficient	Test conditions
W-Ni-Fe board	2.1×10^{-6}	0.18	Dry friction, 20 N, RT
Surface oxidation W alloy plate	1.3×10^{-6}	0.12	The oxide layer is about 2 μm thick
Sprayed zirconia-W composite plate	0.8×10^{-6}	0.10	Ceramic layer significantly improves wear resistance

3. Engineering measures to improve hardness and wear resistance

1. **Material design optimization** :
   - Increase tungsten content and control the ratio of bonding phase;
   - Add strengthening elements (such as Mo, Co, Re);
   - Nanoparticle dispersion strengthening mechanism;
2. **Microstructure control and heat treatment** :
   - Multi-stage sintering improves density;

  - o Rapid cooling or temperature-controlled annealing reduces coarse grains;
3. **Surface treatment technology** :
   - o Plasma nitriding or silicon nitride coating;
   - o Spraying carbide layer or ceramic layer;
   - o Laser surface cladding forms a dense coating.
4. **Composite structure design** :
   - o wear-resistant ceramic composite structural plates such as W- TiC and W-ZrO_2 ;
   - o Local hardening treatment to build a gradient hardness surface.

4. Typical application cases

- **Heat sink board for electronic equipment** : requires high hardness support and scratch resistance;
- **Bulletproof and explosion-proof structural layer** : impact and wear resistance is significantly better than steel;
- **High-speed processing mold lining** : resistant to high-frequency cutting and thermal fatigue wear;
- **Aircraft instrument interface board** : needs to withstand frequent thermal-mechanical coupling loads;

tungsten alloy plates give them significant advantages in replacing traditional wear-resistant metals such as high-cobalt alloys, stainless steel, and nickel-based alloys.

V. Summary

Tungsten alloy plates, with their high hardness and wear resistance, have irreplaceable application value in a variety of high-end manufacturing and extreme working conditions. Their hardness is influenced by the microstructure, alloy composition, and heat treatment state, while their wear resistance is the result of the coordinated optimization of hardness, binder phase design, and surface engineering. In the future, through nanostructured microstructure control, intelligent surface treatment, and composite multifunctional integration, the application potential of tungsten alloy plates in precision wear resistance and heavy-load friction scenarios will continue to expand.

2.4 Thermal conductivity, thermal expansion coefficient and high temperature stability

Tungsten alloy plates are widely used in aerospace, nuclear industry, electronic cooling and other fields due to their high density, high strength and excellent high temperature stability. **The thermal conductivity** , **thermal expansion characteristics** and **high temperature mechanical properties of the material** are directly related to its service life and safety in complex thermal environments, so this section will focus on analyzing these performance indicators and influencing factors.

1. Thermal conductivity

1. Definition and Importance of Thermal Conductivity

Thermal conductivity refers to the ability of a material to conduct heat energy, and the unit is generally W/(m·K). In tungsten alloy plates, high thermal conductivity helps to dissipate heat quickly, avoid thermal stress accumulation, and prevent thermal fatigue and cracking of the material.

2. Thermal conductivity characteristics of tungsten alloy plate

- The thermal conductivity of pure tungsten is extremely high, about 170–180 W/(m·K) (at room temperature);
- tungsten alloy, the thermal conductivity will decrease, but it still remains at a high level, usually 50–100 W/(m·K);
- W-Cu composite tungsten alloy plates have better thermal conductivity, and the thermal conductivity of some materials can exceed 200 W/(m·K), making them suitable for efficient thermal management applications.

3. Factors affecting thermal conductivity

- **Alloy composition** : The high thermal conductivity of copper significantly improves the thermal conductivity of the alloy;
- **Density** : High porosity reduces thermal conductivity;
- **Microstructure** : grain size and interface scattering affect heat flow transmission;
- **Temperature changes** : Generally, thermal conductivity decreases as temperature increases.

2. Thermal Expansion Coefficient

1. Definition of thermal expansion coefficient

The coefficient of thermal expansion (CTE) indicates the ratio of the dimensional change of a material when the temperature changes, and its unit is 10^{-6} /K. Properly matching CTE is critical to avoid thermal stress concentration and structural failure.

2. Thermal expansion characteristics of tungsten alloy plate

- Pure tungsten has a low CTE of approximately 4.5–5.0 × 10^{-6} / K (room temperature to 100°C).
- With the addition of alloying elements such as Ni, Fe, and Cu, the CTE increases, usually in the range of 6–8 × 10^{-6} /K;
- Due to the high copper content, the CTE of W-Cu composite boards can reach 12–16 × 10^{-6} / K, so attention should be paid to matching with the connecting materials.

3. Engineering significance

CTE does not match other materials, which can easily lead to thermal stress, interface delamination, and structural deformation. Strict control is especially necessary in aerospace and nuclear energy applications with frequent thermal cycles.

3. High temperature performance

1. High temperature strength and stability

Tungsten alloy plate can still maintain excellent mechanical properties at high temperature, which is its important advantage:

- The high temperature tensile strength can be maintained at 60%–80% of room temperature;
- The thermal softening temperature exceeds 1200°C, suitable for use in high temperature environments;
- The melting points of elements such as Ni and Fe in the alloy are much lower than that of tungsten, which limits the high temperature limit.

2. Thermal oxidation behavior

Tungsten and tungsten alloys are prone to form brittle oxide films in high temperature oxidation environments, which affects their service life:

- Usually **a protective coating** or **inert atmosphere is required** to slow down oxidation;
- Nano-coating technology and composite material design can effectively improve oxidation resistance.

IV. Conclusion

Tungsten alloy plates offer excellent thermal conductivity and a low coefficient of thermal expansion, making them suitable for use in high-temperature, high-heat-flux environments. Through alloy design and surface treatment, the material's high-temperature stability and oxidation resistance are continuously improved to meet diverse industrial needs.

2.5 Electrical properties, magnetic response and radiation resistance

Tungsten alloy plates are not only famous for their excellent mechanical and thermal properties, but also show unique advantages in the fields of electronics, electromagnetics and nuclear energy. Its **electrical properties** , **magnetic response characteristics** and **radiation resistance** are the basic indicators that determine its performance stability and safety in key applications such as high-tech equipment, nuclear reactor structures and protective materials.

1. Electrical properties

1. Conductivity and resistivity

- Tungsten itself is a transition metal with high electrical conductivity, but after alloying, its electrical conductivity decreases due to doping with elements such as Ni, Fe, and Cu.
- The resistivity of tungsten alloy plates generally ranges from about 5 to 15 μΩ·cm (at room temperature), which is much higher than that of pure copper (about 1.68 μΩ·cm), but lower than that of ceramic materials.
- Resistivity is affected by alloy composition, preparation process, grain size and temperature. When the temperature rises, the resistivity usually shows a positive temperature coefficient.

2. Engineering significance of electrical properties

- In electronic heat dissipation structures, tungsten alloy plates can effectively reduce overheating of electronic components due to their good electrical and thermal conductivity.
- For certain electromagnetic shielding applications, the resistivity properties of tungsten alloy plates are also beneficial in reducing electromagnetic interference.

2. Magnetic response characteristics

1. Magnetic type

- Tungsten and most tungsten alloys are paramagnetic or weakly diamagnetic. The addition of Ni and Fe may introduce magnetic response, but the ferromagnetism in actual alloys is usually suppressed by the high density and crystal structure of tungsten.
- W-Ni-Fe alloy shows weak magnetism under certain ratios and is mainly used in special applications that require magnetic properties to be controlled.

2. Magnetic performance parameters

- The magnetic permeability is low, suitable for high-frequency electronics and radio frequency equipment;
- The magnetic saturation intensity is low, which avoids drastic changes in material properties caused by magnetic fields;
- Certain non- magnetic tungsten alloys (such as W-Ni-Cu) are widely used in aerospace and medical fields to avoid magnetic field interference.

3. Radiation resistance

1. Radiation resistance mechanism

- Tungsten alloy plate has a very high atomic number (Z=74) and high density, and can effectively block and absorb gamma rays, X-rays and neutron radiation;
- Its stable lattice structure and strong bonding force enable it to maintain material integrity in a high-energy radiation environment, reducing material expansion, embrittlement or degradation caused by radiation;
- Elements such as Ni and Fe in the alloy can enhance the ability to repair radiation damage.

2. Application scenarios

- As a protective shielding material in nuclear reactors, it effectively absorbs neutrons and gamma rays;
- Protective covers of medical radiation equipment and components of radiotherapy devices;
- Radiation shielding for spacecraft electronic equipment.

3. Performance stability in radiation environment

- Experiments show that the mechanical properties of tungsten alloys change little after high-dose radiation, and the microstructural damage is limited;

- Surface coating technology needs to be combined to further improve oxidation resistance and radiation tolerance.

4. Conclusion

Tungsten alloy plate has excellent electrical performance adjustment ability, low magnetic response and excellent radiation resistance, which can meet the needs of many high-end fields such as electronic heat dissipation, nuclear energy protection and aerospace. Through material composition design and composite structure optimization, its performance in electromagnetic and radiation environments will be even better, and it has broad development potential in the future.

2.6 Corrosion resistance and chemical stability analysis

Tungsten alloy plates often face complex environmental conditions in industrial applications, such as moisture, atmospheric oxidation, acid-base corrosion, and high-temperature oxidation. Their **corrosion resistance** and **chemical stability** are crucial for ensuring long-term stable operation and extending the material's service life. This section systematically analyzes the corrosion resistance, chemical reaction mechanisms, and related protection strategies of tungsten alloy plates.

1. Corrosion resistance characteristics of tungsten alloy plate

1. **Chemical Stability of**
   Tungsten : Tungsten metal itself possesses strong corrosion resistance, particularly in neutral and slightly alkaline environments. Tungsten's high melting point and strong bonding strength slow its reaction rate in most acid and alkaline solutions, resulting in a dense oxide film forming on its surface that provides protection.
2. **Influence of alloying elements**
   Tungsten alloys usually contain alloying elements such as nickel, iron, and copper. The corrosion resistance of these elements is relatively weak and may become the starting point of corrosion, especially in strong corrosive media such as chloride ions and sulfuric acid.
3. **corrosion**
   performance. Porosity and microcracks can easily lead to local corrosion and promote stress corrosion cracking (SCC).

2. Chemical stability and corrosion mechanism

1. **Atmospheric oxidation**
   Tungsten alloy has strong resistance to atmospheric oxidation at room temperature, and a dense tungsten oxide film (WO_3) can be formed on the surface to protect the internal metal from further oxidation. However, the oxidation rate is accelerated at high temperatures, resulting in thickening of the oxide film and brittleness.
2. **Acid and alkali corrosion**

- **Acidic environment** : such as nitric acid, hydrochloric acid, etc., the surface of tungsten alloy may dissolve or hydrogen embrittlement occurs, and Ni and Fe phases are more susceptible to corrosion;

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- **Alkaline environment** : Tungsten and its oxides are generally stable and weak to alkaline corrosion, but some strong bases such as sodium hydroxide can still damage the material surface at high concentrations.

3. **Electrochemical corrosion**

   In electrolyte media, tungsten alloys may form a micro-battery effect, leading to increased local corrosion. The tungsten phase acts as the cathode and the alloy bonding phase may act as the anode, forming a corrosion current.

3. Technical measures to improve corrosion resistance

1. **Material design optimization**

- Increase the tungsten content and reduce the proportion of corrosion sensitive phase;
- Corrosion-resistant elements such as molybdenum and chromium are added to enhance overall stability.

2. **Surface protection technology**

- Surface oxidation treatment forms a protective oxide film;
- Apply anti-corrosion coating (ceramic, metal compound);
- Electroplating of metal layers such as nickel and chromium can enhance surface corrosion resistance.

3. **Environmental Control**

- Avoid contact with high concentration corrosive media;
- Control temperature and humidity to reduce the risk of electrochemical corrosion.

4. **Process Improvement**

- Improve density and reduce pores and microcracks;
- Refined heat treatment to improve tissue uniformity.

4. Examples of Corrosion Protection in Typical Applications

- **Nuclear industry** : When using tungsten alloy protective materials, inert atmosphere or vacuum packaging is often used to prevent oxidation corrosion.
- **Medical equipment** : Tungsten alloy radiotherapy devices require strict biocompatibility and corrosion resistance, and are often protected by bio-inert coatings.
- **Aerospace** : In high temperature and high humidity environments, surface nitriding or spraying of corrosion-resistant coatings is required to improve material stability.

V. Summary

Tungsten alloy plates, with their high tungsten content and stable lattice structure, exhibit good corrosion resistance and chemical stability in most environments. Through alloy design, surface treatment and environmental control, the corrosion process can be effectively inhibited to ensure the long-term reliable operation of the material in harsh working conditions.

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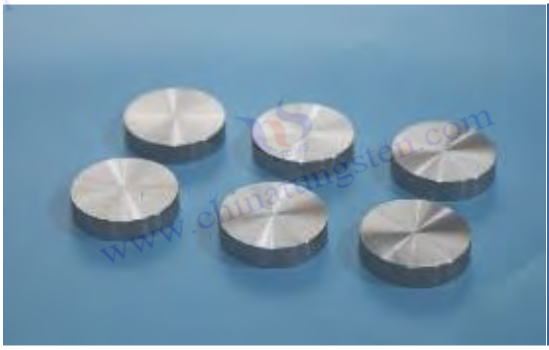
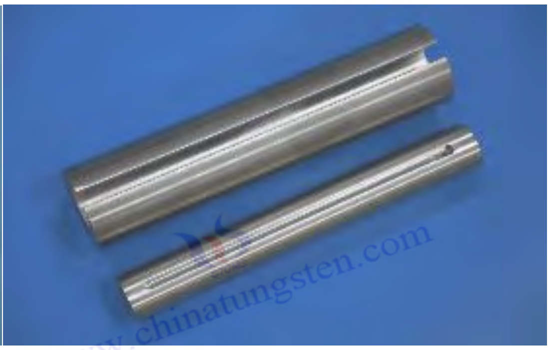

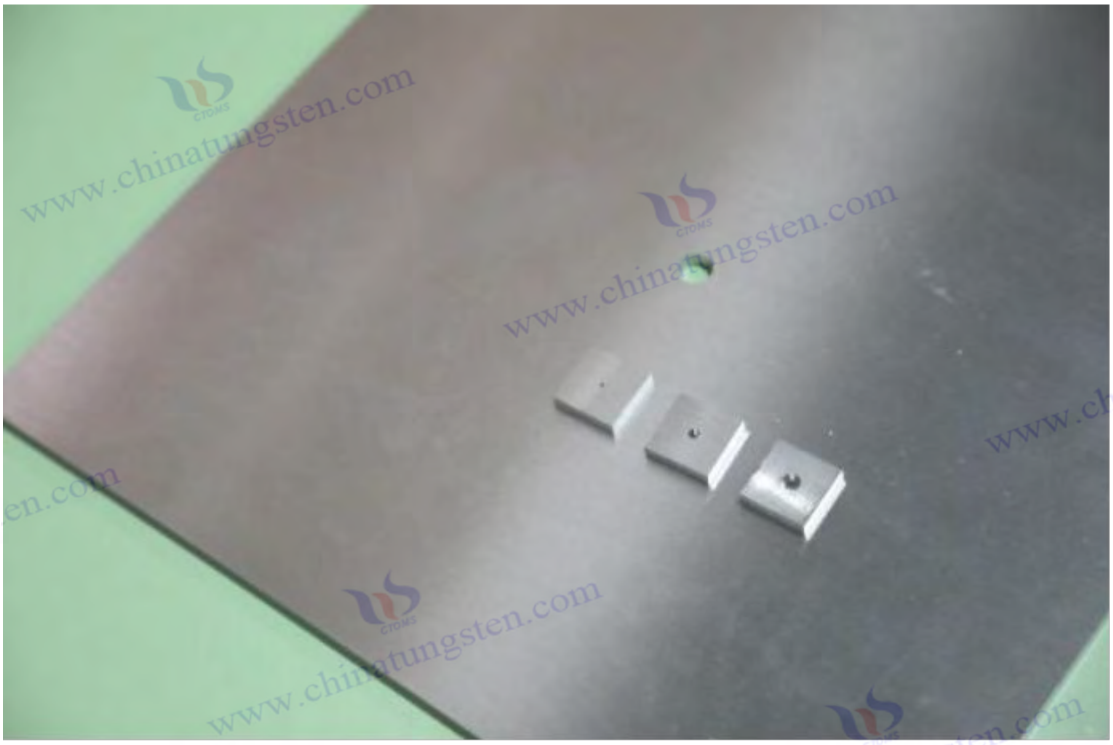

Chapter 3 Preparation and Forming Technology of Tungsten Alloy Plate

3.1 Raw material selection and processing of tungsten powder and binder metal

Tungsten alloy plate lies in the selection and processing of raw materials, especially the quality of tungsten powder and its bonding metal powder, which directly determines the performance stability and forming efficiency of the final alloy plate. This section introduces in detail the characteristics of tungsten powder, the types and functions of bonding metals, and raw material pretreatment technology.

1. Selection and characteristics of tungsten powder

1. **Physical and chemical properties of tungsten powder**
   Tungsten powder is the skeleton material of tungsten alloy and must have the following basic properties:

- **High purity** : Tungsten content is generally ≥99.9% to reduce the impact of impurities on alloy properties;
- **Suitable particle size** : The particle size distribution is uniform, typically 1－10 μm. Fine powder is conducive to sintering densification, while coarse powder is conducive to fluidity and forming;
- **Regular particle shape** : spherical or sub-spherical powders have good fluidity and are conducive to uniform pressing;
- **Low oxygen content** : avoids oxides affecting density and mechanical properties.

2. **Preparation method of tungsten powder**

- **Hydrogen reduction method** : tungstate is reduced to metallic tungsten powder with controllable particle size;
- **Carbothermal reduction method** : using carbon powder to reduce tungsten compounds, which is low in cost but has a larger particle size;
- **Spray drying method** : to produce spherical tungsten powder and improve fluidity;
- **Mechanical alloying** : used to prepare nano-tungsten powder and improve strengthening effect.

2. Types and selection of bonding metals

1. **Main bonding metal**

- **Nickel (Ni)** : A commonly used binder phase with good wettability and high-temperature strength, which can effectively enhance the bonding between tungsten powders ;
- **Iron (Fe)** : used in conjunction with nickel , it can increase the strength and hardness of the alloy and reduce costs;
- **Copper (Cu)** : Used in certain tungsten-copper composite materials to improve thermal conductivity and electrical properties, but has poor bonding ability;
- **Cobalt (Co)** : Used in some high-performance tungsten alloys to improve wear resistance and high-temperature performance.

2. **Physical Requirements for Bonded Metals**

- The powder particle size is uniform and is usually finer than tungsten powder (0.5－5 μm);
- High purity to avoid impurities introducing material defects;
- Good fluidity and mixability ensure uniform mixing.

3. Raw material pretreatment technology

1. **Powder Mixing**

- Use mechanical mixing methods such as ball milling and stirring to ensure that the tungsten powder and the bonding metal powder are evenly dispersed;
- Appropriate addition of additives can improve dispersibility and avoid agglomeration.

2. **Powder drying and deoxygenation**

- After mixing, the powder usually needs to be dried to remove moisture and organic residues;
- Deoxidation treatment under vacuum or hydrogen atmosphere can reduce oxygen content and oxidation during sintering.

3. **Screening and classification**

- Control the particle size distribution by screen or airflow classification to ensure uniformity and densification of pressing;
- Removes abnormal particles that are too large or too fine.

4. Quality Control and Testing

- **Chemical composition analysis** : ICP, XRF and other methods are used to detect the content of tungsten and alloy elements;
- **Particle size distribution detection** : laser particle size analyzer or microscope analysis;
- **Oxygen content test** : using thermal desorption, carbon and sulfur analysis and other instruments for monitoring;
- **Flowability test** : Use flow angle or flow rate measuring equipment to test the powder flowability.

V. Summary

tungsten alloy plate is based on the high-quality raw material selection of tungsten powder and bonding metal and scientific pretreatment process. Reasonable control of powder particle size, purity, oxygen content and mixing uniformity is the key to ensure the smooth subsequent forming and sintering process and stable product quality. In the future, with the development of nano powder and functionalized surface powder, the performance of tungsten alloy plate will be further improved.

3.2 Powder metallurgy preparation process (pressing, isostatic pressing, sintering)

tungsten alloy plate is based on powder metallurgy technology. Through the steps of mixing, forming and sintering tungsten powder and bonding metal powder, high-density and high-performance alloy plates are obtained. This section systematically introduces the key processes of powder metallurgy preparation and the influence of process parameters on material quality.

1. Powder mixing and preparation

- Tungsten powder and bonding metal powder are mixed strictly according to the ratio to ensure uniform composition;
- Use processes such as ball milling and mechanical stirring to improve powder dispersibility;
- Dry and deoxidize the mixed powder to avoid oxidation during sintering;
- Large particles and agglomerates are removed by screening to ensure fluidity and uniform pressing.

2. Pressing process

1. Uniaxial Pressing

- The evenly mixed powder is placed in a mold and pressed into shape under unidirectional pressure;
- Advantages: simple equipment, high production efficiency, suitable for preparing tungsten alloy slabs with simple shapes;
- Disadvantages: The density distribution is uneven during the pressing process, and density gradient is likely to occur, which affects the sintering density.

2. Cold Isostatic Pressing (CIP)

- The powder is placed in a sealed rubber bag, immersed in a liquid medium, and subjected to uniform isostatic pressure;
- Advantages: obtain dense and uniform green body, reduce internal defects and pores;
- Suitable for the production of tungsten alloy plates with complex shapes or high density requirements;
- The pressure range is generally 100 – 300 MPa.

3. Hot Isostatic Pressing (HIP)

- Combining high temperature and high pressure, the powder body is pressurized and sintered in an inert gas environment (such as argon);
- Advantages: Sintering and densification are completed simultaneously, improving the mechanical properties and uniformity of the alloy;
- Suitable for high-end tungsten alloy plate manufacturing, can significantly improve tensile strength and hardness.

3. Sintering process

1. Sintering principle

- By heating at high temperature, the tungsten powder and the bonding metal diffuse and dissolve, thus strengthening the bonding between the particles;
- Eliminate the pores between powders and achieve material densification.

2. Sintering atmosphere

- Hydrogen, nitrogen or high-purity inert gas is usually used for protection to avoid oxidation and impurity contamination;
- The hydrogen atmosphere has a reducing effect and prevents the formation of oxides.

3. Temperature and time control

- The sintering temperature is generally controlled at 1350 – 1600° C, which is determined by the alloy composition and sintering equipment;
- The holding time needs to ensure adequate diffusion of the powder, typically ranging from 30 minutes to several hours;
- Too high a temperature may cause grain growth and affect the mechanical properties.

4. Subsequent treatment and densification

- Some processes will combine hot isostatic pressing (HIP) for secondary densification;
- Heat treatment adjusts the organizational properties and improves toughness and hardness;
- Annealing treatment before machining improves material plasticity and processing properties.

5. Influence of process parameters on performance

Process	Key Parameters	Influence on the performance of tungsten alloy plate

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suppress	Pressure size and holding time	Affects the density of the green body , and the density uniformity determines the sintering quality
sintering	Temperature, atmosphere, time	Affects grain size, bonding strength and density
Hot Isostatic Pressing	Temperature, pressure, time	Further improve density and mechanical properties

VI. Summary

Powder metallurgy preparation is the core technology of tungsten alloy plate manufacturing. Reasonable selection of pressing methods and control of sintering process parameters are the key to obtaining high-performance tungsten alloy plates. With the continuous advancement of equipment and processes, the application of advanced technologies such as hot isostatic pressing has continuously improved the mechanical properties, density and structural uniformity of tungsten alloy plates to meet higher-end application requirements.

3.3 Hot rolling and cold rolling forming processes

After the tungsten alloy plate is formed by powder metallurgy sintering, it is often necessary to go through mechanical processing such as **hot rolling** and **cold rolling** to further adjust the structure and performance of the plate, improve density and mechanical strength, and improve surface quality and dimensional accuracy. This section introduces the process flow, technical points of hot rolling and cold rolling and their impact on the performance of tungsten alloy plate in detail.

1. Hot rolling forming process

1. Process Overview

- Hot rolling is a process in which tungsten alloy slabs are heated to a suitable temperature (usually in the range of 800 – 1200° C) and plastically deformed by applying pressure in a rolling mill.
- Hot rolling can effectively refine the grains, improve the internal structure of the alloy, and enhance toughness and plasticity.

2. Hot rolling temperature control

- Appropriate heating temperature ensures that the material has good plasticity and avoids cracks and fractures;
- Too high a temperature may cause grain growth and reduce mechanical properties;
- Too low a temperature will increase the deformation resistance and may cause cracks on the surface of the plate.

3. Hot rolling deformation and rolling speed

- The deformation is controlled within a reasonable range (single rolling thickness reduction is generally 10%-30%) to ensure uniformity of the structure;

- The rolling speed affects the temperature distribution and needs to be adjusted according to the equipment and material conditions to prevent stress caused by uneven cooling.

4. Annealing

- Annealing is often required after hot rolling to eliminate internal stress and restore material toughness;
- The annealing temperature is usually slightly lower than the hot rolling temperature, and the time is adjusted according to the plate thickness and material properties.

2. Cold rolling forming process

1. Process Overview

- Cold rolling is to perform multiple plastic processing on the hot-rolled tungsten alloy plate at room temperature to further improve the plate precision and surface quality;
- Cold rolling can significantly increase the strength and hardness of the material, making it suitable for manufacturing high-performance tungsten alloy plates.

2. Cold rolling deformation and rolling scheme

- The single deformation is small, usually 5% – 15%, to prevent the plate from cracking;
- Multiple passes of rolling and intermittent annealing to restore plasticity and avoid excessive hardening.

3. Surface quality and size control

- Cold rolling can effectively reduce surface roughness and improve smoothness;
- Precisely control the plate thickness to achieve high dimensional accuracy and uniformity.

3. Comprehensive application of hot rolling and cold rolling

- Generally, a combined process of hot rolling followed by cold rolling is adopted to ensure the plasticity and density of the material while achieving high strength and excellent surface quality.
- tungsten alloy plates can be optimized by rationally designing the rolling route and heat treatment process .

4. The influence of process on the performance of tungsten alloy plate

Process	Key Parameters	Impact
Hot Rolling	Temperature, deformation, speed	Grain refinement, internal stress release, and toughness improvement
Cold Rolling	Deformation, number of passes	Improved strength and hardness, smooth surface and high dimensional accuracy

3.4 Surface treatment technology (polishing, pickling, electroplating, PVD)

After the tungsten alloy plate is prepared, it usually needs to go through a series of surface treatment processes to improve its surface quality, corrosion resistance and functional properties. Surface treatment not only improves the appearance and dimensional accuracy of the material, but also enhances its wear resistance, oxidation resistance and electrical conductivity. This section focuses on the four commonly used surface treatment technologies for tungsten alloy plates: polishing, pickling, electroplating and physical vapor deposition (PVD).

1. Polishing (mechanical polishing)

1. Purpose of polishing

- Remove the oxide layer, burrs and processing marks on the surface of tungsten alloy plate;
- Improve surface flatness and smoothness, and reduce surface roughness;
- Provides a good substrate for subsequent processes such as electroplating and coating.

2. Polishing process

- Use sandpaper, abrasive paste and polishing wheel to gradually grind finely;
- Coarse grinding, medium grinding and fine grinding are processed in stages, and the particle size is gradually refined;
- Automated polishing equipment is used in modern processes to improve consistency and efficiency.

3. Notes

- Control the grinding temperature to avoid surface overheating and tissue deformation;
- Choose appropriate abrasives to prevent surface scratches or pits.

2. Pickling (chemical treatment)

1. Pickling

- Remove surface oxides, rust and impurities;
- Improve surface activity and promote adhesion of coating or electroplating layer;
- Adjust surface roughness and improve wettability.

2. Pickling agent and process parameters

- Commonly used pickling solutions: dilute hydrochloric acid, sulfuric acid or mixed acid;
- The pickling temperature, concentration and time must be strictly controlled to prevent excessive corrosion;
- After pickling, neutralization and cleaning must be carried out in time to prevent residual acid.

3. Safety and environmental protection

- Exhaust and waste liquid treatment facilities must be equipped to prevent acid gas and wastewater pollution;
- Operators must wear protective equipment to ensure safety.

3. Electroplating Technology

1. Purpose of electroplating

- Plating a metal layer (such as nickel, chromium, copper, etc.) on the surface of the tungsten alloy plate to improve corrosion resistance and wear resistance;

- Improve electrical conductivity and welding performance;
- Improve aesthetics and surface hardness.

2. Commonly used electroplated metal layers

- **Nickel plating** : commonly used, to enhance corrosion resistance and hardness, and improve lubrication performance;
- **Chromium plating** : provides high hardness and wear resistance, bright surface;
- **Copper electroplating** : Improves conductivity and is suitable for the electronics industry.

3. Electroplating process

- Surface pretreatment (degreasing, pickling);
- Activation treatment to promote metal ion adsorption;
- Immersed in the electroplating tank, current is applied to deposit the coating;
- Post-processing (passivation, cleaning, drying).

4. Electroplating quality control

- Control coating thickness and uniformity;
- Avoid blistering, pinholes and shedding of the coating;
- Check coating adhesion and hardness regularly.

4. Physical Vapor Deposition (PVD)

1. Introduction to PVD Technology

- thin film technology that evaporates or sputters the target material in a vacuum environment and deposits it on the surface of the tungsten alloy plate;
- Common coating materials include carbides (such as TiC , WC), nitrides (TiN , CrN) and metal layers.

2. Advantages of PVD

- The coating has strong bonding strength, is dense and uniform, and has significantly improved wear resistance and corrosion resistance;
- Environmentally friendly and pollution-free, in line with modern green manufacturing requirements;
- The coating thickness and composition can be controlled to achieve functional surface design.

3. PVD application process

- Material cleaning and pretreatment;
- Placed in a vacuum chamber , the target is heated or sputtered;
- Coating deposition, post-cooling and post-processing.

4. Typical applications

- tungsten alloy plates in aerospace and military fields ;
- Heat dissipation of electronic equipment and surface enhancement of contact parts;
- Wear-resistant and biocompatible coatings for medical devices.

V. Summary

Surface treatment is a key step in improving the overall performance of tungsten alloy plates. Polishing ensures excellent surface quality, pickling effectively removes impurities and oxide layers, electroplating provides a corrosion-resistant and functional metal protective layer, and PVD, an advanced coating technology, imparts excellent wear and corrosion resistance. By rationally combining and optimizing these surface treatment processes, the performance and service life of tungsten alloy plates can be significantly improved.

3.5 Application of Laser Cladding and Additive Manufacturing in Plate Materials

With the continuous development of advanced manufacturing technology, laser cladding and additive manufacturing (3D printing) technologies are gradually applied to the preparation and repair of tungsten alloy plates. These technologies achieve local melting and deposition of materials through high-precision, high-energy-density laser beams, have excellent forming capabilities and material utilization, and significantly expand the application scope and performance improvement space of tungsten alloy plates.

1. Introduction to Laser Cladding Technology

1. **Process Principle**
   Laser cladding uses a high-power laser beam to partially melt metal powder or wire and deposit it on the surface of the substrate to form a dense alloy layer. This layer has good bonding strength and performance gradient, and can improve the wear resistance, corrosion resistance and high temperature performance of the substrate.
2. **Technological advantages**

- Precisely control the thickness and composition of the cladding layer to achieve functionally graded material design;
- Small heat-affected zone, small substrate deformation and low residual stress;
- It can repair the surface defects of tungsten alloy plates and extend their service life.

3. **Application Scenario**

- tungsten alloy plate is strengthened to improve wear resistance and corrosion resistance;
- Local repair of manufacturing defects and wear or corrosion damage caused during use;
- cladding high hardness coating on the surface of tungsten alloy plate .

2. Additive Manufacturing Technology and Its Advantages

1. **Additive Manufacturing Overview**
   Additive Manufacturing (AM) achieves near-net-shape formation of tungsten alloy plates by stacking metal powder layer by layer, combined with energy sources such as lasers and electron beams . Commonly used technologies include selective laser melting (SLM) and electron beam melting (EBM).
2. **Technological advantages**

- High degree of design freedom, capable of manufacturing complex structures and functionally graded parts;
- High material utilization, reducing waste and costs;
- Rapid prototyping shortens product development cycle.

3. **Process Challenges**

- Tungsten alloy powder has a high melting point and high thermal conductivity, which makes melting control difficult;
- Cracks and holes are prone to occur, and process parameters and powder quality need to be optimized;
- The density and mechanical properties of formed parts need to be further improved.

3. Process flow of laser cladding and additive manufacturing

Process	Main content
Powder preparation	Select tungsten alloy powder with appropriate particle size and morphology to ensure fluidity and purity
Equipment preparation	Laser power, scanning speed, gas protection system and other parameter debugging
Preprocessing	The substrate surface is clean to ensure a firm bond between the cladding layer and the substrate.
Cladding /Printing	The laser beam scans the melted powder to achieve layer-by-layer stacking
Post-processing	Heat treatment, machining and surface polishing to improve structure and performance

4. Application Case Analysis

1. **In the aerospace field,**
   laser cladding technology is used to strengthen the surface of tungsten alloy plates to improve their high temperature resistance and wear resistance to meet the high performance requirements of engine components.
2. **The nuclear industry**
   uses additive manufacturing to prepare complex tungsten alloy protective plates to achieve lightweight and efficient shielding, thereby improving the safety and service life of nuclear reactors.
3. **The mold is manufactured by laser**
   cladding a high hardness alloy layer on the surface of the tungsten alloy plate to improve the wear resistance and corrosion resistance of the mold and extend the service life of the mold.

V. Development Trends and Challenges

- **Technology optimization** : Continuously improve laser parameters and powder preparation processes to solve defects such as cracks and holes;
- **Material innovation** : Develop tungsten alloy powder suitable for laser cladding and additive manufacturing to improve forming quality;
- **Multi-material composite manufacturing** : realizing efficient manufacturing of functionally gradient materials and composite structures;
- **Intelligent control** : Introducing artificial intelligence and real-time monitoring to improve process stability and finished product consistency.

VI. Summary

Laser cladding and additive manufacturing technology provide a new solution for the preparation and performance improvement of tungsten alloy plates. Through precise material deposition and structural design, it can not only effectively repair and strengthen the surface of tungsten alloy plates, but also promote the development of tungsten alloy plate manufacturing towards high performance, complex shapes and customization. In the future, with the maturity of technology and material innovation, laser- based manufacturing will play an increasingly important role in the field of tungsten alloys.

3.6 Nanoparticle Reinforcement and Functionally Gradient Plate Fabrication Technology

With the continuous progress of materials science, nanotechnology and functionally graded materials (FGM) have become the key directions to improve the performance of tungsten alloy plates. By introducing nanoparticle reinforcement phases and achieving gradient distribution of composition and structure, the mechanical properties, wear resistance and thermal stability of tungsten alloy plates can be significantly improved to meet more complex and demanding application requirements.

1. Nanoparticle Enhancement Technology

1. Types and functions of nanoparticles

- **Commonly used nanoparticles** : carbides (such as WC, TiC), oxides (such as Al_2O_3 , ZrO_2), carbon nanotubes (CNTs) and graphene, etc.;
- **Enhancement mechanism** : Nanoparticles improve the strength and hardness of the matrix by refining grains, hindering dislocation movement, and forming a uniformly dispersed second phase;
- **Interface strengthening** : Nanoparticles form a strong interface bond with the tungsten matrix, enhancing the overall toughness of the material.

2. Nanoparticle dispersion technology

- **Mechanical alloying** : high-energy ball milling makes the nanoparticles evenly dispersed in tungsten powder;
- **Surface modification** : improving the compatibility of nanoparticles with the matrix and preventing agglomeration by chemical or physical methods;
- **Dispersant addition** : Introducing surfactants to assist in uniform distribution.

3. Process Difficulties and Solutions

- Nanoparticles are prone to agglomeration, and the dispersion process needs to be optimized;
- The interface bonding strength and thermal expansion matching need to be reasonably designed to avoid thermal stress concentration;
- Control the content of nanoparticles to prevent excessive amounts from causing brittleness.

2. Functionally Gradient Plate Preparation Technology

1. Introduction to Functionally Graded Materials

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- Functionally graded tungsten alloy plates optimize the spatial distribution of performance by achieving gradients of different compositions or structures in the thickness direction or on the surface.
- The main goal is to simultaneously meet multiple requirements such as strength, toughness, wear resistance and corrosion resistance.

2. Preparation Method

- **Layer-by-layer sintering** : adjust the powder ratio layer by layer and sinter to form;
- **Gradient heat treatment** : Use heat treatment conditions in different areas to form a performance gradient;
- **Laser cladding or additive manufacturing** : gradients are achieved by localized deposition of materials with different compositions;
- **Rolling and extrusion composite** : plates with different compositions or structures are composited and then machined to form a gradient structure.

3. Typical gradient design

- High hardness wear-resistant layer on the surface and high toughness bearing layer inside;
- The thermal expansion coefficient gradually transitions to reduce thermal stress;
- The functional areas have conductive, corrosion-resistant or radiation-resistant properties respectively.

3. Performance Improvement of Nano-enhancement and Gradient Preparation

Performance indicators	Nanoparticle enhancement effect	Advantages of functionally graded design
tensile strength	Significantly improved	Regional optimization to improve overall strength and toughness
hardness	Significantly enhanced	Surface strengthening, excellent wear resistance
toughness	Moderate improvement	Gradient structure relieves stress concentration
Thermal stability	Improved high temperature performance	Thermal expansion matching to reduce thermal cracking
Corrosion resistance	Nanoparticles and interface strengthening	Surface functional layer improves corrosion resistance

IV. Application Prospects and Development Trends

- Nanoparticle reinforced tungsten alloy plates are suitable for aerospace, nuclear industry and high-end electronics fields, and are particularly critical for components with high strength and wear resistance requirements;
- Functionally graded plates provide new ideas for the application of tungsten alloys in extreme environments, such as thermal protection, radiation shielding and mechanical property optimization;

- Combined with advanced additive manufacturing technology, precise control and efficient production of complex gradient structures can be achieved.

V. Summary

Nanoparticle enhancement and functional gradient preparation technology provide strong support for the performance upgrade of tungsten alloy plates. Through the combination of material design and advanced technology, tungsten alloy plates can achieve synergistic improvements in strength, toughness, wear resistance, corrosion resistance and other properties, and promote tungsten alloy plates to move towards high-end and complex application fields.

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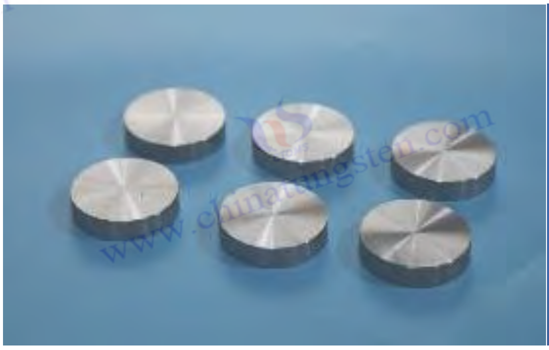
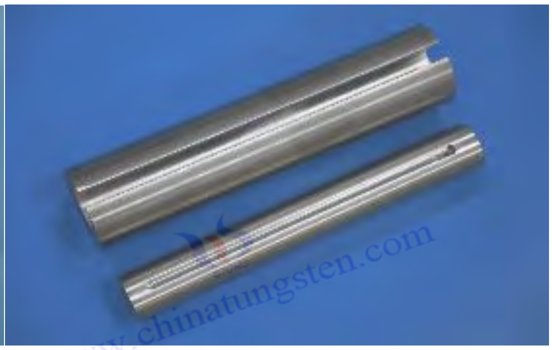

Chapter 4 Quality Inspection and Performance Evaluation of Tungsten Alloy Plate

4.1 Geometric dimensions and surface flatness inspection

The geometric dimensions and surface flatness of tungsten alloy plates are important indicators to ensure their assembly accuracy and performance. Accurate dimensions and excellent surface conditions directly affect the mechanical strength, contact performance and quality of subsequent processing of the plates. This section focuses on the commonly used testing methods, instruments and equipment, and testing processes to ensure that tungsten alloy plates meet design requirements and application standards.

1. Geometric dimension detection

1. Main test parameters

- Length, width, thickness: Use high-precision measuring tools to measure the basic dimensions of the plate;
- Straightness: measures the degree of bending deformation of the plate along the length direction;
- Flatness: Evaluate the overall flatness of the board surface.

2. Commonly used testing equipment

- **Vernier calipers and micrometers** : suitable for rough measurement of length and thickness, with an accuracy of generally 0.01 mm;
- **Coordinate measuring machine (CMM)** : high-precision, multi-parameter measurement, suitable for complex shapes and high-precision requirements;

- **Laser scanner** : non-contact measurement, rapid acquisition of surface point cloud data, and flatness analysis;
- **Plate and feeler gauge** : Traditional straightness and flatness testing tools, simple and economical.

3. Testing process

- Place the plate on the testing table to ensure it is firmly fixed;
- Select measurement points and directions according to design requirements;
- Multi-point measurement to obtain dimension data and flatness curve;
- Compliance with the tolerance range is determined through statistical analysis.

2. Surface flatness detection

1. Flatness definition

- Surface flatness refers to the degree of deviation of the tungsten alloy plate surface from the ideal plane, which affects the sealing, contact performance and appearance.

2. Detection Method

- **Ruler and feeler gauge method** : Place a ruler on the surface and use the feeler gauge to measure the gap to quickly determine the flatness;
- **Optical interferometer** : uses interference fringes to accurately measure micron-level surface fluctuations;
- **Laser profiler** : scans surface profile and constructs 3D surface model;
- **Stylus profilometer** : A mechanical stylus scans the surface, obtaining height variation data.

3. Evaluation Criteria

- Set flatness tolerance according to national and industry standards (such as GB, ISO);
- Surface grades are differentiated according to the application, with high-precision applications requiring more stringent requirements.

3. Influencing factors and control

- Pressing uniformity and sintering deformation during the preparation process;
- The stability of subsequent machining and the accuracy of the equipment;
- Ambient temperature and humidity affect detection accuracy, so the test should be carried out under constant temperature and humidity conditions.

IV. Summary

Geometric size and surface flatness testing are important aspects of tungsten alloy plate quality control. Combining advanced measuring equipment with scientific testing methods can ensure that the plate meets design and application requirements, providing a solid foundation for subsequent performance evaluation and application.

4.2 Microstructure and density characterization (SEM, XRD)

tungsten alloy plates are key indicators that affect their mechanical properties, wear resistance and stability. By analyzing its microstructure, we can deeply understand the grain morphology, phase composition, pore distribution and interface bonding state of the material, thereby optimizing process parameters and improving material quality. This section focuses on the commonly used microstructure analysis techniques and density characterization methods.

1. Scanning electron microscopy (SEM) analysis

1. Technical Principle

- SEM uses an electron beam to scan the sample surface and obtains high-resolution surface morphology and microstructure images by detecting secondary electrons and backscattered electrons;
- Different phases, particle distribution, pores, cracks and other micro defects can be observed and analyzed.

2. Application Content

- Grain size and morphology analysis: Determine the grain size and uniformity through SEM images;
- Particle distribution and interface bonding: observe the bonding state between the tungsten matrix and the reinforcement phase (such as Ni, Fe, Cu, etc.);
- Porosity and defect detection: Identify pores, cracks, and inclusions in materials;
- Surface corrosion morphology: analysis of corrosion mechanism and distribution of corrosion products.

3. Sample Preparation

- Tungsten alloy plate samples need to be pre-treated by polishing, corrosion etching, etc. to expose the microstructure;
- The sample size and shape must meet the requirements of the SEM equipment.

2. X-ray diffraction (XRD) analysis

1. Technical Principle

- XRD identifies the crystal structure and phase composition by detecting the diffraction pattern of the material sample to the incident X-ray;
- The position, intensity and width of the diffraction peak reflect the crystal phase type, crystallinity and grain size of the material.

2. Application Content

- Phase composition identification: confirm the metal phase or compound phase formed by tungsten phase and other alloying elements in tungsten alloy;
- Crystal structure analysis: determine the lattice parameters and crystal types of each phase;
- Grain size and stress measurement: Calculate grain size and internal stress state through peak width analysis;
- Quality control: monitoring the impact of material processing on crystal structure.

3. Sample Preparation

- The sample surface should be flat to avoid surface roughness affecting the diffraction results;
- Either bulk or powder samples can be used for analysis.

3. Density test method

1. Theoretical density and actual density

- Theoretical density is calculated based on the chemical composition and crystal structure of tungsten and alloying elements;
- The actual density is obtained through experimental measurement and is an important indicator for evaluating the density of materials.

2. Common measurement methods

- **Archimedean method** : Calculate density by measuring the mass difference of the sample in the liquid. It is suitable for samples with regular shapes.
- **Geometric method** : measure the sample size and mass to calculate the density, which is suitable for samples with regular shapes and no pores;
- **Gas permeability method** : evaluates porosity and indirectly reflects density.

3. Relationship between density and performance

- The higher the density, the better the mechanical properties and corrosion resistance of the material;
- High porosity will reduce material strength and service life.

4. Comprehensive Analysis and Application

- Combining SEM and XRD analysis, the microstructural characteristics and phase composition of tungsten alloy plates can be systematically understood;
- Density testing helps evaluate the material's densification degree and process optimization effect;
- Provide scientific basis for process adjustment and material improvement, and improve the performance of tungsten alloy plates.

V. Summary

Microstructure and density characterization are the core contents of tungsten alloy plate performance research and quality control. Through the application of SEM and XRD technology, we can deeply understand the microstructure and crystal state of the material; density test provides a quantitative index for the degree of material densification. Systematic characterization methods provide a solid guarantee for the high-performance manufacturing and application of tungsten alloy plates.

4.3 Mechanical properties test standards (ASTM, GB, ISO)

As an important high-performance material, accurate testing and evaluation of the mechanical properties of tungsten alloy plates is crucial to ensure product quality and meet application requirements. A series of mechanical property testing standards have been formulated both internationally and domestically to standardize test methods and ensure the accuracy and comparability of data. This section focuses on the main mechanical property testing standards commonly used for tungsten alloy plates, including the relevant specifications of the American

Society for Testing and Materials (ASTM), the Chinese National Standard (GB) and the International Organization for Standardization (ISO).

1. Main mechanical properties

- **Tensile** Strength: The maximum stress a material can withstand in a tensile test;
- **Yield Strength** : The stress at which a material undergoes permanent deformation;
- **Elongation** : The percentage of elongation before the material breaks, reflecting the plasticity;
- **Hardness** : The ability of a material to resist local plastic deformation;
- **Impact Toughness** : The ability of a material to resist impact damage.

2. ASTM Standard System

1. ASTM E8 / E8M — Tensile Test Method

- Suitable for measuring the tensile strength, yield strength and elongation of metal materials;
- It specifies the specimen size, test speed, data collection and calculation methods;
- Tungsten alloy plates are usually tested using flat tensile specimens.

2. ASTM E23 - Impact Test Method (Charpy Impact)

- Used to measure the impact toughness of materials and evaluate fracture properties;
- Use standard notched specimens, specify test temperature and energy absorption determination;
- Suitable for evaluating the toughness performance of tungsten alloy plates under dynamic loads.

3. ASTM E92 — Vickers Hardness Test

- Suitable for hardness measurement of cemented carbide and high hardness metal materials;
- Specify the load range and indentation measurement method to ensure accurate data.

3. Chinese National Standard (GB)

1. GB/T 228 — Room temperature tensile test method for metallic materials

- Similar to ASTM E8, it is suitable for tensile properties testing of various metal materials;
- Detailed specifications for specimen preparation, test equipment and data processing.

2. GB/T 229 — Impact test method for metallic materials (Charpy test)

- Specifies standard methods and conditions for impact testing;
- Suitable for evaluating the fracture resistance of tungsten alloy plates.

3. GB/T 4340 — Hardness test of metal materials

- Contains methods for determining Brinell, Vickers and Rockwell hardness;
- The appropriate hardness test method can be selected according to the specific application of tungsten alloy plate .

4. ISO International Standards

1. ISO 6892 — Tensile testing of metallic materials

- Common tensile properties test specifications in international standards;

- Emphasis is placed on the standardization of the testing process and the reliability of the test data.

2. ISO 148 — Charpy impact test

- Standardize the preparation of impact specimens and test conditions;
- Promote consistency and comparability of data across countries.

3. ISO 6507 — Vickers hardness test

- Specify in detail the technical requirements for hardness testing;
- It is widely used in the hardness evaluation of hard materials such as tungsten alloy.

5. Test equipment and environmental control

- The test equipment should meet the technical requirements of relevant standards to ensure loading accuracy and data collection accuracy;
- Environmental conditions (temperature, humidity) have a significant impact on test results and should be kept stable;
- tungsten alloy plates require the use of special fixtures and measuring devices.

6. Notes on Standard Application

- The specimen preparation should be carried out strictly in accordance with the standard size and shape to avoid stress concentration and defects affecting the results;
- Tungsten alloy plates for different purposes can select appropriate test standards and parameters according to actual performance requirements;
- Combined with a variety of mechanical property tests, material properties are comprehensively evaluated to guide process optimization and application design.

VII. Summary

The perfect mechanical properties testing standard system provides a scientific basis for the research and development, production and quality control of tungsten alloy plates. ASTM, GB and ISO standards have their own characteristics and complement each other, promoting the internationalization and standardization of tungsten alloy plate testing methods. Enterprises and research institutions should reasonably select test standards according to actual needs to ensure the accuracy and reliability of test results.

4.4 Element composition and impurity content analysis (ICP, XRF, ONH)

tungsten alloy plates depends largely on the accurate control of their chemical composition and the strict limit of impurity content. Accurate detection of elemental composition not only helps to ensure the design performance of the material, but also plays a key role in monitoring and quality control of the production process. This section focuses on the commonly used elemental composition and impurity content analysis techniques, including inductively coupled plasma emission spectroscopy (ICP), X-ray fluorescence spectroscopy (XRF) and oxygen, nitrogen and hydrogen analyzer (ONH), and discusses their application in tungsten alloy plate testing.

1. Inductively Coupled Plasma Optical Emission Spectroscopy (ICP)

1. Technical Principle

- ICP uses high-temperature plasma to excite atoms and ions in the sample to produce characteristic spectra;
- According to the intensity and wavelength of the emission spectrum, the content of multiple elements in the sample can be quantitatively analyzed.

2. Scope of application

- Accurately determine the content of main elements (tungsten, nickel, iron, copper, etc.) and trace alloying elements in tungsten alloy plates;
- Detect trace impurity elements such as lead, sulfur, phosphorus, etc. to ensure the purity of materials;
- High sensitivity and multi-element simultaneous analysis capability, suitable for complex alloy systems.

3. Sample Preparation

- Usually, solid samples need to be dissolved into a solution, usually using acid dissolution (such as aqua regia);
- Sample pretreatment must be strictly regulated to avoid contamination and element loss.

2. X-ray fluorescence spectroscopy (XRF)

1. Technical Principle

- XRF is based on the emission of characteristic fluorescent X-rays by samples after being excited by X-rays, and element identification and quantification are achieved by analyzing their energy and intensity;
- No need to dissolve the sample, suitable for direct detection of solid, powder and flake samples.

2. Scope of application

- Rapid determination of the main element content in tungsten alloy plates;
- Used for rapid elemental composition screening and quality control at production sites;
- The detection depth is limited and mainly characterizes the surface or near-surface components of the sample.

3. Advantages and Disadvantages

- The detection speed is fast and the operation is simple, but the sensitivity is lower than that of ICP;
- The detection capability for light elements (such as oxygen, nitrogen, and hydrogen) is limited.

3. Oxygen, Nitrogen and Hydrogen Analyzer (ONH)

1. Technical Principle

- The ONH analyzer measures the oxygen, nitrogen, and hydrogen gas content released by burning or pyrolyzing the sample;
- Quantitative analysis is performed using a thermal conductivity detector or infrared absorption technique.

2. Scope of application

- Accurately measure the content of non-metallic impurities such as oxygen, nitrogen, and hydrogen in tungsten alloy plates;
- Non-metallic impurities have a significant impact on the mechanical properties and corrosion resistance of tungsten alloy plates;
- Important quality control indicator.

3. Sample requirements

- The shape and weight of the sample must be strictly controlled to ensure test repeatability;
- The sample surface should be clean, free of grease and contamination.

4. Comprehensive application and quality control

- The three technologies complement each other to form a complete detection system for the chemical composition of tungsten alloy plates;
- ICP is suitable for accurate quantification of complex element systems, XRF is suitable for rapid on-site detection, and ONH is for non-metallic impurities;
- Regular testing helps monitor the production process, optimize process parameters, and ensure stable product quality.

V. Summary

Accurate analysis of element composition and impurity content is the basis for ensuring the high performance of tungsten alloy plates. ICP, XRF and ONH technologies each have their own advantages. Their combined application can meet the different levels of testing needs of tungsten alloy plates and provide a scientific basis for production control and R&D innovation.

4.5 Surface defect detection (ultrasonic, CT, eddy current, magnetic particle)

As a key high-performance material, the surface quality of tungsten alloy plate directly affects the service life and performance stability of the product. Timely and accurate detection of surface and near-surface defects is crucial to ensure the overall quality and safety of tungsten alloy plate. Commonly used surface and near-surface defect detection technologies include ultrasonic testing (UT), computed tomography (CT), eddy current testing (ET) and magnetic particle testing (MT). This section introduces the principles, application scope and advantages of these technologies in detail.

1. Ultrasonic Testing (UT)

1. Technical Principle

- When high-frequency ultrasonic waves propagate inside the material and encounter defects, they will generate reflected waves, and the reflected signals will be detected to determine the location and size of the defects.
- The probe transmits and receives ultrasonic waves to achieve non-destructive testing of internal and surface defects.

2. Scope of application

- Suitable for detecting defects such as internal cracks, inclusions, pores and interlayer delamination of tungsten alloy plates;
- It has good detection sensitivity for internal defects of thick plate materials;
- Can be used for online and offline detection.

3. Advantages

- Non-destructive, non-polluting, large detection depth, high resolution;
- The defect size and shape can be quantitatively analyzed.

2. Computed Tomography (CT)

1. Technical Principle

- tungsten alloy plate at multiple angles through X-rays and reconstruct a three-dimensional image using a computer;
- Accurately display the three-dimensional spatial distribution and morphology of internal defects.

2. Scope of application

- High-resolution inspection of complex internal structures to identify tiny cracks, pores and inclusions;
- Suitable for R&D and high-end quality control;
- There are certain restrictions on thicker tungsten alloy plates, and the parameters need to be adjusted according to the equipment power.

3. Advantages

- Provide intuitive 3D images to facilitate defect location and morphology analysis;
- Capable of detailed structural integrity evaluation.

3. Eddy Current Testing (ET)

1. Technical Principle

- The alternating magnetic field is used to induce eddy currents on the surface of the conductive material. The eddy current distribution at the defect changes, and the defect characteristics are reflected by detecting the eddy current signal.
- Mainly used for surface and near-surface defect detection.

2. Scope of application

- Suitable for detecting surface cracks, corrosion and local damage of tungsten alloy plates;
- Can quickly scan large surfaces;
- Non-contact detection, suitable for workpieces with complex shapes.

3. Advantages

- Fast response speed and high sensitivity;
- The testing process is non-destructive and requires no special preparation.

4. Magnetic Particle Testing (MT)

1. Technical Principle

- The magnetic material is magnetized by applying an external magnetic field, and leakage magnetic field is generated at the surface and near-surface defects, and the defect position is revealed by magnetic powder adsorption;
- Suitable for detecting surface and near-surface cracks.

2. Scope of application

- Tungsten alloy contains iron alloy elements and has certain magnetism, which is suitable for magnetic particle testing;
- Suitable for detecting surface cracks, pores and fatigue cracks;
- Mostly used for rapid detection of production lines.

3. Advantages

- Easy to operate and low cost;
- Suitable for rapid on-site testing.

V. Comprehensive Detection Strategy

- Select appropriate inspection methods according to the inspection object and defect type;
- It is recommended to use a combination of multiple detection technologies for complex defects and key components to improve detection accuracy;
- Establish standardized testing processes to ensure the reliability and repeatability of test results.

VI. Summary

Ultrasonic, CT, eddy current and magnetic particle testing technologies constitute a diverse toolbox for surface and near-surface defect detection of tungsten alloy plates. The rational application of these non-destructive testing technologies can fully reveal the distribution of defects inside and on the surface of the material, ensure the quality and safety of tungsten alloy plates, and provide a solid guarantee for the research and development and industrial application of tungsten alloy plates.

4.6 Surface roughness and coating adhesion evaluation

tungsten alloy plate not only affects its appearance, but also directly affects its mechanical properties, corrosion resistance and the effect of subsequent processing technology. Surface roughness is a key indicator for evaluating the flatness and fineness of the material surface, while coating adhesion determines the stability and durability of the protective layer or functional layer during use. This section focuses on the measurement method of tungsten alloy plate surface roughness and the evaluation technology of coating adhesion.

1. Surface roughness measurement

1. Importance

- Surface roughness directly affects the matching accuracy and friction performance of tungsten alloy plates and other components;
- Too high roughness may cause stress concentration and reduce fatigue life;
- Good surface roughness is conducive to uniform adhesion of the coating.

2. Common measurement methods

- **Contact profilometer** : Scans the surface profile through a stylus to obtain roughness parameters (such as Ra, Rz, etc.);
- **Optical profilometer** : non-contact measurement using laser or white light interference, suitable for micron and nanometer roughness analysis;
- **Atomic force microscope (AFM)** : Suitable for ultra-high precision surface morphology measurement, mainly used in scientific research and high-end applications.

3. Key parameters

- **Ra (arithmetic mean roughness)** : reflects the average value of surface ups and downs, and is the most commonly used indicator;
- **Rz (ten-point height roughness)** : reflects the difference between peaks and valleys and evaluates the maximum degree of surface undulation;
- **Rq (root mean square roughness)** : Statistical square average, suitable for evaluating complex surfaces.

2. Coating Adhesion Evaluation

1. The importance of adhesion

- The coating protects the tungsten alloy plate from environmental influences such as corrosion, wear and high temperature;
- Good adhesion ensures the long-term stability of the coating during use;
- Poor adhesion can cause coating flaking, reducing material life and performance.

2. Evaluation Methodology

- **Pull-off Test** : Use special equipment to measure the maximum pulling force required for the coating to be peeled off from the substrate and quantitatively evaluate the adhesion;
- **Scratch Test** : Scratch with gradually increasing force to observe the coating shedding and judge the adhesion strength;
- **Impact test** : Evaluate the coating's anti-peeling performance through impact load;
- **Tape stripping method** : quickly peel off the tape after sticking, observe the coating peeling situation, and conduct rapid qualitative testing.

3. Experimental conditions

- The test environment temperature and humidity should be kept stable to avoid affecting the results;
- The surface of the sample needs to be pre-treated and cleaned to ensure the consistency of coating adhesion;
- Select appropriate test standards and methods to ensure comparability of results.

3. Relationship between surface roughness and adhesion

- Moderately rough surface can enhance the mechanical bite of the coating and improve adhesion;
- A surface that is too rough or too smooth will affect coating performance;
- The surface roughness needs to be optimized according to the coating type and the usage environment.

4. Quality Control and Process Optimization

- Monitor critical parameters during the manufacturing process by regularly measuring roughness and adhesion;
- Optimize grinding, polishing and surface pretreatment processes to improve surface quality;
- Based on the characteristics of coating materials, scientific and reasonable surface treatment standards are formulated.

V. Summary

Surface roughness and coating adhesion are important indicators that affect the function and life of tungsten alloy plates. The use of advanced measurement and evaluation methods can effectively control product quality, improve the comprehensive performance of tungsten alloy plates, and provide strong guarantees for their wide application.

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Quality cost: optimized design, optimal mold and processing mode, excellent cost performance.
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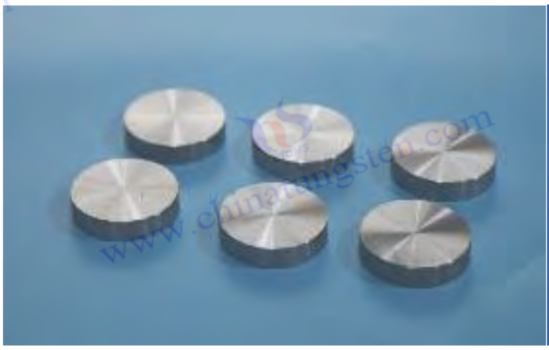
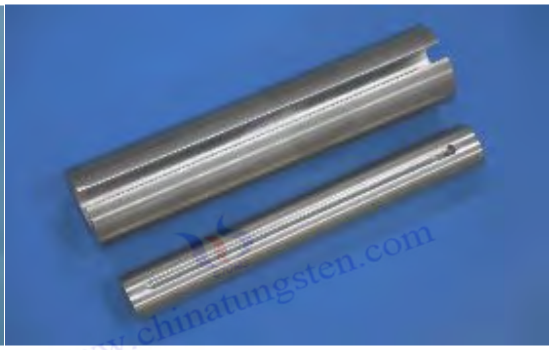

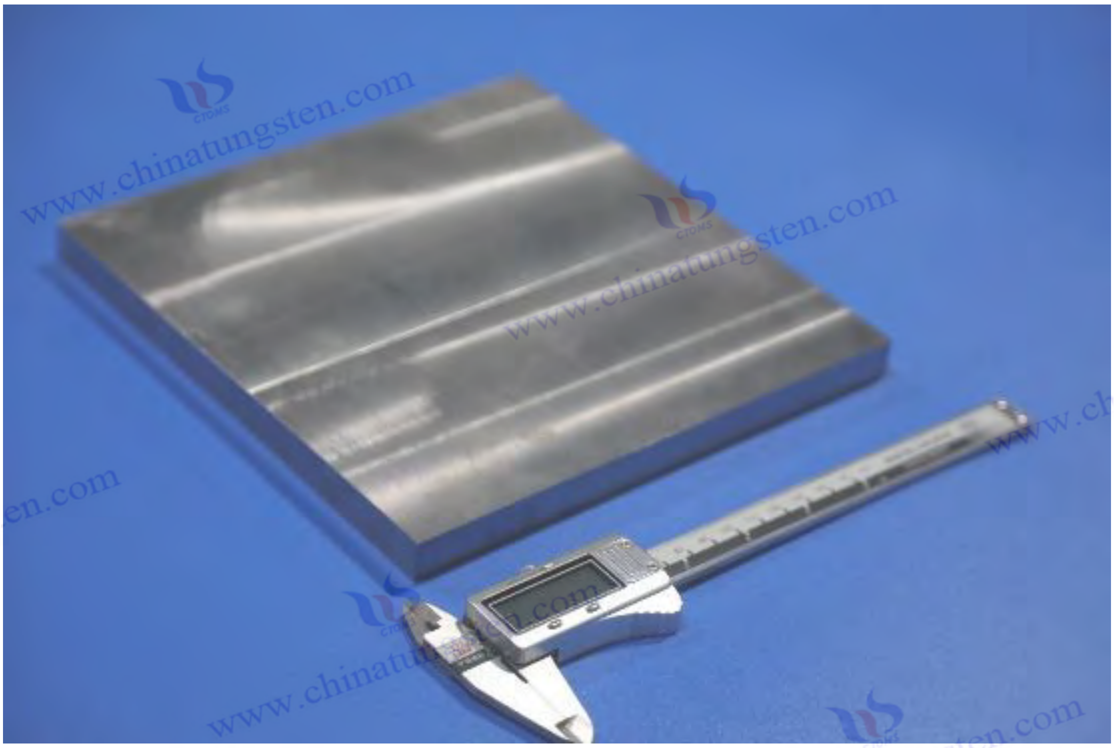

Chapter 5 Typical Application Fields of Tungsten Alloy Plate

5.1 Nuclear industry shielding plates and thermal control devices

Tungsten alloy plates are widely used in the fields of shielding and thermal control in the nuclear industry due to their high density, high melting point and excellent radiation resistance, playing a key role. With the development of nuclear technology, higher requirements are placed on the radiation resistance, mechanical strength and thermal stability of materials. Tungsten alloy plates have become an ideal choice due to their unique properties.

1. The role and demand of nuclear industry shielding plates

1. Radiation Shielding

- Nuclear reactors, nuclear waste treatment facilities, nuclear medicine equipment and other places must effectively shield radiation to ensure the safety of operators;
- Tungsten alloy plate has excellent absorption capacity for gamma rays and X-rays due to its high atomic number (Z=74) and high density (about 17.0-18.5 g/cm³);
- It can replace traditional lead shielding and avoid lead toxicity and environmental pollution.

2. Neutron absorption

- In nuclear reactors, some tungsten alloys are enhanced to absorb neutrons by adding specific elements (such as nickel and iron);
- The shielding plate must have good structural stability and resistance to radiation damage to ensure long-term service.

3. Mechanical and thermal performance requirements

- Need to withstand high temperature, high pressure and radiation environment, requiring tungsten alloy plates to have high strength and excellent thermal stability;
- The coefficient of thermal expansion needs to match that of other structural materials to prevent cracking and deformation caused by thermal stress.

2. Application characteristics of thermal control devices

1. Thermal Management

- Nuclear reactors and nuclear facilities generate a large amount of heat energy, which requires the use of high thermal conductivity materials for effective heat dissipation;
- tungsten alloy plate is better than other heavy metal materials, which helps to maintain the temperature of the system stable.

2. High temperature resistance

- Tungsten alloy plates can maintain structural integrity and stable performance in high temperature environments, and are suitable for the manufacture of thermal control components;
- Special alloy design improves mechanical strength and oxidation resistance at high temperatures.

3. Structural support

- In the thermal control device, tungsten alloy plates serve as load-bearing and supporting components to ensure the safe operation of the system;
- It has good processing performance and can meet the customization needs of complex shapes.

3. Advantages of Tungsten Alloy Plate in Nuclear Industry

- **High density advantage** : Provides effective radiation protection and reduces shielding thickness and weight;
- **Strong radiation resistance** : resists radiation-induced material degradation and extends service life;
- **Excellent thermal stability** : adapt to temperature changes under complex working conditions in the nuclear industry;
- **Environmentally friendly and non-toxic** : It replaces toxic lead materials and meets modern environmental protection requirements.

4. Typical application cases

- reflector shielding panels in nuclear power plants;
- Nuclear waste storage and transport container liners;
- Radiation shielding panels in medical radiotherapy equipment;
- Thermal control support structure in nuclear fuel cycle system.

V. Development Trends and Challenges

- Tungsten alloy plates in nuclear industry will tend to develop into high-performance, multifunctional composite materials;

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- Improving high temperature resistance, oxidation resistance and radiation damage resistance is the research and development focus;
- Achieving mass production of large-sized, high-density tungsten alloy plates and reducing costs are industry challenges.

VI. Summary

tungsten alloy plates play an irreplaceable role in shielding and thermal control devices. Through continuous technological innovation and process optimization, the performance of tungsten alloy plates will continue to improve to meet the needs of nuclear industry safety, environmental protection and efficient operation.

5.2 Aerospace protective structures and counterweight plates

Tungsten alloy plates play an important role in the protective structures and counterweight systems in the aerospace field due to their high density, high strength, and excellent radiation and heat resistance. With the continuous advancement of aerospace technology, the performance requirements of materials are becoming increasingly stringent. Tungsten alloy plates have become a key material for improving the safety and performance of aircraft due to their unique advantages.

1. Application in protective structures

1. Protective radiation shielding

- Aerospace vehicles are exposed to cosmic rays and solar radiation in high altitude or space environments. Tungsten alloy plates can effectively absorb high-energy particles and rays to protect the safety of spacecraft electronic equipment and personnel.
- Compared with traditional materials, tungsten alloy has higher radiation shielding efficiency, reduces shielding thickness and weight, and improves the load-bearing capacity of aircraft.

2. Bulletproof and impact-resistant structure

- In the key parts of military aircraft and spacecraft, tungsten alloy plates are used to make bulletproof armor and impact-resistant layers, effectively resisting the impact of high-speed projectiles and micrometeorites;
- tungsten alloy make it an ideal protective material to ensure the safety of equipment and personnel.

3. Thermal protection system

- During the flight, the surface temperature of the spacecraft changes dramatically. Tungsten alloy plates have excellent high temperature resistance and thermal expansion performance and can be used as thermal insulation layers and heat shields.
- Helps protect structures from high temperature ablation and thermal fatigue damage.

2. The key role of the counterweight plate

1. Center of gravity balance and flight stability

- Tungsten alloy plates are used in the counterweight system of aerospace vehicles to adjust the center of gravity of the aircraft and ensure attitude control and stability during flight;
- The high density makes the counterweight small in size, saving space and meeting the needs of compact design.

2. Vibration reduction

- Tungsten alloy counterweights can effectively reduce aircraft vibration, reduce mechanical fatigue, and extend equipment life;
- Helps improve flight comfort and system reliability.

3. Compact design

- tungsten alloy plates allow for the design of thinner and lighter counterweight structures, which helps reduce overall weight.
- Supports customized processing of complex shapes to meet the design requirements of different aircraft.

3. Advantages of Tungsten Alloy Plate

- **High specific gravity** : significantly improves counterweight efficiency and reduces volume and weight;
- **Excellent mechanical properties** : ensure the strength and toughness of the protective structure;
- **High temperature resistance** : adapt to high temperature and extreme environment;
- **Excellent radiation resistance** : ensuring the safety of spacecraft electronic systems.

4. Typical application cases

- Radiation shielding and counterweight systems in satellite platforms;
- Bulletproof armor and center of gravity adjustment counterweights for fighter jets and military drones;
- Thermal insulation panels and structural counterweights for aerospace vehicles.

V. Development Trends and Challenges

- With the increasing demand for lightweight and high performance, microstructure optimization and composite material integration of tungsten alloy plates have become research hotspots;
- Improving the thermal fatigue resistance and impact toughness of tungsten alloy plates is a key technical difficulty;
- Low-cost, high-efficiency large-scale production technology urgently needs a breakthrough.

VI. Summary

Tungsten alloy plates play a vital role in aerospace protective structures and counterweight systems. Their unique physical and mechanical properties not only meet the needs of high-strength protection and precise counterweight, but also help aircraft achieve safe, stable and efficient operation. In the future, through material innovation and process improvement, tungsten alloy plates will show broader application prospects in the aerospace field.

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5.3 High-density protective plates in medical radiotherapy devices

Tungsten alloy plates are widely used in medical radiotherapy equipment due to their high density and excellent radiation shielding performance. They are mainly used to manufacture efficient radiation protection plates. The safe operation of radiotherapy equipment places strict requirements on the radiation protection of patients and medical staff. Tungsten alloy plates have become an important material to ensure the safety of radiotherapy due to their excellent physical and mechanical properties.

1. Necessity of radiation protection in radiotherapy equipment

- The X-rays and gamma rays generated during radiotherapy have extremely strong penetrating power and high energy. Without effective protection, they may cause radiation damage to surrounding personnel and equipment.
- The protective plate must effectively absorb and block radiation, prevent radiation leakage, and ensure the safety of the treatment environment.

2. Advantages of Tungsten Alloy Plate's Protection Performance

1. Superior shielding effect due to high density

- tungsten alloy plates is usually between 17-19 g/cm³, which is much higher than traditional materials such as lead. It can achieve the same or even better shielding effect at a thinner thickness.
- Make the overall structure of the radiotherapy equipment more compact and easier to design and install.

2. Excellent mechanical strength and durability

- Tungsten alloy plates have good mechanical strength and toughness, which can meet the long-term use requirements of medical equipment;
- The corrosion and wear resistance extend the service life of the guard plate and reduce maintenance costs.

3. Environmental safety

- Compared with toxic materials such as lead, tungsten alloy plates are more environmentally friendly, avoid the toxicity risk of lead, and are more in line with modern medical safety standards.

3. Application forms and typical configurations

- **Protective cover and shielding door** : Use tungsten alloy plate to make protective cover and door to prevent radiation leakage;
- **Radiation beam limiter and filter :** Precisely control the direction and intensity of radiation through tungsten alloy plates;
- **Equipment brackets and linings** : enhance the structural strength of radiotherapy equipment and ensure radiation safety.

4. Manufacturing and processing requirements

- The density and uniformity of the tungsten alloy plate must be ensured to avoid micropores and defects that affect the shielding effect;
- Strict surface treatment requirements to ensure smoothness and anti-corrosion performance;
- Precision machining to meet the special structural and dimensional requirements of radiotherapy equipment.

V. Development Trends and Challenges

- Promote the combination of tungsten alloy plates and composite materials to further improve shielding efficiency and lightweight level;
- tungsten alloy protective materials for new radiotherapy equipment ;
- Solve the manufacturing problem of large-size high-performance tungsten alloy plates and reduce costs.

VI. Summary

As a high-density protective material in medical radiotherapy devices, tungsten alloy plates ensure the safety and effectiveness of radiotherapy with their excellent shielding and mechanical properties. With the advancement of medical technology, tungsten alloy plates will play a more important role in the field of radiotherapy equipment protection and promote the continuous improvement of medical safety levels.

5.4 Tungsten alloy plate for high temperature furnace wall and thermal environment

Tungsten alloy plates are widely used in high-temperature furnace walls and various thermal environments due to their excellent high-temperature performance, thermal stability and corrosion resistance, and have become key structural and protective materials for high-temperature equipment. With the development of high-temperature process technology, higher requirements are placed on the heat resistance and mechanical strength of materials. Tungsten alloy plates, with their unique advantages, have shown excellent performance under extreme working conditions.

1. Performance requirements of high temperature furnace wall materials

1. High temperature resistance

- The furnace wall material needs to withstand high temperature environments ranging from hundreds to thousands of degrees Celsius to ensure long-term stable operation;
- tungsten alloy plate is as high as 3422°C. It has excellent high temperature resistance and can effectively resist thermal corrosion and oxidation.

2. Thermal expansion matching

- Tungsten alloy plate has a low coefficient of thermal expansion and can match well with other furnace materials, reducing thermal stress concentration and preventing cracking and deformation.

3. Mechanical strength and toughness

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- It needs to maintain sufficient strength and toughness in high temperature environments to withstand thermal shock and mechanical loads;
- Tungsten alloy improves its comprehensive mechanical properties at high temperatures through alloy element regulation and heat treatment process.

2. Application characteristics of tungsten alloy plates in thermal environment

1. Thermally stable structural parts

- Used as structural material for high-temperature furnace walls, heat exchangers and heat shielding devices to ensure the structural integrity of the equipment;
- Tungsten alloy plates can effectively prevent oxidation and corrosion damage in high temperature atmospheres.

2. Thermal radiation protection

- In a thermal environment, tungsten alloy plates can effectively reflect and absorb thermal radiation and protect sensitive parts of equipment due to their high density and high melting point.
- It helps to maintain a stable thermal field distribution and improve thermal efficiency.

3. Thermal fatigue resistance

- Tungsten alloy plate has a special organizational design to improve the material's resistance to thermal fatigue and thermal cycle stability, thereby extending its service life.

3. Typical application examples

- High temperature furnace lining and protective plates, used in metallurgy, ceramic sintering and semiconductor manufacturing furnaces;
- Structural components of heat treatment furnaces and vacuum furnaces;
- Heat-resistant insulation panels for high-temperature reactors and heat exchangers.

4.Material processing and key points of technology

- Tungsten alloy plates need to undergo precision heat treatment and surface strengthening treatment to improve high temperature resistance and oxidation resistance;
- Optimize the microstructure of the plate, improve density and uniformity, and enhance high-temperature mechanical properties;
- Advanced forming technology is used to ensure that the size and shape of the plate meet the equipment installation requirements.

V. Development Trends and Technical Challenges

- Improve the comprehensive performance of tungsten alloy plates in extreme thermal environments, including oxidation resistance and thermal stability;
- Research and develop multifunctional composite tungsten alloy materials to achieve integration of high temperature resistance, corrosion resistance and thermal management ;
- Reduce the production cost of high temperature tungsten alloy plates and realize large-scale application.

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VI. Summary

tungsten alloy plates provide a solid guarantee for the safe and reliable operation of high-temperature industrial equipment with their excellent high-temperature resistance and structural stability. In the future, with the continuous advancement of material science and processing technology, tungsten alloy plates will play a more extensive and important role in the high-temperature field.

5.5 Die steel composite plate and mechanical parts lining

Tungsten alloy plates are widely used in mold steel composite plates and lining materials for mechanical parts due to their high density, high strength, excellent wear resistance and heat resistance, improving the performance and service life of the overall structure. Through compounding with mold steel and other materials, tungsten alloy plates not only enhance the wear resistance and impact resistance of parts, but also effectively resist high temperature and corrosive environments, achieving efficient and stable operation of mechanical structures.

1. Application background and advantages of mold steel composite plate

1. Application requirements

- The mold is subjected to high pressure, high temperature and high-speed friction during operation, so the mold material must have high hardness, high wear resistance and thermal stability;
- composite tungsten alloy plate and die steel can achieve an optimal combination of surface hardness and internal toughness.

2. Advantages of tungsten alloy plate

- Tungsten alloy plates have high hardness and excellent wear resistance, effectively extending the service life of the mold;
- The high density helps to improve the overall rigidity and deformation resistance of the mold;
- Good thermal conductivity promotes even heat distribution and reduces thermal stress concentration.

2. Functions and requirements of mechanical parts lining

1. Wear and corrosion resistance

- Linings for mechanical parts are often used in high wear and corrosion environments, such as bearing seats, valve body inner walls, etc.
- Tungsten alloy plate lining improves the surface hardness and corrosion resistance of parts and reduces maintenance frequency.

2. Carrying capacity and stability

- Tungsten alloy plates enhance the load-bearing capacity and impact resistance of the lining structure;
- Improve the overall stability and service life of mechanical parts.

3. Composite technology and process

1. Powder metallurgy composite

- tungsten alloy and die steel is achieved through powder metallurgy process to ensure a dense and crack-free interface;
- It can achieve composition gradient transition and reduce stress caused by thermal expansion difference.

2. Mechanical bonding and welding

- Mechanical fastening or laser welding technology is used to achieve the combination of tungsten alloy plate and steel, with flexible process;
- Welding quality has a significant impact on composite performance, and process parameters need to be strictly controlled.

3. Surface treatment

- The tungsten alloy composite surface is ground , polished and coated to improve surface quality and corrosion resistance;
- Coatings such as ceramic coatings further improve wear resistance and high temperature resistance.

4. Typical application cases

- High wear-resistant mold composite plates for plastic molding and metal stamping molds;
- Mechanical equipment bearing seats and valve linings to improve wear resistance and corrosion resistance;
- Lining material for high-load mechanical structural parts to extend the service life of equipment.

V. Development Trends and Challenges

- Research and develop high-strength and high-toughness tungsten alloy composite materials to meet the needs of complex working conditions;
- Optimize the composite interface structure to improve bonding strength and thermal stability;
- Reduce composite manufacturing costs and promote the industrial application of tungsten alloy composite plates.

VI. Summary

tungsten alloy plates in mold steel composite plates and mechanical parts linings effectively improves the wear resistance, corrosion resistance and thermal stability of mechanical parts, helping equipment to achieve efficient and long-life operation. Through advanced composite technology and surface treatment, tungsten alloy composite materials will show broader application prospects in the field of mechanical manufacturing.

5.6 Heat dissipation/anti-radiation structures in precision instruments and electronic products

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With the development of electronic technology and precision instruments, higher and higher requirements are placed on the heat dissipation efficiency, dimensional stability and radiation resistance of materials. Tungsten alloy plates, with their high density, high thermal conductivity and excellent radiation resistance, have become key heat dissipation and protective structural materials in precision instruments and electronic products, and are widely used in high-end electronic equipment, communication base stations, laser devices and space electronic systems.

1. The key role of heat dissipation structure

1. High thermal conductivity

- Tungsten alloy plates have good thermal conductivity, which can effectively and quickly conduct heat generated by electronic components to prevent overheating;
- Excellent thermal conductivity ensures stable temperature of the device during high power operation, improving reliability and lifespan.

2. Dimensional stability

- Tungsten alloy plate has a low thermal expansion coefficient, which ensures the stability of the structure size when the temperature changes, and prevents the performance degradation caused by thermal deformation;
- It is especially suitable for heat dissipation brackets in microelectronic devices that require extremely high dimensional accuracy.

2. Application requirements of radiation-resistant structures

1. Anti-electromagnetic radiation

- In aerospace, military and medical electronic equipment, tungsten alloy plates are used as shielding materials to effectively block electromagnetic interference (EMI);
- Ensure the stable transmission of electronic signals and the normal operation of equipment.

2. Anti-nuclear radiation

- Used in nuclear medicine equipment and radioactive detection instruments, tungsten alloy plates can protect high-energy particles and sensitive components;
- Ensure long-term stable operation of equipment and improve safety.

3. Typical application scenarios

- Heat dissipation substrate for high-frequency communication base stations to ensure stable operation of communication equipment;
- Heat dissipation brackets and shielding covers in lasers and optical instruments;
- Radiation shielding for aerospace electronics;
- Radiation protection and heat dissipation components in medical electronic equipment.

4. Design and processing requirements

- Tungsten alloy plates must have high purity and uniform microstructure to ensure thermal conductivity and mechanical properties;
- thermal contact efficiency with other components ;

- Surface coating can be applied as needed to improve corrosion resistance and electromagnetic shielding performance.

V. Development Trends and Technical Challenges

- Integrated, lightweight heat dissipation structure design, combined with tungsten alloy and other functional materials to achieve multifunctional composite;
- Improve the microstructure control of tungsten alloy plates to further enhance thermal conductivity and radiation resistance;
- Reduce manufacturing costs and promote popularization and application in the field of civilian electronics.

VI. Summary

Tungsten alloy plates have become an important material for ensuring equipment performance and life in the heat dissipation and radiation resistance structure of precision instruments and electronic products due to their excellent thermal conductivity and radiation protection capabilities. With the continuous development of electronic technology, tungsten alloy plates will demonstrate their irreplaceable value in more high-end electronic fields.

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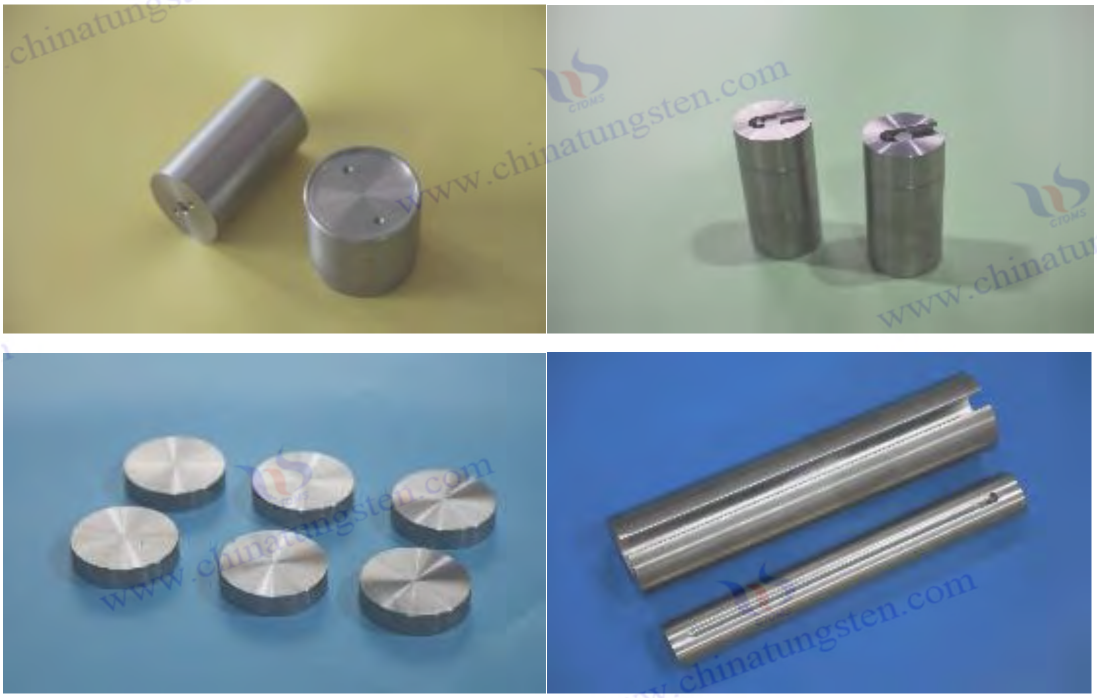

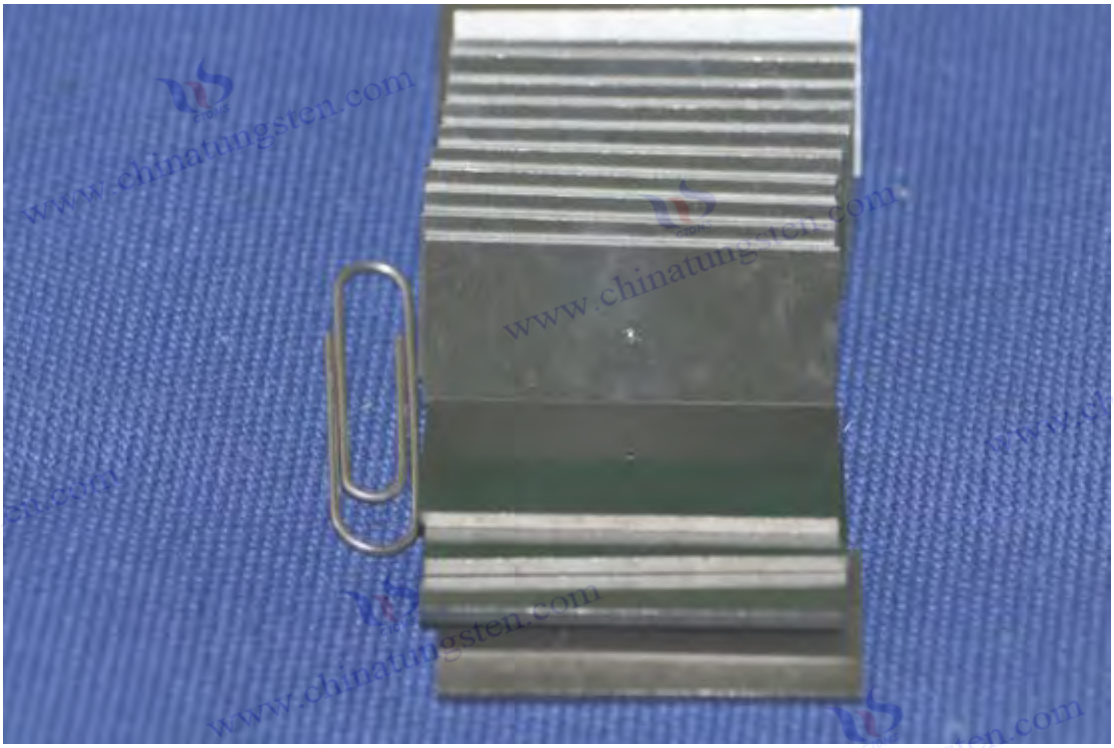

Chapter 6 Research and Development and Innovation of Special Tungsten Alloy Plates

Preparation and Properties of Nanostructured Tungsten Alloy Plates

With the development of material science, nanotechnology has been gradually applied in the preparation of tungsten alloy plates, significantly improving the mechanical properties, thermal stability and functional characteristics of traditional tungsten alloy plates. Nanostructured tungsten alloy plates achieve grain refinement, interface strengthening and phase optimization by regulating the microstructure, greatly improving the comprehensive performance of the material and providing a new choice for high-end application fields.

1. Preparation technology of nanostructured tungsten alloy plates

1. Nanopowder Preparation

- Nano-scale tungsten powder and alloy powder are prepared using advanced technologies such as high-energy ball milling, vapor deposition, and chemical reduction;
- The powder particle size is refined to the range of tens of nanometers, which improves the material densification and interface bonding performance.

2. High-energy ball milling and uniform mixing

- Uniform mixing and enhanced mechanical alloying of powders are achieved through high-energy ball milling;
- Effectively refine grains and evenly distribute strengthening phases to improve mechanical strength and toughness.

3. Rapid sintering technology

- Use rapid sintering processes such as spark plasma sintering (SPS) and microwave sintering to shorten sintering time and inhibit grain growth;
- Maintain nano-grain structure to ensure high density and excellent performance.

4. Heat treatment optimization

- Use low-temperature heat treatment process to stabilize the nanocrystalline structure and reduce internal stress;
- Adjust tissue state to achieve optimal performance balance.

2. Performance advantages of nanostructured tungsten alloy plates

1. Improved mechanical properties

- Grain refinement significantly improves tensile strength and yield strength, achieving a high strength and toughness combination;
- Nano-interface strengthening mechanism increases fracture toughness and improves impact resistance.

2. Thermal stability and wear resistance

- Nanostructured tungsten alloy plates exhibit excellent thermal stability and can resist grain growth and performance degradation at high temperatures;
- The surface hardness and wear resistance are significantly enhanced to adapt to harsh working conditions.

3. Excellent thermal conductivity and electrical properties

- The nano-grain structure optimizes the heat conduction path and improves the heat conduction efficiency;
- It has good electrical conductivity and can meet the heat dissipation requirements of electronic devices and high-frequency equipment.

3. Typical application areas

- High-strength and lightweight structural parts for aerospace;
- Radiation-resistant shielding panels for the nuclear industry;
- High performance electronic heat dissipation substrate;
- Precision molds and high wear-resistant mechanical parts.

IV. Challenges and Future Directions

- The high cost of nanopowder preparation and complex production process limit large-scale application;
- Nano-crystals tend to grow in high temperature environments, affecting long-term performance stability;
- The sintering and heat treatment processes need to be further optimized to achieve a balance between performance and cost.

V. Summary

Nanostructured tungsten alloy plates significantly improve the mechanical strength, toughness and functional properties of materials through fine regulation of microstructure, promoting the application and upgrading of tungsten alloy plates in high-end fields. In the future, with the continuous improvement of preparation technology and the reduction of costs, nanostructured tungsten alloy plates will become an important direction for the development of tungsten alloy material technology.

6.2 Microalloying and multicomponent alloy design strategies

With the diversification of tungsten alloy material performance requirements, microalloying and multi-component alloy design have become key technical paths to improve the comprehensive performance of tungsten alloy plates. By introducing trace alloying elements and multi-component alloy systems, the mechanical properties, thermal stability and functional characteristics of tungsten alloys can be significantly improved , and the performance of materials can be precisely controlled to meet the stringent requirements of aerospace, nuclear industry and high-end manufacturing.

1. Overview of Microalloying Technology

1. Definition and mechanism of action

- Microalloying refers to the addition of alloying elements in very low concentrations (usually less than 1%) to tungsten-based alloys ;
- These trace elements improve the strength and toughness of the alloy through mechanisms such as solid solution strengthening, precipitation strengthening and grain boundary strengthening;
- Microalloying elements can also refine grains, optimize microstructure and improve the overall performance of materials.

2. Commonly used microalloying elements

- Titanium (Ti), niobium (Nb), vanadium (V), zirconium (Zr), aluminum (Al), molybdenum (Mo), etc.;
- Different elements have different effects on the hardness, toughness and thermal stability of tungsten alloy. Choosing the right element combination is the key to design.

2. Multi-element Alloy Design Strategy

1. Construction of multi-component alloy system

- Adopt multi-element ratio design to achieve the synergistic effect of alloy elements;
- Optimize microstructure and performance gradient by properly matching matrix and strengthening elements;
- For example, W-Ni-Fe-Ti, W-Ni-Cu-Mo and other systems.

2. Application of the concept of high entropy alloys

- Introducing the design concept of high entropy alloys, using equimolar mixing of multiple elements to improve the material's stability and resistance to thermal fatigue;
- This allows tungsten alloy plates to exhibit excellent durability in extreme environments.

3. Microalloying and performance improvement of multicomponent alloys

1. Mechanical properties

- Microalloying elements promote fine grain strengthening and increase yield strength and tensile strength;
- By controlling the precipitation phase, the fracture toughness and impact resistance of the material can be improved.

2. Thermal stability

- Microalloying elements inhibit grain growth and phase transformation, and enhance high temperature performance;
- Improve thermal expansion matching, reduce thermal stress, and increase thermal fatigue life.

3. Features

- Optimize electrical conductivity and magnetic properties to meet the needs of electronic and magnetic applications;
- Improve radiation resistance and enhance the reliability of materials used in the nuclear industry.

4. Preparation process and technical challenges

- The uniform distribution of trace alloying elements is difficult and requires precise control of powder mixing and sintering processes;
- The design of alloy composition is complex and requires a combination of computational simulation and experimental verification;
- The preparation process of high-entropy multi-component alloys is still in the research stage, and industrial application requires breaking through technical bottlenecks.

V. Future Development Direction

- Combined with advanced computational materials science, high-performance microalloyed tungsten alloys are designed;
- Develop low-cost, high-efficiency preparation processes to achieve large-scale production of multi-component alloys;
- the performance and application potential of microalloyed tungsten alloys under extreme working conditions.

VI. Summary

Microalloying and multi-component alloy design provide an important way to improve the performance of tungsten alloy plates. Through the fine control of elements and the synergistic effect of multiple components, the mechanical properties and functional characteristics of the material are fully optimized. In the future, with the continuous advancement of theory and technology, microalloyed tungsten alloy plates will play a greater role in the field of high-end manufacturing.

6.3 Organization Optimization and Heat Treatment of High-Temperature Resistant

Tungsten Alloy Plates The stability and performance of tungsten alloy plates in high-temperature environments directly affect their application in aerospace, nuclear industry, and high-temperature manufacturing. Through reasonable organization optimization and heat treatment process design, the high-temperature resistance of tungsten alloy plates, including thermal stability, oxidation resistance, and mechanical strength, can be significantly improved to meet the needs of extreme service conditions.

1. Key factors affecting high temperature resistance of tungsten alloy plate

1. Microstructure

- Grain size, grain boundary characteristics, and the distribution of the second phase all directly affect the thermal stability of the material;
- Refined grains and uniformly distributed strengthening phases help to inhibit grain growth and improve high temperature strength.

2. Material composition

- Alloy elements such as titanium (Ti), molybdenum (Mo), and niobium (Nb) enhance high-temperature oxidation resistance and creep resistance by forming stable phases;
- Reasonable ratio can optimize thermal expansion characteristics and reduce thermal stress.

2. Organizational Optimization Strategy

1. Grain refinement and homogenization

- Adopt high-energy ball milling, rapid sintering and other technologies to obtain fine and uniform grain structure;
- The grain boundary strengthening mechanism effectively prevents grain growth at high temperatures.

2. Second phase strengthening

- Introducing small and stable second phase particles to strengthen grain boundaries and improve creep resistance;
- The second phase particles are evenly distributed to avoid the formation of stress concentration areas.

3. Heat treatment process design

1. Pre-sintering heat treatment

- Regulate powder particle size and composition uniformity to prevent defects during sintering;
- Adopt suitable temperature and atmosphere conditions to promote densification.

2. High temperature solution treatment

- Through high-temperature solution heat treatment , phases are dissolved and separated, alloy elements are evenly distributed, and material homogeneity is improved;
- Prevent the precipitation of coarse phases and maintain organizational stability.

3. Timeliness processing

- Control the size and distribution of precipitated phase to enhance high temperature strength;
- Optimize aging temperature and time to achieve optimal mechanical properties.

4. Atmosphere control

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- Heat treatment is performed in a protective atmosphere (such as argon, nitrogen) to reduce oxidation;
- Some processes use vacuum heat treatment to ensure surface quality and internal purity.

4. Performance Improvement Effect

- After heat treatment, the tungsten alloy plate has fine grains, uniform structure, and significantly improved creep resistance;
- High temperature strength and fracture toughness are significantly improved to adapt to high temperature loads and thermal shock;
- Enhanced thermal stability extends the service life of the material in high temperature environments.

5. Application Examples and Development Trends

- High temperature protection materials for aircraft engine turbine blades and structural parts;
- Heat-resistant structural materials for high-temperature components of nuclear reactors;
- Key high temperature resistant components in high temperature industrial furnaces and heat treatment equipment.

In the future, combined with advanced microstructure characterization technology and numerical simulation, the organizational design and heat treatment process of high-temperature resistant tungsten alloy plates will be further optimized to achieve continuous breakthroughs in material performance.

VI. Summary

Organization optimization and fine heat treatment are the core means to improve the performance of high temperature resistant tungsten alloy plates. By controlling the grain size, strengthening phase distribution and heat treatment process parameters, the thermal stability and high temperature mechanical properties of the material can be significantly enhanced, providing a solid guarantee for the reliable application of tungsten alloy plates in extreme environments.

6.4 Interface bonding mechanism of tungsten-copper/tungsten-nickel composite plates

Tungsten copper (W-Cu) and tungsten nickel (W-Ni) composite sheets combine the high density, high melting point and mechanical strength of tungsten with the good electrical conductivity, thermal conductivity and toughness of copper and nickel, and are widely used in the fields of electronic heat dissipation, thermal management and high-temperature structural materials. The performance of composite sheets depends largely on the interface bonding quality and bonding mechanism. A deep understanding of the interface bonding process is crucial to optimizing material properties and manufacturing processes.

1. Interface structure characteristics of tungsten copper/tungsten nickel composite plate

- There are significant differences in physical and chemical properties between tungsten and copper and nickel, including melting point, thermal expansion coefficient, lattice structure, etc.
- There is usually a transition layer or diffusion layer in the interface area, which affects the mechanical bonding strength and thermal conductivity of the interface;
- Excellent interface bonding requires good wettability and metallurgical bonding between metals and reduction of interface cracks and pores.

2. Analysis of interface binding mechanism

1. Mechanical bonding

- Through physical pressing and plastic deformation, tungsten and copper, nickel powder or plate are closely contacted to form a preliminary bond;
- Mechanical bonding provides the basic structural support of the interface, but the bonding strength is limited.

2. Metallurgical bonding

- During high-temperature sintering or thermal diffusion, tungsten diffuses and dissolves with copper and nickel atoms ;
- Form a transition diffusion layer to enhance interface bonding and thermal conductivity;
- Tungsten and nickel form a certain solid solution or interstitial phase, which improves the interface toughness.

3. Diffusion and interfacial reactions

- Elements diffuse at the interface, forming fine alloy phases or transition phases, which facilitate stress transfer;
- Controlling the diffusion process can avoid the formation of brittle phases and improve interface stability.

3. Key factors affecting interface bonding performance

1. Powder particle size and distribution

- Fine and uniform powder helps to form a dense interface;
- Large differences in particle size may lead to interface defects.

2. Sintering temperature and atmosphere

- The sintering temperature needs to be high enough to promote diffusion and metallurgical bonding, but avoid excessive grain growth;
- The protective atmosphere prevents interface oxidation and keeps the interface clean.

3. Suppress pressure and time

- Sufficient pressure helps eliminate interfacial pores and improve mechanical bonding;
- Sintering time affects the diffusion depth and interface structure uniformity.

4. Impact of interface bonding on performance

- Good interface bonding improves the thermal conductivity and electrical conductivity of the composite board, meeting the needs of efficient heat dissipation;

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- The interface bonding strength directly determines the mechanical strength and thermal fatigue resistance of the material;
- Poor interfacial bonding can lead to crack formation and reduce the overall reliability of the material.

5. Interface Engineering and Optimization Technology

- Surface activation treatments, such as plasma cleaning, improve wettability and bonding quality;
- Adding interface activators or interface layer materials to promote diffusion bonding and interface stabilization;
- Adopt gradient alloy interface design to alleviate thermal expansion differences and reduce thermal stress.

6. Application Examples

- Tungsten copper composite plates are widely used in electronic device heat dissipation substrates and high-power switching devices;
- Tungsten-nickel composite plates are used for wear-resistant, high-strength structural parts and nuclear industry shielding materials;
- Optimizing interface bonding improves the service life and performance stability of composite panels in extreme environments.

VII. Summary

tungsten copper and tungsten nickel composite plates is a key factor in determining material performance. Through the optimization of mechanical bonding, metallurgical diffusion and interface engineering, high-strength, high-thermal conductivity and high-toughness composite materials can be achieved to meet the stringent requirements of electronic heat dissipation and high-temperature structural materials. In the future, the development of interface design and control technology will further promote the performance improvement and application expansion of tungsten alloy composite plates.

6.5 Research and Development of Surface Coatings and Wear-Resistant and Corrosion-Resistant Sheets

Tungsten alloy plates often face complex challenges such as mechanical wear, corrosion and high-temperature oxidation in many industrial applications. In order to improve the wear resistance and corrosion resistance of tungsten alloy plates, surface coating technology has become a key research and development direction. Through diversified coating materials and advanced coating processes, not only the surface properties of tungsten alloy plates have been significantly improved, but also their application areas have been broadened.

1. Overview of tungsten alloy plate surface wear and corrosion

- Tungsten alloy plates are prone to surface wear in high-load and frequent friction environments, which affects their service life.
- High temperature oxidation and chemical corrosion lead to surface degradation, weakening mechanical strength and overall performance;
- Surface defects and microcracks can easily become corrosion sources, leading to larger-scale material damage.

2. Types and characteristics of surface coating technology

1. Ceramic coating

- Commonly used materials include aluminum oxide (Al_2O_3), titanium oxide (TiO_2), silicon nitride (Si_3N_4), etc.
- It has high hardness, high wear resistance and excellent high temperature resistance;
- Suitable for use in extreme wear and high temperature conditions.

2. Metal coating

- Metal coatings such as copper, nickel, and chromium are achieved through electroplating, spraying, and other methods;
- Improve surface conductivity and corrosion resistance;
- Suitable for electronic cooling and protection applications.

3. Composite coating

- Ceramic-metal composite coating combines the advantages of both, with both hardness and toughness;
- It is prepared using advanced processes such as physical vapor deposition (PVD) and chemical vapor deposition (CVD).

4. Nano-coating technology

- Use nanomaterials to prepare ultrafine structure coatings to improve adhesion and wear resistance;
- Has excellent self-repairing and anti-corrosion properties.

3. Coating preparation process

1. Physical Vapor Deposition (PVD)

- The thin film is deposited by evaporation or sputtering technology, and the coating is dense and uniform;
- Commonly used to prepare hard ceramic and metal composite coatings.

2. Chemical Vapor Deposition (CVD)

- Suitable for large-area uniform coating, with strong coating adhesion;
- Coating composition and thickness can be controlled to meet specific performance requirements.

3. Electroplating and spraying

- The electroplating process is simple and efficient, suitable for metal coating applications;
- The spraying technology is flexible and suitable for thick coatings and complex-shaped workpieces.

4. The role of surface coating in improving performance

- Significantly improve the surface hardness and wear resistance of tungsten alloy plates and extend their service life;
- Effectively prevent oxidation and chemical corrosion, and protect the material structure;
- Improve thermal conductivity and surface electrical properties to meet the needs of high-end electronics and precision instruments.

V. R&D Progress and Challenges

- New functional coating materials continue to emerge, such as superhard ceramics and nanocomposites;
- The bonding strength and thermal expansion matching between the coating and the tungsten alloy plate substrate are technical difficulties;
- It is necessary to develop low-temperature coating processes to reduce substrate thermal stress and performance degradation;
- Consider the environmental friendliness and cost-effectiveness of the coating and promote its industrial application.

VI. Future Development Direction

- Research and development of multifunctional composite coatings to achieve integrated wear resistance, corrosion resistance, thermal conductivity and radiation resistance;
- Smart coating technologies, such as self-healing and environmentally responsive coating materials;
- Combined with surface nanostructure design, adhesion and performance are further improved;
- Optimize the process flow to achieve efficient and energy-saving coating preparation.

VII. Summary

Surface coating technology is a key way to improve the wear resistance and corrosion resistance of tungsten alloy plates. Through material innovation and process optimization, the service life and reliability of tungsten alloy plates under harsh working conditions have been greatly improved, providing strong guarantees for their application in aerospace, nuclear industry, electronic devices and other fields.

6.6 Design of Thermal and Electrical Conductive/Antimagnetic Functional Tungsten Alloy Plate

Tungsten alloy plates are widely used in high-end fields such as electronics, aerospace, and nuclear energy due to their excellent high density, high strength, and high melting point. With the development of technology, the functional design of tungsten alloy plates has gradually extended to the direction of thermal conductivity, electrical conductivity, and anti-magnetic properties to meet the diverse needs under complex working conditions. Through composition control, microstructure design, and composite technology, the thermal conductivity, electrical conductivity, and magnetic performance of tungsten alloy plates can be effectively improved.

1. Design principle of thermal and electrical conductive tungsten alloy plate

1. Alloy composition control

- Introducing high thermal conductivity metal elements, such as copper (Cu), silver (Ag) and aluminum (Al), significantly improves the thermal conductivity and electrical conductivity of the material;
- Adjust the ratio of tungsten to other elements to achieve a reasonable distribution of the matrix and conductive phase, taking into account both strength and conductivity.

2. Microstructure optimization

- Optimize the grain size and morphology of the tungsten matrix, reduce the grain boundary thermal resistance, and improve the thermal conduction efficiency;
- The phase interface is controlled through powder metallurgy and rapid sintering process to reduce interface resistance and thermal resistance.

3. Composite material design

- Adopt tungsten-copper, tungsten-silver and other composite systems to form a continuous conductive network to ensure high thermal and electrical conductivity;
- Develop functionally graded materials to achieve zoned optimization of surface and internal performance.

Design Strategy of Antimagnetic Tungsten Alloy Plate

1. Magnetic element control

- Reduce or avoid the use of strong magnetic elements (such as iron Fe, cobalt Co, nickel Ni) to reduce the magnetic response of the material;
- Non-magnetic or weakly magnetic metals are used as alloy elements to ensure overall low magnetic permeability.

2. Crystal structure and defect control

- By refining the grains and reducing the magnetic domain structure, the magnetic anisotropy is increased and the macroscopic magnetic performance is reduced;
- Control the morphology and distribution of the precipitated phase and reduce the aggregation of the magnetic phase.

Performance characteristics of functional tungsten alloy plate

1. High thermal and electrical conductivity

- The thermal conductivity can reach several times that of traditional tungsten alloys, meeting the needs of heat dissipation of electronic devices and high-frequency communications;
- The resistivity is reduced, ensuring good electrical properties, and is suitable for contact materials and electrode structures.

2. Low magnetic response characteristics

- Low magnetic permeability and excellent anti-magnetic properties, suitable for precision magnetic field control and medical magnetic resonance equipment;

- Reduce magnetic field interference and improve system stability and measurement accuracy.

4. Application fields

- High-performance electronic device heat dissipation substrates and conductive structural parts;
- Instruments and equipment structures in aerospace that are sensitive to magnetic interference;
- The nuclear industry requires protective materials that take into account both heat dissipation and anti-magnetic properties;
- Key structural materials in medical magnetic resonance imaging (MRI) equipment.

5. Design and Manufacturing Challenges

- The balance between thermal and electrical conductivity and mechanical strength requires comprehensive optimization in many aspects;
- The control of thermal resistance and electrical resistance of composite interface is difficult and the preparation process requires high requirements;
- Improving antimagnetic properties places higher demands on alloy element selection and microstructure control.

6. Future Development Trends

- Using computational materials science to guide component design and achieve precise control of thermal conductivity, electrical conductivity and anti-magnetic properties;
- Develop nanostructured and functionally gradient materials to improve interface performance and overall stability;
- Promote the application of additive manufacturing technology in functional tungsten alloy plates to achieve integrated manufacturing of complex structures;
- Explore smart material technology to achieve dynamic response and adjustment of tungsten alloy plate performance.

VII. Summary

Through scientific composition design and microstructure control, the heat-conducting, electrical-conducting and anti-magnetic functional tungsten alloy plates meet the multiple requirements of thermal management, electrical properties and magnetic properties in high-end applications. With the advancement of material technology and manufacturing processes, this type of functional tungsten alloy plate will play an increasingly important role in the fields of aerospace, electronic communications, nuclear industry and medical equipment.

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Core advantages: 30 years of experience: deeply familiar with tungsten alloy production, mature technology.
Precision customization: support high density (17-19 g/cm³), special performance, complex structure, super large and very small parts design and production.
Quality cost: optimized design, optimal mold and processing mode, excellent cost performance.
Advanced capabilities: advanced production equipment, RMI, ISO 9001 certification.
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Widely involved, covering aerospace, military industry, medical equipment, energy industry, sports and entertainment and other fields.
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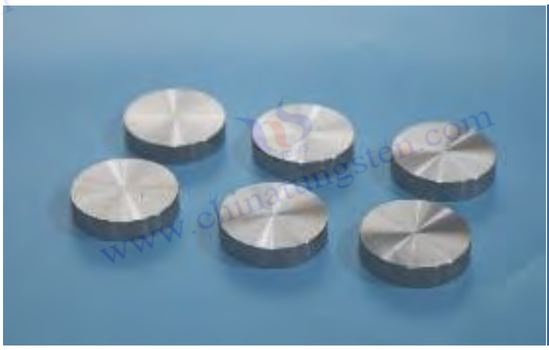
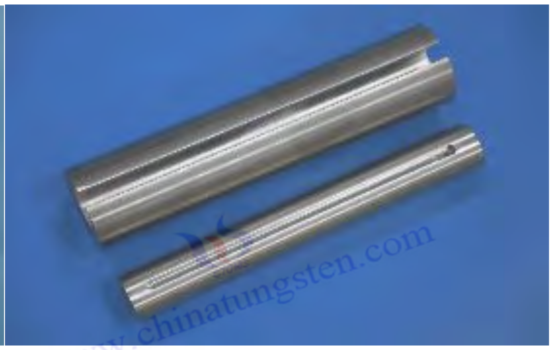

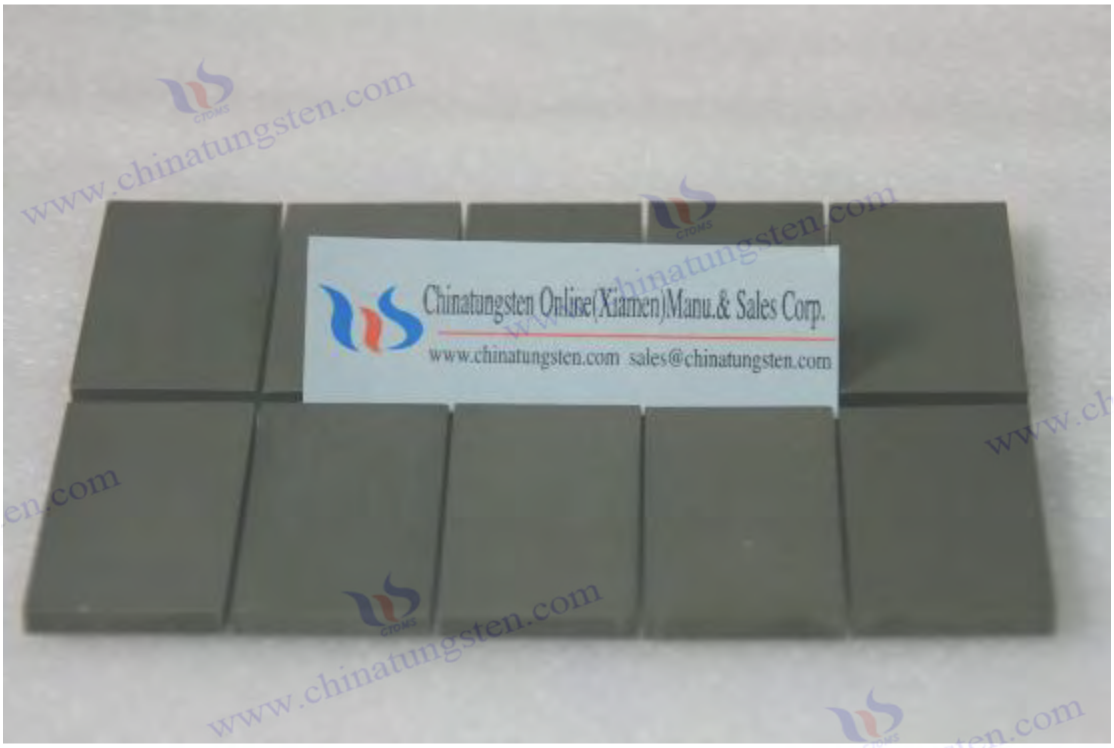

Chapter 7 International Standards and Quality System of Tungsten Alloy Plates

7.1 China Tungsten Alloy Plate Related Standards (GB/T, YS/T)

As one of the world's major tungsten resource suppliers and tungsten material manufacturers, China has established a relatively complete standard system for tungsten and tungsten alloy products, covering the technical conditions, test methods, dimensional tolerances, surface quality, performance indicators and testing specifications of tungsten alloy plates. The national standard (GB/T) and the non-ferrous metal industry standard (YS/T) together constitute the quality basis and industry specifications of tungsten alloy plates in the Chinese market.

1. Overview of the Standard System

1. National Standard (GB/T)

- **GB/T standards** are recommended national standards with high authority and universality;
- It is mostly used to guide the size, tolerance, technical conditions and testing methods of tungsten alloy plates;
- It is applicable to quality assessment benchmarks in various general industrial fields, export products and domestic procurement contracts.

2. Industry Standard (YS/T)

- **The YS/T standard** is formulated by the China Nonferrous Metals Industry Association and reflects the latest technical level of the industry;

- More specific and detailed, often used in the technical index requirements of special tungsten alloy plates;
- It has stronger foresight and applicability for tungsten alloy products with new materials and new processes.

2. Examples of Commonly Used National Standards (GB/T)

Standard No.	Standard Name	Contents
GB/T 4187	Tungsten Plate	Specifies the classification, size, appearance, mechanical properties and test methods of tungsten plates
GB/T 3462	Dimensional tolerances for rare metal sheets	Covers thickness and width tolerance standards for tungsten, molybdenum and other plates
GB/T 2040	Chemical analysis methods for tungsten products	Applicable to the analysis of W, Fe, Ni, Cu and other elements in tungsten alloy plates
GB/T 8170	Numerical rounding rules	the size control and inspection of tungsten plates

Note: In actual procurement and acceptance, GB/T 4187 is often widely used as the basic standard.

3. Examples of Commonly Used Nonferrous Metal Industry Standards (YS/T)

Standard No.	Standard Name	Scope of application
YS/T 519	Heavy Tungsten Alloy Products	applicable to tungsten nickel iron, tungsten nickel copper plates and other products
YS/T 795	Tungsten Alloy Plate	Provide clear indicators for the performance and appearance of thick plates, medium plates and thin plates
YS/T 670	Testing methods for powder metallurgy tungsten materials	Testing specifications for microscopic properties such as density and porosity
YS/T 629	Chemical composition analysis method of tungsten-based alloy	High-precision analytical methods involving simultaneous detection of multiple elements

IV. Main indicators of standard content

1. Dimension and tolerance control

- Thickness deviation, width deviation, board surface flatness;
- Edge uniformity, warpage control, etc.

2. Mechanical properties

- Tensile strength, yield strength, elongation;
- Hardness index (HV, HB), impact toughness, etc.

3. Surface quality

- No cracks, peeling, oxide scale or inclusions are allowed;

- Surface roughness Ra≤specified value, slight scratches are allowed.

4. Internal defects and organizational control

- Specify testing methods such as ultrasonic, CT and other non-destructive testing;
- The microstructure is uniform, without significant inclusions or holes.

5. Chemical composition range

- Contents of main and impurity elements such as W, Ni, Fe, Cu, and Mo;
- Conforms to specific grade classifications (e.g., Grade 1, Grade 2, Special Grade).

V. Standard Implementation and Quality Certification Practice

1. Applicable objects

- For production enterprises, purchasing units, scientific research institutions and quality inspection departments;
- Provide unified technical support for trade, export and project bidding.

2. Align with international standards

- In recent years, Chinese standards have been moving closer to ISO and ASTM;
- Improve the international compatibility of standards by adopting equivalent conversion, supplementary explanations and other methods.

3. Enterprise internal control standards

- Some leading enterprises have formulated stricter enterprise technical specifications based on the implementation of GB/T and YS/T;
- For example, higher dimensional accuracy, lower impurity limits and finer surface quality.

VI. Summary

China's tungsten alloy plate standard system provides a basic basis and technical support for the design, production, testing and circulation of products. The GB/T standard reflects the national unified technical management specifications, and the YS/T standard reflects the level of technological development in the industry. With the expansion of tungsten alloy plates in high-end application fields, these standards are also being continuously revised and improved, playing a key role in ensuring product quality and promoting technological upgrades.

7.2 Interpretation of American Standards (ASTM, MIL)

As an important leader in the global high-end materials industry, the United States has established a relatively complete and widely used standard system for tungsten and tungsten alloy materials. This system is mainly composed of **ASTM (American Society for Testing and Materials) standards** and MIL (US Military Standards). It not only provides technical specifications for domestic military, aerospace, electronics and other fields, but also plays an important role in global trade, quality management and international certification.

1. Overview of ASTM Standard System

1. Nature of the Standard

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ASTM (American Society for Testing and Materials) standards are **an internationally accepted technical standard system that** emphasizes material properties, testing methods and general specifications, and are widely used in industrial manufacturing, quality control, trade compliance and other fields.

Typical ASTM standards related to tungsten alloy plates

Standard No.	Standard Name	Scope of application
ASTM B702	Specification for powder metallurgy products of heavy tungsten alloys	Including technical requirements for various products such as plates, bars, round cakes and forgings
ASTM B777	High Density Tungsten Alloy Product Standard	Clarify the mechanical properties, chemical composition and dimensional tolerance of materials
ASTM B760	Technical specifications for tungsten and molybdenum plates, sheets and strips	Suitable for the preparation and quality inspection of thick and thin plates
ASTM E1477	Reference Methods for Rare Metal Detection	Spectral, thermal analysis and structural detection of materials such as tungsten and molybdenum

3. Key points of the standard

- **Composition requirements** : specify tungsten content, alloy element ratio and impurity limits;
- **Dimensions and tolerances** : including thickness, width, flatness and edge shaping;
- **Mechanical properties** : tensile strength, yield strength, ductility;
- **Test methods** : including tensile test, hardness test, ultrasonic test, etc.;
- **Surface quality** : Oxidation, peeling, inclusions, etc. are clearly defined.

2. Overview of the MIL Military Standard System

1. Nature of the Standard

MIL-STD (Military Standard) is **a military product standard system developed by the U.S. Department of Defense** and is widely used in high-tech applications such as military weapons, aerospace, and precision engineering. The system emphasizes reliability, safety, and consistency under extreme conditions.

Representative standards related to tungsten alloy plates

Standard No.	Standard Name	Features
MIL-T-21014	Tungsten Alloy High Density Material Standard	Including the size, performance and process requirements of plates, rods and rings
MIL-C-14550	Nickel plating process standards for metal surfaces	Electroplating requirements and environmental adaptability of tungsten -based materials

MIL-STD-45662	Measurement and testing equipment control standards	For material inspection and quality traceability management
MIL-STD-883	Electronic component testing standards	Suitable for tungsten alloys used in chip support plates or heat dissipation materials

3. Military Standard Features

- **High requirements for environmental adaptability** : Emphasis on stable performance under high temperature, radiation and impact environments;
- **Strict mechanical reliability** : clear lower limits for strength, fracture toughness, and fatigue performance;
- **Strict batch consistency control** : good traceability and consistency verification are required;
- **Equal emphasis on safety and environmental certification** : covering restrictions on harmful elements, material aging tests, etc.

3. Complementary relationship between ASTM and MIL standards

Comparison Dimensions	ASTM Standards	MIL Standard
Applicable areas	General industry, civil use, scientific research	Aerospace, defense, and military industry
Standard Type	Product Specifications + Test Methods	Application performance + environmental adaptability
Inspection focus	Material properties	System reliability and working condition matching
Standard openness	Public resources, widely adopted	Military background, partially confidential

Note: In the actual design and production of high-end tungsten alloy plates, companies often need to meet both ASTM and MIL requirements.

4. Application in the production and export of tungsten alloy plates

- **Technical contract basis** : ASTM B702, B777, etc. are often used as basic standards for international procurement and technical agreements;
- **Quality management system interface** : MIL standards require compatibility with ISO 9001, AS9100 and other systems;
- **International certification** : Compliance with ASTM/MIL standards helps enter high-end markets such as North America and the European Union;
- **Guidance on testing methods** : The physical and chemical testing methods specified in the standard are widely adopted as the basis for testing.

V. Summary

The ASTM and MIL standard systems constitute an important pillar of the quality management of tungsten alloy materials in the United States. Their rigor, systematicness and authority are recognized worldwide. ASTM provides general material performance evaluation criteria, while the MIL standard focuses on service reliability under extreme conditions. In the international market competition, Chinese companies should actively benchmark ASTM/MIL standards to improve the international adaptability and high-end market competitiveness of their products.

7.3 Compilation of European and ISO Tungsten Alloy Plate Standards

With the development and application expansion of tungsten alloy material technology around the world, Europe and the International Organization for Standardization (ISO) have also established a set of tungsten alloy plate-related standard systems with wide applicability and high authority. These standards not only serve local industrial manufacturing, trade supervision and environmental compliance in Europe , but also become an internationally accepted reference, greatly promoting the widespread application of tungsten alloy plate products in high-end fields such as nuclear energy, aviation, electronics and medical treatment.

1. Introduction to the ISO International Standards System

1. Nature of ISO standards

- ISO (International Organization for Standardization) is the most authoritative and influential standards-setting organization in the world;
- Its tungsten material standards are mainly handled by technical committees such as ISO/TC 119 (powder metallurgy technical committee) and ISO/TC 261 (additive manufacturing);
- ISO standards focus on universality, coordination, and mutual recognition, and are widely used in international trade, certification, and compliance inspections .

2. Examples of common ISO tungsten alloy related standards

Standard No.	Standard Name	Involved content
ISO 4499	Microstructure analysis method of metal powder and its products	of tungsten powder and sintered tungsten alloy plate
ISO 5755	Tungsten material density determination method	Determination of density using Archimedean and geometric methods
ISO 6892-1	Tensile testing of metallic materials Part 1: Test method at room temperature	Applied to the tensile properties test of tungsten alloy plate
ISO 3928	Metal material bending test	Testing the ductility and fracture behavior of tungsten alloy plates

ISO standards mostly use common test methods, complementing ASTM, and some have been integrated with EU standards.

2. Overview of European EN Standard System

1. Standard Source

- EN (European Norm) standards are uniformly formulated by the European Committee for Standardization (CEN);
- involving tungsten alloy plates are mainly derived from member country standards such as German DIN, French NF, British BS, and Spanish UNE;
- It has legal effect within the EU and is the compliance basis for products entering the European market.

2. Examples of typical EN standards

Standard No.	Standard Name	Original national standard
EN 2516	High Density Tungsten Alloy Material Specifications	Derived from the French Aeronautical Industry Standard (NF L)
EN 10204	Material quality certification document standards	Widely used in tungsten alloy plate quality traceability system
EN ISO 6507	Metal Micro-Vickers Hardness Test Method	Equivalent to ISO 6507 for hardness testing
EN ISO 9001	Quality management system requirements	for Tungsten Alloy Plate Manufacturers

3. Implementation and characteristics of European standards

1. Refinement of technical indicators

- There are more detailed grading for plate thickness control, tolerance grade, edge shaping, etc.
- There are high requirements for the control of surface quality, microstructure, non-metallic inclusions, etc.

High environmental protection and compliance requirements

- Emphasis on RoHS (Restriction of Hazardous Substances) and REACH (Registration and Evaluation of Chemicals) compliance ;
- Setting strict limits for harmful impurities such as lead, cadmium, and mercury;
- Safety Data Sheet (SDS/MSDS) and full life cycle material information are required.

3. The certification system is highly standardized

- Products must pass CE mark certification, RoHS declaration of conformity and third-party testing;
- The company needs to pass ISO 9001, ISO 14001 (environment) and other management system certifications;
- The military, nuclear energy, and aviation supply chains need to additionally meet advanced systems such as EN 9100 and ISO/TS 16949.

4. The international significance of ISO and EN standards

- **Globally accepted** : ISO standards are widely used in technical documents and acceptance protocols for international trade;
- **Technical coordination** : EN ISO standards accelerate the mutual recognition of European and international quality standards;
- **Promote exports** : If Chinese tungsten alloy plate manufacturers pass ISO/EN standard certification, it will be easier for them to enter the high-end markets in Europe and the United States;
- **Technology integration** : Most European importers and end users prefer to use ISO/EN dual-certified products.

5. Implications for Chinese Manufacturing Enterprises

direction	suggestion
Technology Upgrade	Benchmarking EN 2516, ISO 4499 and other standards to improve product structure and performance
Quality System	Establish a full-process quality control system that complies with ISO/EN requirements
Environmental Compliance	Strengthen the research and implementation of environmental regulations such as RoHS and REACH
International Certification	Actively obtain CE, ISO, and EN certifications to enhance the brand's international influence

VI. Summary

The European and ISO tungsten alloy plate standard system is highly standardized, environmentally friendly and technologically advanced, and is the only way for Chinese and global manufacturers to move towards the high-end market. Its standard content not only focuses on material performance and inspection methods, but also incorporates more systematic requirements such as environmental safety, life cycle management and system certification. For the upstream and downstream of the tungsten alloy plate industry chain, actively benchmarking and adapting to these standards is a key step to enhance international competitiveness and build sustainable development.

7.4 RoHS, REACH and MSDS Environmental Compliance Requirements

As the world's attention to environmental protection and human health continues to increase, the production, use and circulation of tungsten alloy plates must also meet a series of international environmental regulations and material safety standards. Among them, the compliance system represented by **the EU RoHS Directive, REACH regulations and **Material Safety Data Sheet (MSDS)**** has become a necessary threshold for entering the international market. Tungsten alloy plate manufacturers need to attach great importance to the integrity and accuracy of their material composition, chemical management and information disclosure.

1. RoHS Directive (Restriction of the Use of Certain Hazardous Substances)

1. Introduction to RoHS

RoHS (Restriction of Hazardous Substances Directive) is a mandatory environmental directive issued by the European Union, which restricts the use of certain hazardous substances in electronic and electrical products. Its goal is to protect human health and the environment and promote the gradual replacement of harmful elements in electronic products.

2. Applicability of tungsten alloy plates

Although tungsten alloy plates are not typical electronic and electrical finished products, **when they are used in electronic equipment structural parts, heat sinks, thermal conductive base plates or packaging components** , they must meet RoHS requirements, especially when exported to Europe or involved in electronic terminal products.

3. Restricted substances and limit values

Restricted substances	Maximum allowed concentration (in homogeneous material)
Lead (Pb)	0.1% (1000 ppm)
Cadmium (Cd)	0.01% (100 ppm)
Mercury (Hg)	0.1% (1000 ppm)
Hexavalent chromium (Cr^{6+})	0.1%
Polybrominated biphenyls (PBBs)	0.1%
Polybrominated diphenyl ethers (PBDEs)	0.1%
Phthalates (DEHP, BBP, DBP, DIBP)	0.1% each

4. Compliance measures

- Strictly control the source of alloy raw materials and impurity elements;
- Establish a RoHS testing system (such as XRF testing);
- Obtain third-party RoHS compliance declaration or test report;
- The RoHS symbol must be marked on product packaging and labels.

2. REACH Regulation (Registration, Evaluation, Authorization and Restriction of Chemicals)

1. Introduction to REACH

REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) is the most stringent chemical regulation in the EU. It applies to **all chemicals and products containing chemicals manufactured or put on the market in the EU** , and aims to assess their impact on human health and the environment.

2. Tungsten alloy plate related requirements

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- Although tungsten itself is not restricted, if the tungsten alloy plate contains **substances of very high concern (SVHC)** , such as certain heavy metal impurities, adhesives, surface coating materials, etc., it needs to be declared;
- Alloy plates with annual production or import volume exceeding 1 ton must be registered;
- Products containing ≥0.1% SVHC must be proactively notified to customers and submitted to ECHA (European Chemicals Agency) for notification.

3. Compliance Strategy

- Always update the SVHC list published by ECHA;
- compliance classification of chemicals used in tungsten alloy plates ;
- Cooperate with downstream customers to complete REACH declarations;
- Establish a tracking system to ensure supply chain transparency.

3. MSDS (Material Safety Data Sheet)

1. The role and status of MSDS

MSDS (Material Safety Data Sheet) is an internationally accepted chemical safety information document that lists the material's composition information, physical and chemical properties, hazards, emergency treatment, transportation and disposal, etc. It is the basic information for export trade, safety management, customer use and compliance declaration.

2. MSDS requirements for tungsten alloy plates

- Tungsten alloy plates are generally considered as **solid products** , but MSDS is still required for customer reference, especially when there is dust or cutting fluid contact;
- MSDS should cover all alloying elements, impurities and processing risk information;
- Must comply with GHS (Globally Harmonized System of Classification and Labelling of Chemicals) format.

3. MSDS sample content elements (16 items in total)

1. Product and Company Information
2. Ingredients
3. Hazards Identification
4. First aid measures
5. Firefighting measures
6. Leakage emergency treatment
7. Handling and storage requirements
8. Exposure controls and personal protection
9. Physical and chemical properties
10. Stability and reactivity
11. Toxicology Information
12. Ecological information
13. Disposal methods

14. Shipping Information
15. Regulatory Information
16. Other information

Note: MSDS should be prepared in English, and multilingual versions (such as Chinese, German, Japanese, etc.) should be provided when necessary.

4. Compliance Practices and Suggestions for Tungsten Alloy Plate Enterprises

Compliance Direction	Enterprise response strategy
Material selection	Avoid using restricted or high-concern elements and establish a raw material review system
Testing system	RoHS/REACH/XRF rapid screening and ICP testing during the procurement phase
File Management	Establish MSDS, RoHS, REACH and other compliance files and update them regularly
Customer collaboration	Proactively provide compliance statements, test reports and technical support documents
Third-party certification	Enhance trust with certification from authoritative organizations such as SGS, TÜV, and Intertek

V. Summary

RoHS, REACH and MSDS constitute the three core environmental compliance systems for tungsten alloy plate products to enter the international market, especially the EU market . These regulations not only limit the use and emission of hazardous substances in tungsten alloy plates, but also require companies to take more responsibility for their material composition, safety characteristics and environmental impact. Faced with increasingly stringent global green barriers, tungsten alloy plate manufacturers need to build a systematic environmental compliance management mechanism, strengthen green design concepts, and comprehensively enhance the sustainable competitiveness of their products.

7.5 Quality management systems in the aviation, nuclear energy and medical fields (AS9100, ISO 13485, etc.)

Tungsten alloy plates are widely used in key industries such as aerospace, nuclear energy engineering and medical equipment due to their high density, high strength, high temperature resistance and radiation resistance. However, these industries have extremely stringent requirements on the reliability, safety, traceability and consistency of materials. Therefore, if companies want to enter these high-end markets with tungsten alloy plates, they must fully establish and comply with specific industry quality management systems, such as AS9100 (aerospace), ISO 13485 (medical devices), NQA-1 (nuclear energy) and other standard systems.

1. AS9100: Aerospace Quality Management System

1. Introduction to the Standard

AS9100 is an aerospace-specific quality management system standard developed by the International Aerospace Quality Group (IAQG). It expands on ISO 9001 and expands on the unique requirements of the aviation, aerospace and defense industries. It is a common global supply chain standard for companies such as Boeing, Airbus, NASA, and Lockheed.

2. Key requirements

- **Product traceability** : The production process, raw material source, process parameters, and test records of each batch of tungsten alloy plates must be traceable;
- **Risk management** : Identify and control risks such as raw material defects, process deviations, and delivery delays;
- **Change control** : Any changes to product design, process or materials must be strictly approved;
- **Anti-counterfeiting and anti-interference capabilities** : prevent counterfeit and inferior materials from entering the aviation system;
- **Continuous Improvement and Customer Satisfaction** : Emphasizes process collaboration and continuous optimization between suppliers and customers.

3. The significance of application in tungsten alloy plate

If tungsten alloy plates are used as **components such as aerospace flight structures, satellite counterweights, inertial elements, etc.** , they must pass AS9100 control to prove that they meet the comprehensive requirements of the aviation field for material reliability, mechanical properties and consistency.

2. ISO 13485: Medical device quality management system

1. Introduction to the Standard

ISO 13485 is an international quality management standard developed for medical device products. It is applicable to all companies involved in the design, production, installation and service of medical devices, with special emphasis on **product safety, regulatory compliance and risk control** .

2. Core Content

- **Regulatory consistency** : requiring products to comply with relevant medical regulations in different markets around the world (such as EU MDR, US FDA, etc.);
- **Hygiene control and pollution prevention** : Raw materials, semi-finished products and finished products must avoid biological contamination or cross infection;
- **Biocompatibility evaluation** : If tungsten alloy plates are used for **radiotherapy equipment protection, imaging device components** , etc., their contact safety with the human environment needs to be evaluated;
- **Record and document management** : Establish detailed quality records, traceability information and customer complaint handling mechanism;
- **Risk management** : covering the design, production, storage and recycling of the product life cycle.

3. Application scenarios

alloy plates used **in medical accelerator protection components, X-ray shielding, nuclear medicine carrier devices** , etc. need to establish production control and quality review processes based on ISO 13485.

3. NQA-1 / ASME / RCC-M: Quality requirements for the nuclear energy industry

1. Overview of Nuclear Energy Industry Standards

- **NQA-1 (Nuclear Quality Assurance)** : Developed by ASME (American Society of Mechanical Engineers), it is the quality assurance standard for nuclear facilities and nuclear-grade material supply;
- **ASME Sec III** : Technical standards for the design, manufacture, and inspection of nuclear energy system equipment and materials;
- **RCC-M (French Nuclear Island Structural Design and Manufacturing Code)** : Used for material and structural assessment of European nuclear power projects.

2. Application and quality requirements of tungsten alloy plates

Tungsten alloy plates are commonly used in the nuclear energy field:

- Nuclear power core shielding structure;
- control rods and neutron absorber components;
- Containers for transport and storage of radioactive materials.

3. Key quality control factors

Control Dimension	Request Description
Material composition	Strictly limit radioactive impurities and neutron-activated substances (such as boron, cobalt, etc.)
Mechanical properties	Meet the requirements of high temperature strength and creep resistance in irradiation environment
Nondestructive Testing	All tungsten alloy plates must undergo comprehensive non-destructive testing such as UT, RT, and magnetic powder
File Integrity	Traceable quality files and third-party assessment reports must be retained for more than 20 years

IV. System Integration and Certification Practice Suggestions

System Name	Applicable areas	Recommended Practices
AS9100	Aerospace	Establish professional document process and engineering change control system
ISO 13485	Medical Devices	Optimize cleaning controls, supply chain validation, and biosafety assessments

NQA-1 / ASME	Nuclear power engineering	Strengthen the quality record system and accept third-party authorization, certification and supervision

Enterprises can achieve standard integration and cost optimization through **Integrated Management System (IMS)**, such as using ISO 9001 as a general framework and adding AS9100 or ISO 13485 modules to improve management efficiency.

V. Summary

tungsten alloy plates in the fields of aviation, nuclear energy, and medical treatment relies on a complete set of strict quality management systems covering design, materials, manufacturing, and after-sales service. Standards such as AS9100, ISO 13485, and NQA-1 are not only a symbol of product quality, but also an important pass to open up the international market. If China's tungsten alloy industry wants to achieve high-end and internationalization, it must start with system construction and build a full-process quality assurance mechanism that is in line with global technical standards.

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Precision customization: support high density (17-19 g/cm³), special performance, complex structure, super large and very small parts design and production.
Quality cost: optimized design, optimal mold and processing mode, excellent cost performance.
Advanced capabilities: advanced production equipment, RMI, ISO 9001 certification.
100,000+ customers
Widely involved, covering aerospace, military industry, medical equipment, energy industry, sports and entertainment and other fields.
Service commitment
1 billion+ visits to the official website, 1 million+ web pages, 100,000+ customers, 0 complaints in 30 years!

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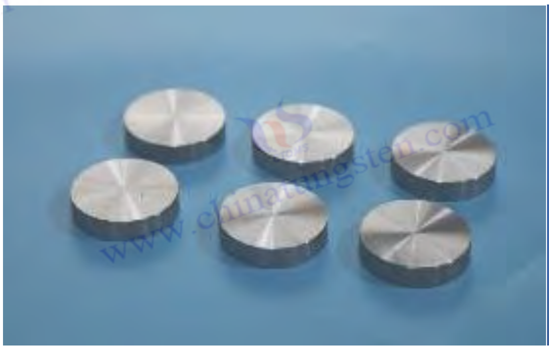
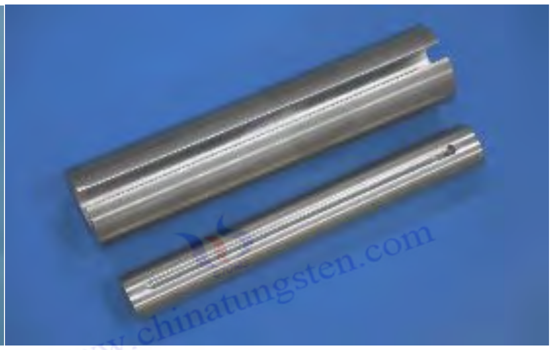

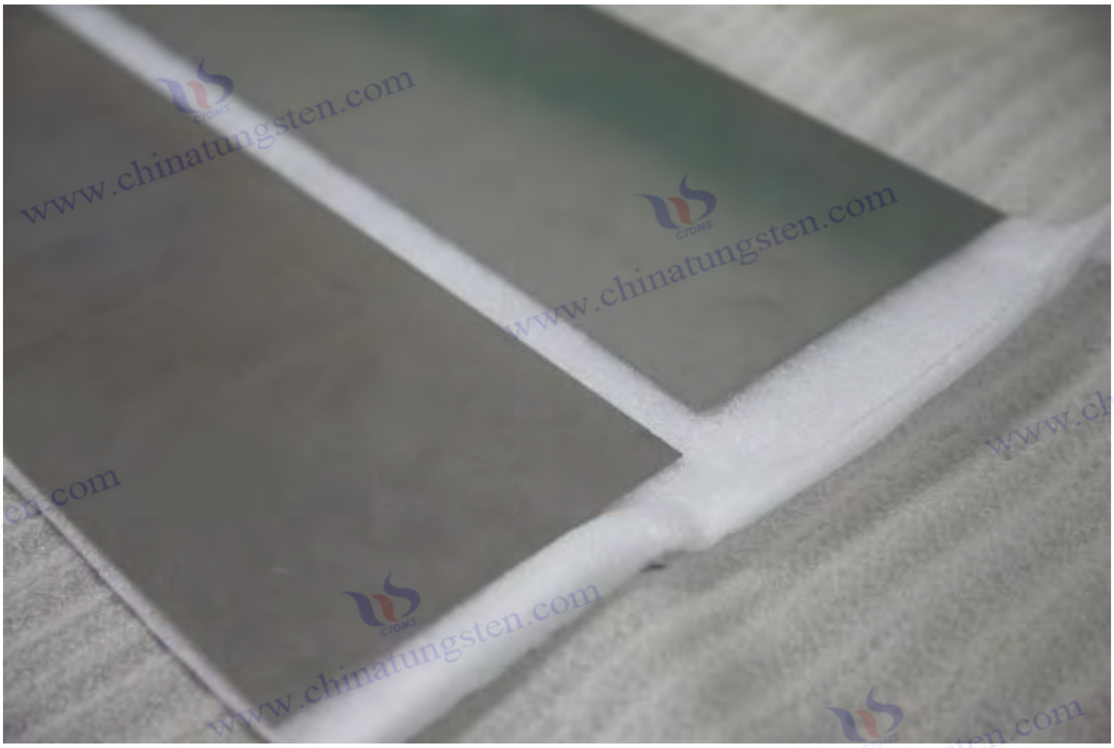

Chapter 8 Packaging, Storage and Transportation of Tungsten Alloy Plates

8.1 Packaging materials and forms (vacuum packaging, desiccant, tray packaging)

Tungsten alloy plates have high density, high added value, and extremely high requirements for surface quality and precision. After production and testing, the packaging process is not only a simple step in the logistics process, but also an important means to ensure its quality stability and appearance integrity during transportation, storage and delivery. Reasonable selection of packaging materials, scientific packaging forms, and effective isolation of environmental factors are crucial to ensure that tungsten alloy plates do not suffer from oxidation, corrosion, mechanical damage, deformation, and other problems during transportation.

1. Basic principles and objectives of packaging

The packaging of tungsten alloy plates should follow the following basic principles:

- **Anti-oxidation, moisture-proof, dust-proof and mechanical shock-proof** ;
- **Easy to carry, stack and transport** ;
- **Comply with international trade and customs regulatory requirements** ;
- **Clear identification and strong traceability** ;
- **Green, environmentally friendly and recyclable materials are preferred** .

Packaging not only serves logistics needs, but should also be included in the management of the entire production process as part of the product delivery quality control system.

2. Commonly used packaging materials and their functions

Material Type	Main Function	Application Notes
Polyethylene (PE) film	Moisture and dust proof	Used to coat the surface of tungsten plates to prevent oxidation and particle adhesion
Vacuum aluminum-plastic composite film	Moisture-proof and anti-oxidation	Tungsten alloy plate vacuum packaging for long term storage or export
Foam gasket/EPE pearl cotton	Cushioning and shockproof	Place in the gap between the plates to prevent friction or breakage
Desiccant (silica gel/molecular sieve)	Moisture absorption and dehumidification	Place in sealed packaging to maintain a dry environment
Wooden pallets (fumigation or fumigation-free)	Support and handling	Carrying tungsten alloy plate finished products, convenient for forklift loading and unloading and container shipping
Sealing tape/stretch film	Fixed outer packaging structure	Prevent sheet slippage and packaging cracking

3. Typical packaging form of tungsten alloy plate

1. Vacuum packaging

Suitable for long-term storage, export transportation or when customers have extremely high requirements on surface quality.

- Use aluminum-plastic composite film to seal single or multiple tungsten plates in a bag;
- Put in a desiccant (usually silica gel, molecular sieve or activated carbon) before sealing;
- Evacuate to above -0.08 MPa and heat seal;
- Can be used with gas replacement (such as nitrogen) to improve corrosion resistance;
- The exterior is protected by hard cartons or wooden boxes to prevent overall collision.

Advantages: Effectively isolate air and moisture, and extend the shelf life of the bright surface of the tungsten plate.

2. Stacked packaging (inter-board buffering + plastic sealing)

- Place 1~2mm thick foam or pearl cotton between each tungsten alloy plate;
- The whole stack is wrapped with PE stretch film or composite plastic film;
- If conditions permit, add cardboard to strengthen the protection of the board surface;
- Suitable for passivated boards or short-term transportation.

Advantages: strong buffering, convenient operation, low cost, suitable for domestic distribution.

3. Pallet packing and wooden box packing

Used for bulk shipments, especially suitable for export and sea freight conditions.

- The whole board is placed on a wooden pallet (it needs to be fixed with strapping tape);
- Additional wooden box or steel side box protection;
- A high load-bearing pallet or reinforced structure must be selected according to the weight;
- There must be forklift holes at the bottom of the pallet to facilitate loading and unloading.

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Export packaging wood must comply with **ISPM 15 international phytosanitary standards** and use heat-treated or fumigation-free materials.

4. Packaging identification and label management

Scientific packaging label management is not only a component of quality management, but also an important means to prevent logistics errors and customer identification confusion. It should include the following basic information:

- **Product name, specification, model, quantity, batch number** ;
- **Net weight, gross weight, dimensions, packaging date** ;
- **Manufacturer's name and contact information** ;
- **Compliance marking** : such as RoHS, REACH, MSDS number **;**
- **Transportation signs** : icons such as moisture-proof, pressure-proof, upward, and center of gravity;
- **Customer customization information** (such as project number, order number, etc.).

Barcode or QR code systems can be used to support intelligent traceability management.

5. Special packaging requirements and customized services

In high-end customized orders, some customers (such as nuclear energy agencies, aerospace companies, and scientific research institutions) will put forward the following special packaging requirements:

- **Clean packaging** : vacuum packaging is completed in a Class 1000 clean room;
- **Multi-layer metal bag vacuum protection** : prevents radioactive protective materials from penetrating or absorbing moisture;
- **Anti-static packaging** : used for tungsten alloy plates for electronic equipment;
- **Combined packaging solution** : various sizes of classified packaging, sleeve tube fixed structure.

a standard packaging solution database and **customized packaging response mechanism** based on customer needs .

VI. Summary

tungsten alloy plates is not only related to the appearance and safety of the product, but also to the stability of material quality and customer satisfaction during transportation. By selecting appropriate packaging materials, structural forms and label management systems, and combining differentiated designs with customer industry characteristics, transportation risks can be effectively reduced, and corporate brand image and export capabilities can be enhanced. As the threshold for international market access increases, green packaging, intelligent identification and standardized pallet systems will become important directions for the development of tungsten alloy plate packaging.

8.2 Storage environment requirements and anti-oxidation and moisture-proof measures

a high-density, high-precision, high-value-added material, tungsten alloy plates are prone to **surface oxidation, corrosion spots, dimensional expansion or packaging failure due to environmental**

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humidity, oxygen exposure, dust pollution or temperature changes if not properly managed during storage after production , which seriously affects their availability and customer satisfaction. Therefore, it is very important to establish scientific and standardized storage environment standards and practical moisture-proof and anti-oxidation measures to ensure the quality and safety of tungsten alloy plates in the short-term or long-term storage.

1. Basic requirements for storage environment

tungsten alloy plates should meet the following control indicators:

Control factors	Recommended range	illustrate
temperature	5°C～30°C	Avoid sudden temperature fluctuations, condensation or thermal expansion
relative humidity	≤ 50% RH	Too high relative humidity will accelerate tungsten surface oxidation and hydrogen corrosion
Air cleanliness	Dust-free or low-dust environment (ISO Class 8 or above)	Prevent dust particles from adhering, avoid mechanical scratches and conductive pollution
Direct sunlight	avoid	UV exposure may cause surface discoloration or material aging
Corrosive gas	Prohibited (such as NH_3 , Cl_2 , H_2S , etc.)	Sulfur and chlorine-containing gases will react slowly with tungsten
Air flow	Good ventilation but not strong vents	Keep the air dry and prevent moisture accumulation

If the enterprise has the conditions, it can set up a constant temperature and humidity warehouse or a clean warehouse to achieve long-term and precise storage management of high-end tungsten alloy plates .

2. Common anti-oxidation technologies and measures

Although tungsten itself has good chemical stability, tungsten alloy plates (especially alloys containing binder metals such as Ni and Cu) may still experience slight oxidation or electrochemical corrosion **in humid or oxygen-rich environments . Therefore, the following measures should be taken to improve oxidation resistance:**

1. Surface passivation treatment

- After pickling, alkali washing or neutral washing of the tungsten alloy plate, use a passivating agent to treat it;
- It can form a dense protective film on the surface to inhibit the reaction between oxygen and water;
- Common passivators include citric acid, chromates, phosphates, etc.;
- It is particularly suitable for processing finished products before leaving the factory to improve storage stability.

2. Vacuum or nitrogen sealing

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- Vacuum seal or nitrogen-fill the finished tungsten alloy plate to prevent the intrusion of oxygen and water vapor;
- Suitable for plates with extremely high requirements for smoothness and surface condition;
- It is usually used together with aluminum-plastic composite bags and high barrier films.

3. Micro-oil coating method (sealed oil)

- Lightly apply neutral sealing oil on the surface of the board to form a physical isolation layer;
- Can effectively isolate direct contact with oxygen, water vapor and sulfide in the air;
- It can be cleaned with alcohol or alkaline water before use;
- Commonly used for medium- and long-term storage of industrial-grade tungsten plates .

3. Moisture control measures and humidity management

If tungsten alloy plates are stored in a humid environment, they are prone to surface darkening due to "water vapor adsorption-slow oxidation" and even intergranular corrosion. Moisture-proof measures must be implemented simultaneously in three aspects: packaging, storage equipment, and environmental control:

1. Add desiccant in the packaging process

- Use drying materials such as silica gel packs and activated mineral adsorbents;
- The desiccant needs to be placed in a vacuum bag or sealed box;
- Check the desiccant regularly to see if it is saturated and replace it if necessary.

2. Use dehumidifier/constant humidity air conditioner to control the humidity in the warehouse

- storage area for tungsten alloy plates;
- 24-hour operation is especially necessary in rainy season or plum rain climate;
- Maintaining RH $\leq$ 50% is especially important for bright surface tungsten alloy plates.

3. Elevated storage space/moisture-proof pad

- Tungsten alloy plates should **avoid direct contact with the ground** or wall;
- Use pallets, shelves, and wooden frame structures for support, with moisture-proof partitions at the bottom ;
- Prevent moisture and condensation from affecting the tungsten plate .

4. Tiered Storage Strategy and Cycle Control

According to the different uses and storage periods of tungsten alloy plates, a hierarchical management strategy should be formulated:

Classification	Typical Uses	Recommended storage method	Recommended storage period
High-purity board	Medical, nuclear energy, electronic devices	Vacuum seal + desiccant + constant humidity chamber	12-18 months
Standard industrial board	Molds and mechanical structures	PE coating + drying oven	6-12 months
Temporary turnover board	For internal processing	Ordinary packaging, short-term storage	≤ 3 months

Plates with a long cycle need to be regularly inspected for surface condition and dimensional stability to ensure that they still meet performance requirements before use.

V. Summary

tungsten alloy plates is a systematic management task. It is necessary not only to pay attention to the physical properties of the material and the sensitivity of the alloy composition to the environment, but also to formulate a moisture-proof and anti-oxidation strategy with strong adaptability and high operability in combination with storage facilities, climate conditions and use cycles. With the continuous improvement of global standards for the storage and transportation of high-performance materials, companies are in urgent need of establishing a complete **storage risk assessment mechanism** and **inventory quality monitoring system** to ensure the stability, reliability and consistency of tungsten alloy plates throughout the supply chain.

8.3 Domestic and International Transportation Precautions and Regulations

As a metal material with high specific gravity, corrosion resistance and high added value, the transportation of tungsten alloy plates is not only related to physical safety and economic losses, but also to customer delivery cycles, international compliance management and brand reputation. Especially in complex scenarios such as cross-border trade, air transportation, and sea container transportation, if the transportation method or declaration process is not standardized, it is very easy to cause problems such as plate damage, rust, misdeclaration, and even return. Therefore, it is very important for material suppliers, foreign trade personnel, and warehousing and logistics managers to master the key precautions and regulatory requirements during the transportation of tungsten alloy plates at home and abroad .

1. Basic Challenges and Risks of Tungsten Alloy Plate Transportation

Tungsten alloy plates mainly face the following problems during transportation:

- **Deformation and damage under high-density load** : The density of tungsten alloy plate can be as high as 17~19 g/cm³. If the support is unstable during long-term transportation, it is very easy to be squeezed, bent, and damaged at the corners;
- **Surface scratches and abrasions caused by vibration and shock** : Improper bundling in trucks and ship cabins may cause the plates to rub against each other or against the metal of the pallet;

- **Oxidation, condensation or hygroscopic expansion caused by changes in temperature and humidity** : especially when transported across climate zones without drying protection;
- **Incomplete export declaration materials lead to customs clearance delays or returns** : Customs has strict management over rare metal goods, and irregular declarations are prone to detention;
- **Differences in applicable transportation safety and environmental regulations** : For example, some European and American countries classify some tungsten alloys as strategic or military sensitive materials, which require special permission.

2. Domestic Transportation Precautions

tungsten alloy plates by land or air within China , the following points should be noted:

1. Packaging stability and stacking control

- Pallets should be made of solid wood or plastic with high load-bearing capacity and uniform bottom plate;
- tungsten alloy plates and use protective corner wraps at the four corners;
- Use nylon straps, shrink film or steel straps to prevent the whole package from slipping;
- other heavy objects on the tungsten plate to avoid squeezing and deformation.

2. Transport mode selection and route evaluation

- For high-value or precision tungsten plates, it is recommended to give priority to **special vehicle delivery, air express** or **low-vibration logistics channels** ;
- When transporting over long distances, avoid risk areas such as high temperature and high humidity seasons, concentrated long holidays, and bumpy roads in mountainous areas;
- We can cooperate with experienced third-party professional metal logistics companies, such as SF Express Large Cargo, Deppon Heavy Cargo, and Sinotrans Logistics.

3. Clear labeling and handling instructions

- The outside of the package must be printed with icons such as "Please hoist heavy objects", "Moisture-proof", and "Do not invert";
- If the total weight of the pallet exceeds 500 kg, it should be moved by forklift or crane. Manual forced unloading is strictly prohibited.

III. International Transport Standards and Compliance Management

1. Common export transportation methods

Mode of transport	Applicable Scenarios	Features
Ocean Freight (FCL/LCL)	Large-scale exports	The transportation cycle is long and moisture-proof treatment is required
Air freight (DHL, FedEx, SF Express)	Urgent order, light plate	High cost, aviation certification required
Railway/China-Europe Express	Economical and practical for export to Europe	The speed is medium, and customs clearance is required
International express (UPS, etc.)	Small batch samples	Convenient customs declaration, limited size and weight

2. Customs declaration standards and coding classification

Tungsten alloy plates are usually classified into the Chinese Customs Code (HS Code) as follows:

- **8101.99.10** : Tungsten alloy plates and sheets (unprocessed or pre-processed)
- **8101.99.90** : Other tungsten products (to specify alloy content and purpose)

The required documents for export include:

- Product invoice and packing list;
- Certificate of origin (e.g. Chinese products exported to the EU or RCEP member countries);
- Confirmation of customs code and standardized description of commodity name;
- If military, nuclear or high-tech uses are involved, **an export license** or **end-use statement may be required** .

3. Notes on shipping containers

- Try to use 20 -foot heavy cabinets (20GP) to load tungsten alloy plates, and avoid stacking and mixing in ordinary wooden boxes;
- Buffer space should be reserved between each plate pallet to prevent collision during long-distance transportation;
- Install desiccant packs and moisture-proof mats to ensure that the RH inside the container is less than 60%;
- Labels such as "High-density heavy metal product" and "Lifting point location" should be affixed to the outside of the cabinet door.

4. International Certification and Transportation Safety Compliance

If the product is exported to Europe, America, Japan, South Korea and other regions with high requirements, the following transportation compliance terms should be paid attention to :

- **MSDS Material Safety Data Sheet** : must indicate the physical and chemical properties of tungsten alloy and transportation and storage recommendations;
- **RoHS / REACH Description** : Certifies that the product does not contain harmful heavy metals or organic pollutants;
- **Declaration of applicable regulations for transportation (non-dangerous goods)** : Most tungsten alloy plates are not classified as dangerous goods, but a material stability statement is required to facilitate customs clearance;
- **UN packaging mark or non-UN piece description** : as required to indicate that the transported article does not involve items on the United Nations Dangerous Goods List.

IV. Transport Accident Prevention and Insurance Mechanism

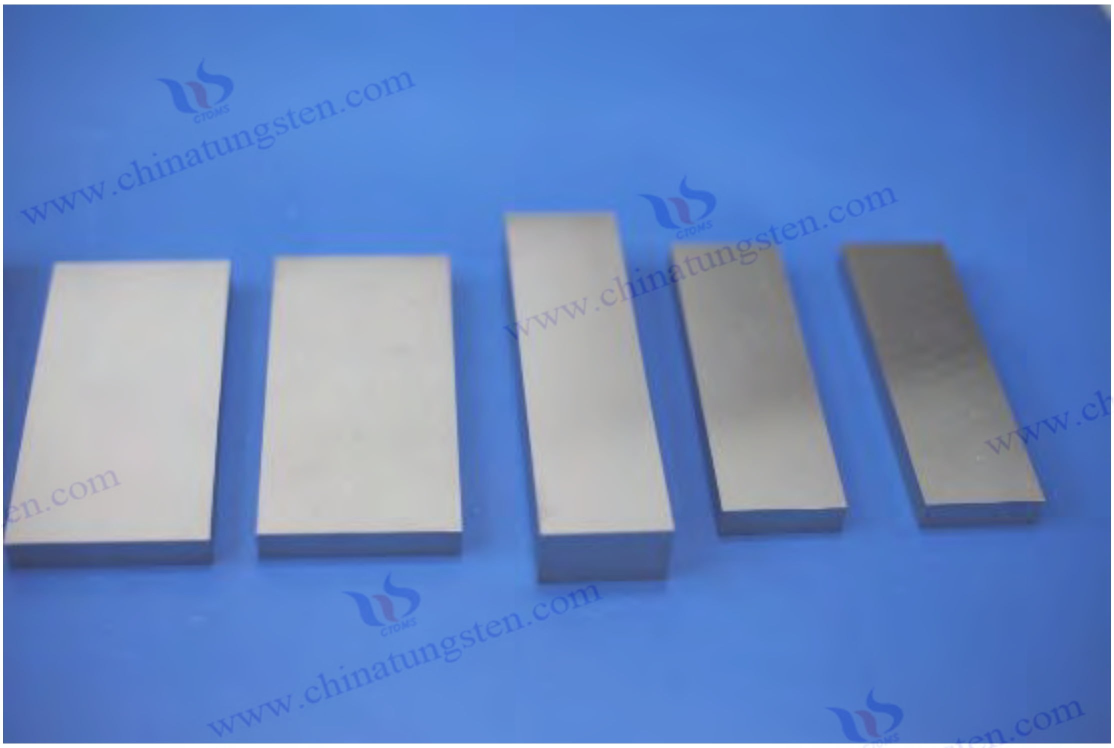
tungsten alloy plates are damaged, lost, or misdelivered during transportation , it often involves significant economic losses. Therefore, it is recommended to establish a risk response mechanism:

- **Take photos and archive them before leaving the factory** : record the status of the finished product as a basis for logistics claims;
- **Full transportation insurance** : You can choose "full value transportation insurance" to cover loss, damage, delayed delivery, etc.
- **Logistics Cooperation Agreement** : Sign a contract with the transport company to clearly define the boundaries of responsibilities and avoid ambiguity in responsibilities;

- **Use GPS logistics tracking system** : Real-time monitoring of transportation routes for key orders.

V. Summary

tungsten alloy plates is one of the links in the entire supply chain that is most susceptible to environmental and management impacts. From domestic to international, from packaging methods to declaration processes, multi-dimensional coordination is required to ensure that it is "safe, compliant, and efficient" in terms of physics, regulations, and customer experience . For export-oriented companies, establishing a mature transportation standard system, customs declaration document template library, and logistics risk response mechanism will significantly enhance customer trust and market delivery capabilities.



Chapter 9 Industrial Structure and Market Trend of Tungsten Alloy Plate

9.1 Global Tungsten Resource Status and Plate Processing Chain

Tungsten is a strategic rare metal. It is widely used in key fields such as national defense, aerospace, nuclear energy, electronics and medical treatment due to its high melting point, high density, high hardness and good thermal, electrical and mechanical properties. Tungsten alloy plate is an important part of tungsten deep processing products and a key intermediate to achieve high performance, structural and functional application of tungsten materials. The development of its industrial chain is closely related to the global distribution of tungsten resources.

1. Global tungsten resource distribution and reserve pattern

According to the 2024 statistics of the United States Geological Survey (USGS), the world's proven tungsten reserves are approximately 3.5 million tons of metal, with distribution showing **regional concentration and country-led** characteristics:

Country/Region	Tungsten ore reserves (10,000 tons)	Global share	Main mining areas
China	190	About 54%	Dayu, Jiangxi, Shizhuyuan , Hunan , Luanchuan, Henan
Russia	120	About 34%	Trans-Baikal region, Far East
Vietnam	9	< 3%	Perey Mine

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Bolivia	5	< 2%	Oruro Province
Other countries (Portugal, Austria, South Korea, etc.)	Less than 5%	More scattered	—

China is the world's largest owner and major producer of tungsten resources . It not only controls more than half of the mineral resources, but also dominates more than 70% of the world's tungsten raw material exports and primary processing capabilities, and has an important influence on the global tungsten industry chain.

2. Mining and primary smelting process of tungsten ore resources

Tungsten is mainly found in tungstate minerals, including wolframite (high WO_3 content), scheelite, and tungstenite. The industrial extraction process is as follows:

1. **Mining and ore dressing** : Underground mining and open-pit mining are used to obtain high-grade tungsten concentrate through gravity separation, flotation and electromagnetic separation ;
2. **Chemical conversion** : Tungsten concentrate is converted into **ammonium paratungstate (APT) or sodium tungstate** through alkali decomposition, acid precipitation and crystallization .
3. **Reduction smelting** : APT is reduced with hydrogen to produce high-purity tungsten powder;
4. **Preparation of powder for deep processing** : Tungsten powder is classified by particle size and used for powder metallurgy pressing or high temperature casting;

This process constitutes **the upstream resource base for tungsten alloy plate manufacturing** .

3. Production chain structure of tungsten alloy plates

tungsten alloy plates consists of "mineral resources → metallurgical purification → alloy design → plate forming → surface treatment → application integration", which can be divided into the following links:

1. Raw materials

- Including APT, metal tungsten powder, tungsten-nickel-iron alloy powder, tungsten-copper alloy powder, etc.;
- It requires high purity, controllable particle size and good distribution uniformity.

2. Alloying and pressing

- molybdenum and other bonding metals in proportion ;
- The slab is formed by compression molding or isostatic pressing.

3. Sintering and thermal processing

- High temperature sintering (1300~1600°C) in hydrogen or inert atmosphere;
- Subsequent secondary processing processes include hot rolling, hot isostatic pressing, vacuum treatment, etc.

4. Plate surface finishing and performance optimization

- Including polishing, pickling, electroplating, physical vapor deposition (PVD), etc.
- To improve surface finish, thermal conductivity, oxidation resistance and other properties.

5. Downstream integrated applications

- Aerospace structural parts, radiation protection armor, radiotherapy masks, high-temperature vacuum furnace structural parts, electronic cooling components and other fields.

4. Characteristics of the global industrial chain division of tungsten alloy plates

tungsten alloy plates reflects obvious characteristics of **global division of labor and regional coordination** :

- **China** : It has the most complete tungsten industry chain, including mining, smelting, alloying and plate forming, and is the world's main supply source;
- **European and American countries** : They are good at high value-added applications, military technology and testing standard systems. Some special tungsten alloy plates rely on imports or custom processing;
- **Japan and South Korea** : Specializes in precision tungsten alloy processing, vacuum heat treatment, and surface coating technology. Products are used in high-end electronics and medical industries.
- **Developing countries** (such as Vietnam and Bolivia): rich in resources but weak in processing capabilities, mainly serving as raw material export destinations.

V. Summary

tungsten resources determine the high threshold and high technology content of the tungsten alloy plate industry . As the world's largest tungsten resource country and processing center, China has advantages in the entire chain from mines to plates, but it also faces multiple challenges such as **upgrading of technical standards, diversification of downstream demand, and intensified international market competition** . In this context, building a green, efficient, and high-value-added tungsten plate processing system and expanding the international high-end market will become the core direction of future development.

9.2 Tungsten Alloy Plate Market Capacity and Future Growth Analysis

tungsten deep-processing products, tungsten alloy plates have an irreplaceable position in many high-end fields due to their excellent physical and chemical properties. In recent years, with the high-end global manufacturing industry, military industry and energy security strategy drive, as well as the growth of emerging market demand such as medical and electronics, the market capacity of tungsten alloy plates has shown a steady expansion trend. This section will analyze the production capacity, demand structure, market growth drivers and future development trends of tungsten alloy plates from the two levels of the global and Chinese markets.

1. Global Tungsten Alloy Plate Market Overview

According to data from the International Tungsten Industry Association (ITIA) and several market research institutions, by 2024, the global tungsten alloy plate market capacity will be approximately US **$1.4 to US$1.6 billion** , with an average annual compound growth rate of **6% to 8%** , and will exhibit the following characteristics:

1. Diversified market structure

Tungsten alloy plates are widely used in many fields, including national defense, aerospace, energy, medical treatment, mechanical manufacturing and precision electronics.

Industry	Proportion (estimated in 2024)
Aerospace and military	30%
Nuclear energy and new energy	20%
Medical Radiation and Shielding	15%
High-temperature metallurgy and equipment manufacturing	10%
Semiconductor and Electronic Packaging	15%
Others (molds, scientific research, etc.)	10%

Especially in **radiation protection plates, heat dissipation structure plates, and high-temperature thermal field components** , tungsten alloy plates have advantages that cannot be replaced by traditional materials such as lead, steel, and copper.

2. The proportion of high value-added products increased

As the application fields tend to be more precise and functional, the market demand for high-purity, high-strength, and high-density tungsten alloy plates continues to rise. The proportion of products including nanostructured plates, functional gradient materials, and coated composite plates is increasing year by year.

2. Development Trend of Tungsten Alloy Plate Market in China

As the world's largest tungsten resource and producer, China's tungsten alloy plate industry has transformed over the past decade from a "resource export" to a "material deep processing" industry. Currently, China's tungsten alloy plate market is estimated to exceed **3 billion RMB (approximately US$400 million)** and continues to expand in the following areas:

1. Strong demand for high-end equipment manufacturing

National strategies such as "High-end Manufacturing 2025" and "Military-Civilian Integration" have promoted the strong growth of tungsten alloy plates in the following fields:

- Hypersonic vehicle counterweight and heat protection structure;
- Nuclear power core protection and neutron absorption plates;
- Precision shielding components in radiotherapy and CT imaging systems;
- Thermal isolation components in laser processing equipment and plasma equipment.

2. Rapid expansion of production capacity and continuous technological iteration

A number of key enterprises represented by China Tungsten High-Tech, AVIC Matt, Xiamen Golden Heron, CTIA GROUP LTDand other enterprises have continued to increase investment in the field of tungsten alloy plates , and have laid out the following:

- High-density powder metallurgy plate production line;
- Vacuum hot-rolled plate production line;
- Surface coating composite process line;
- High-purity precision plate production system for medical nuclear protection plates.

This series of investments not only improved the domestic market supply capacity, but also enhanced the international export competitiveness.

3. Core driving force of market growth

tungsten alloy plate market is mainly driven by the following aspects:

1. Emerging application demands continue to emerge

For example, third-generation nuclear energy, nuclear fusion devices, aerospace nuclear power, extreme high-temperature metallurgy, and high thermal conductivity materials for electronic chip packaging all put forward higher performance requirements for tungsten alloy plates and drive the growth of its material demand.

2. Global manufacturing reshoring and domestic substitution strategy

Manufacturing powerhouses such as the United States, Germany, and Japan are promoting the return of high-end industries and continuously purchasing tungsten-based functional materials ; at the same time, China is carrying out domestic substitution of "bottleneck materials" and accelerating breakthroughs in high-performance tungsten alloy plates in key areas.

3. Material upgrades brought about by green environmental protection policies

Under the restrictions of environmental regulations such as RoHS and REACH, tungsten alloy plates have obvious advantages as lead substitutes in radiation protection and electronic materials, and their market penetration rate continues to increase.

IV. Market Growth Forecast for the Next Five Years (2025-2030)

Taking into account global policy guidance, downstream demand intensity, and technological evolution speed, the tungsten alloy plate market is expected to maintain **a medium-to-high growth trend in the next five years** :

years	Global market size (billion US dollars)	China market size (100 million yuan)	Notes
2024	15.5	30	Current Estimates
2025	16.8	34	Demand for nuclear energy and electronics has grown significantly
2026	18.5	39	Medical and new energy drive the release of new production lines
2027	20.3	44	Multi-element alloys and intelligent manufacturing integration

2028	22.0+	50+	Nano-sheets and composite functional materials are becoming more and more popular

Among them, **high-density protective panels for medical use** , **superconducting electronic cooling structure panels** , and **laser thermal protection coating panels** will become the fastest growing market segments.

V. Summary

Tungsten alloy plates are becoming increasingly prominent in the global high-end manufacturing industry, especially playing a key role at the intersection of strategic materials and functional materials. With the continuous expansion of application scenarios, the continuous improvement of performance standards, and the continuous strengthening of green requirements, the market for tungsten alloy plates will evolve towards **high precision, high functionality, and high efficiency** . Seizing the window of industrial chain upgrading and global demand will be the key to success for tungsten alloy plate companies in the next five years .

9.3 CTIA GROUP LTD Tungsten Alloy Plate

As an important promoter in the field of new tungsten alloy materials in China, CTIA GROUP LTD focuses on the research and development, production and industrial application of tungsten and its alloy deep processing materials. Especially in the field of tungsten alloy plates, the company has established a systematic and complete technical system and product matrix, with strong technical integration capabilities, equipment development capabilities and industry influence, and occupies an important position in the domestic high-end tungsten alloy plate market.

1. Corporate Overview and Strategic Positioning

CTIA GROUP LTD is positioned as a "high-performance tungsten alloy material solution provider". Relying on China's industrial advantages in tungsten resources, metallurgical technology, powder metallurgy equipment, etc., it focuses on the systematic development of **high-density tungsten alloys, high-purity tungsten plates, and special-shaped tungsten alloy structural parts** . Its products widely serve high-end fields such as aerospace, nuclear energy engineering, medical equipment, high-temperature equipment, and precision electronics.

The company focuses on differentiated competitive strategies and focuses on the following strategic directions:

- **substitution of high-end tungsten plates : Achieve domestic breakthroughs** in tungsten plate varieties that rely on imports , such as nuclear shielding plates, precision thermal control plates, medical protection plates, etc.;
- **Diversified customized services** : We can develop different alloy systems (such as W-Ni-Fe, W-Ni-Cu, W-Mo-Ti, etc.) and size specifications of plates according to customer requirements;
- **Intelligent process upgrade : Promote** the construction of integrated intelligent production lines for powder processing - pressing - sintering - rolling - finishing ;

- **Green manufacturing and compliant exports :** Strictly follow environmental protection systems such as RoHS, REACH, ISO14001, and establish quality channels for international markets such as Europe, America, Japan and South Korea.

2. Main tungsten alloy plate product system

China Tungsten Intelligence mainly cover the following types:

Board Category	Alloy system	Typical density (g/cm^3)	Application Areas
High specific gravity tungsten plate	W-Ni-Fe, W-Ni-Cu	17.0~18.5	Aerospace, inertial components, balancing weights
Medical protective plate	W-Ni-Cu non-magnetic type	17.0~17.8	Radiotherapy equipment, CT radiation protection
Nuclear Engineering Shielding Panel	W-Mo, W-Re	18.0~19.0	Nuclear reactor protection , neutron absorption structure
Precision heat sink	High purity W or W-Cu	17.5~19.0	Microelectronics heat sink, packaging substrate
Ultra-high temperature structural panels	W-Ti-Cr	18.0~18.8	Thermal field components, reaction device lining
Functionally graded plates	W-FGM composite structure	Designable	Multifunctional laminated structure

The product size range covers **thickness 0.3mm ~ 50mm, width 10mm ~ 300mm, length 20mm ~ 1500mm** , and special-shaped plates, perforated plates, grooved plates, coated plates and other structural parts can be customized according to drawings.

3. Core Technology Advantages

CTIA GROUP LTD's technical advantages in the field of tungsten alloy plates are mainly reflected in the following aspects:

1. Powder preparation and grading control

- Independently developed a multi-stage reduction tungsten powder preparation process;
- Achieve particle size control within the range of 0.5~10μm and support customized distribution parameters;
- Optimize the active dispersion mechanism according to different alloy system ratios.

2. Multi-process path forming capability

- Compression molding: suitable for regular sizes and mass production;
- Isostatic pressing: used for high density and complex shape requirements;
- Hot rolling + vacuum annealing: improve plate uniformity and processing performance;
- Surface grinding/pickling/vacuum PVD composite treatment meets multiple performance requirements such as thermal conductivity and corrosion resistance.

3. Intelligent production system

- Introducing the MES management system to achieve data traceability throughout the entire production process;
- Establish an automatic plate defect image recognition system;
- Self- developed low oxygen content protection device to improve the purity of the board.

IV. Industry Cooperation and Market Application Results

CTIA GROUP LTD's tungsten alloy plates have been widely used in many key domestic projects and corporate projects, including:

- Jointly developed ultra-high density plates for inertial counterweights with **China Aerospace Science and Technology Corporation ;**
- Provide nuclear-grade shielding plates for **CGN and CNNC Engineering ;**
- tungsten alloy protective plates to medical equipment manufacturers such as **Shanghai United Imaging and Mindray Medical ;**
- Provide thermal conductive tungsten plates and heat dissipation composite structural parts to **Huawei, BYD Electronics , etc.**

V. Development Challenges and Prospects

Although CTIA GROUP LTDhas established a solid position in the domestic market, it still faces the following challenges in the future:

- High-purity raw materials rely on imports and are subject to cost constraints;
- There is still a gap between us and international giants in terms of testing systems and technical barriers;
- Basic research in special areas such as neutron absorption and high-frequency heat dissipation needs to be strengthened.

To this end, the company will focus on the following directions:

- Build **our own production line for high-purity powder** to reduce costs and control risks;
- Deeply cooperate with scientific research institutes to promote the cutting-edge research and development of **tungsten functional plates** ;
- Strengthen customized collaboration with end customers and develop an integrated solution of "tungsten plate + processing + packaging + application".

VI. Summary

tungsten alloy plate industry, CTIA GROUP LTDis evolving from a traditional materials manufacturer to a comprehensive solutions provider. Its continuous optimization of product lines, process capabilities, and application development has not only elevated the overall quality of domestically produced high-performance tungsten plates , but has also injected new momentum into the global tungsten alloy plate industry through the "China Production Capacity + China Intelligent Manufacturing" strategy.

9.4 Analysis of the linkage between raw material costs, energy prices and plate prices

tungsten alloy plates is jointly affected by upstream raw material price fluctuations, energy consumption costs, manufacturing process complexity, and downstream demand fluctuations. Among them, raw materials (tungsten powder, binder metal), energy (electricity, atmosphere gas), equipment investment and labor costs occupy a core position in the cost structure of tungsten plates . This section will deeply analyze the internal mechanism of tungsten alloy plate price formation, and explore the transmission path and response cycle of raw material and energy price changes to tungsten alloy plate market prices.

1. Cost Structure Analysis of Tungsten Alloy Plate

Generally speaking, the manufacturing cost of tungsten alloy plate consists of the following parts:

Cost components	Percentage range (typical estimate)
Raw material costs (APT, tungsten powder, Ni/Cu/Fe)	45% ~ 60%
Energy consumption (electricity, hydrogen, inert gas)	10% ~ 20%
Process Manufacturing and Equipment Depreciation	10% ~ 15%
Labor and management costs	5% ~ 10%
Surface treatment and quality inspection	5% ~ 10%

It can be seen that **raw material prices** and **energy consumption** are the main variables that dominate the price fluctuations of tungsten alloy plates .

2. Transmission mechanism of APT and tungsten powder price to plate price

1. Impact path of upstream raw material price fluctuations

tungsten alloy plate is mainly APT (ammonium paratungstate), which is reduced by hydrogen to obtain tungsten powder, and then Ni, Cu and other bonding metals are added. The price of APT is closely related to the price of tungsten concentrate, and has certain periodicity and suddenness. The price fluctuation of tungsten powder will be transmitted to the terminal price of tungsten alloy plate through the following paths:

Tungsten concentrate price ↑ → APT price ↑ → Tungsten powder price ↑ → Alloy powder cost ↑ → Plate unit price rises

a lag period of about 2 to 4 weeks in this transmission process , but if it is a long-term trend change, manufacturing companies often reduce risks by signing quarterly/annual procurement contracts and adjusting inventory strategies.

2. Synergy of bonding metal prices

- **Nickel (Ni) prices fluctuate widely** and have been significantly affected by the demand for new energy (batteries) in recent years;
- **The prices of copper (Cu) and iron (Fe) are closer to the cyclical fluctuations of industrial metals** , but their overall fluctuations have less impact than tungsten powder.

Although the cost changes of binder metal are not as drastic as those of tungsten powder, its fluctuations in bulk alloy plates (such as W-Ni-Cu system) will also significantly affect the terminal pricing.

3. The impact of energy prices on sheet production costs

tungsten alloy plates is a highly energy-intensive process, with the main energy consumption concentrated in:

- **Sintering stage in hydrogen protective atmosphere** ;
- **High temperature electric furnace required for hot rolling and annealing** ;
- **Compressed air, cooling water and electrolyte maintenance required for cold processing and surface treatment** .

energy on tungsten plate prices is as follows:

Electricity and hydrogen prices ↑ → Unit energy cost of sheet metal ↑ → Marginal cost of sheet metal production ↑ → Market price rises

Taking the changes in industrial electricity prices in some provinces of China from 2022 to 2024 as an example, a 15% to 30% increase in electricity prices can increase the unit energy consumption cost of tungsten alloy plates by 3% to 5%, especially for companies using vacuum electric furnaces and isostatic pressing sintering processes.

4. Tungsten Alloy Plate Price Fluctuation Cyclicity and Market Linkage

tungsten alloy plates shows the following **regular characteristics** :

1. Cyclical type: the superposition effect of raw material cycle and industrial inventory

- When APT or tungsten powder enters the rising channel, enterprises prepare materials in advance, which drives up the price of plates;
- When downstream demand is insufficient and inventory is piling up, plate prices will fall with a lag.

2. Structural type: price differentiation between high-end panels and standard panels

- high-purity, high-density, thin plates, and small-size customized plates fluctuate more and are more affected by labor and energy consumption;
- Standard panels have strong economies of scale and relatively stable prices, making them easy to become industry reference prices.

3. Regional: Different countries have different price transmission mechanisms

- China mainly uses cost-based pricing, and prices are strongly affected by the linkage between APT and energy;
- European and American companies tend to adopt long-term supply agreements and functional pricing (such as pricing based on radiation shielding efficiency), which makes price fluctuations more "blunt".

5. Summary and Trend Outlook

tungsten alloy plate pricing reflects a triple-linked relationship: **raw materials play a leading role, energy plays a synergistic role, and the market plays a regulatory role** . It is expected that over the next five years, with the tightening of global tungsten resource strategies and the continued high prices of electricity and hydrogen, tungsten plate prices will continue to fluctuate within a "high-level fluctuation and structural differentiation" pattern.

Tungsten alloy plate manufacturers should:

- Strengthen the purchasing, bargaining and reserve capabilities of APT and tungsten powder;
- Improve process energy efficiency and equipment automation ratio;
- Avoid price risks through functional pricing and differentiated product strategies.

Only in this way can we achieve stable profits and enhance market risk resistance in a volatile resource and energy environment.

9.5 Technical Barriers and Industry Chain In-depth Development Strategy

As a representative of high-end metal functional materials, tungsten alloy plates are widely used in nuclear protection, aerospace, medical equipment, precision electronics, high-temperature manufacturing and other fields, which have extremely high requirements for performance, precision, consistency and reliability. Therefore, there are significant technical barriers and entry barriers in this field. At the same time, the global industrial chain is extending towards high-precision, customization and greening, which poses higher challenges to the integrated coordination capabilities of upstream, midstream and downstream.

This section will analyze the key barriers and strategic response plans of the tungsten alloy plate industry from the perspectives of technical thresholds, core process difficulties, upstream and downstream coordination mechanisms, domestic substitution bottlenecks, and in-depth development paths.

1. Analysis of key technical barriers of tungsten alloy plate

tungsten alloy plates involves multiple interdisciplinary disciplines such as metallurgy, thermal engineering, material science, and surface engineering. Its technical barriers are mainly reflected in the following aspects:

1. Raw material purity and powder control technology

- The production of high-performance tungsten alloy plates must be based on high-purity APT and the impurities (such as Mo, Si, P, O, C) must be controlled at the ppm level;
- The powder particle size distribution needs to be precisely controlled within the range of 1~10μm. Different particle sizes have a significant impact on the densification rate, sintering density, and organizational uniformity.
- Powder activity control (such as surface oxygen content) is directly related to the ductility of the sheet and the control of sintering shrinkage.

2. Sintering and densification technology

- High temperature and high pressure isostatic sintering equipment is expensive and complex to control;
- The control of hydrogen protective atmosphere requires precise adjustment of oxygen potential, flow rate and thermal field distribution;
- For special-shaped plates and extra-large-sized plates, there are problems such as difficulty in controlling sintering deformation and risk of stress cracking.

3. Plate rolling and heat treatment process

- tungsten alloy lead to a very narrow hot rolling window, which is prone to defects such as edge cracks, warping, and coarse grains;
- Cold rolling needs to be combined with intermediate annealing to prevent stress concentration from causing cracks;
- Precise control of sheet thickness, flatness, and tolerance (within ±0.02 mm) is a must for high value-added markets such as medical panels.

4. Surface treatment and composite function control

- High temperature oxidation, surface roughness control, and high requirements for electroplating/coating adhesion;
- Functionally graded panels and multi-layer composite panel technologies are still in the pilot stage and have not yet been commercialized on a large scale;
- Surface activity regulation (hydrophilic/hydrophobic, radiation resistance) still relies on imported high-performance membrane materials.

2. The main bottlenecks in the depth of tungsten alloy plate industry chain

1. The bottleneck phenomenon in the raw material link

- The production of high-purity APT and high-activity tungsten powder is still concentrated in a few leading companies, and the purity and stability of raw materials have a great impact on the yield of downstream products;
- Binder metals (such as Ni, Re, and Mo) are mostly imported or rely on small-batch smelting, are price sensitive, and have fragile supply chains.

2. Advanced equipment relies on imports

- Most of the key process equipment, such as high-temperature vacuum sintering furnaces, precision rolling mills, plasma PVD systems, and CT non-destructive testing equipment, rely on imports from Europe, the United States, Japan, and South Korea, and have problems such as long equipment maintenance cycles, technical confidentiality, and high upgrade costs.

3. Imperfect quality control system

- High-end customers (nuclear power, military industry, and medical) have extremely high requirements for consistency and batch-to-batch stability , but the quality systems of some domestic companies do not match;
- There is a lack of standardized non-destructive testing platforms and high-precision physical simulation systems.

3. International comparison: technology gap and breakthrough direction

project	Europe, America, Japan and South Korea (representative companies)	Current Situation in China (Representative Enterprises)	Gap direction

Plate purity and tissue uniformity	Plansee , Tosoh, Hitachi	CTIA GROUP LTDManufacturing	Control particle size consistency and sintering densification
Composite structural panels and functional integration	Toshiba、 MolyWorks	Most of them are experimental or military projects	PVD coating, FGM technology
Precision inspection and testing system	GE, Bruker, Zeiss	Dependence on some imports	High-end CT/NDT equipment
Military/Nuclear Quality Certification System	Perfect (AS9100, MIL-SPEC, ISO13485)	Accelerating progress	Most are still in the matching and conversion stage

4. Suggestions on the in-depth development strategy of the tungsten alloy plate industry chain

1. Upstream extension: Building self-sufficiency in high-purity tungsten powder and high-end binder metals

- Promote the integration of tungsten resource deep processing capabilities and enhance APT refining and multi-stage reduction capabilities;
- Support the construction of domestic production lines for rare and precious metal microalloy materials (such as Re and Ta) ;
- Build a complete production system for tungsten-based alloy powder to achieve integrated control of particle size/purity/fluidity.

2. Midstream breakthrough: intelligent production technology and independent development of key equipment

- Introducing intelligent control system to achieve closed-loop regulation of sintering-rolling-cold working-heat treatment;
- Overcome the problem of domestic substitution of isostatic pressing/vacuum sintering furnaces and promote digital integration of equipment;
- Build a "production line-level pilot + customer collaborative testing" platform to accelerate the batch production verification of new materials.

3. Downstream collaboration: functional panel development and joint innovation with end users

- Deeply integrate electronics, nuclear energy, and medical equipment companies, and develop customized products centered around "performance integration + structural weight reduction + precise matching";
- Develop integrated delivery capabilities, from raw materials to tungsten alloy plates to semi-finished devices or assembly units;
- Promote the digital quality traceability system and establish the ability to track the entire life cycle of materials, products and applications .

4. Standard system and talent project construction

- Formulate technical standards and testing specifications covering the entire chain of powder-sheet-composite structures;

- Build a composite R&D team covering tungsten materials science, surface engineering, physical simulation, etc.;
- Encourage universities, research institutes and enterprises to jointly build the "Tungsten Alloy Plate Advanced Manufacturing Technology Research Center".

V. Summary

The tungsten alloy plate industry must achieve the transformation from "resource-based advantages" to "technology-driven", and must break through a series of technical barriers such as high-purity raw materials, dense sintering, functional composites, surface engineering, and precision processing, and promote collaborative innovation across the entire industry chain. Only through in-depth integration of the industry chain, introduction of intelligent manufacturing systems, and improvement of the standard system can the brand competitiveness and strategic initiative of "Made in China" tungsten alloy plates be built in the fierce global market competition.

CTIA GROUP LTD
High-Density Tungsten Alloy Customization Service

CTIA GROUP LTD, a customization expert in high-density tungsten alloy design and production with 30 years of experience.

Core advantages: 30 years of experience: deeply familiar with tungsten alloy production, mature technology.
Precision customization: support high density (17-19 g/cm³), special performance, complex structure, super large and very small parts design and production.
Quality cost: optimized design, optimal mold and processing mode, excellent cost performance.
Advanced capabilities: advanced production equipment, RMI, ISO 9001 certification.
100,000+ customers
Widely involved, covering aerospace, military industry, medical equipment, energy industry, sports and entertainment and other fields.
Service commitment
1 billion+ visits to the official website, 1 million+ web pages, 100,000+ customers, 0 complaints in 30 years!

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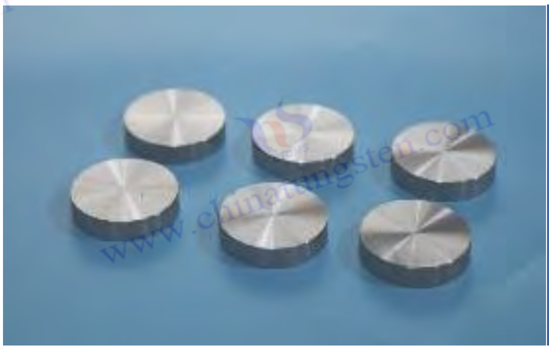
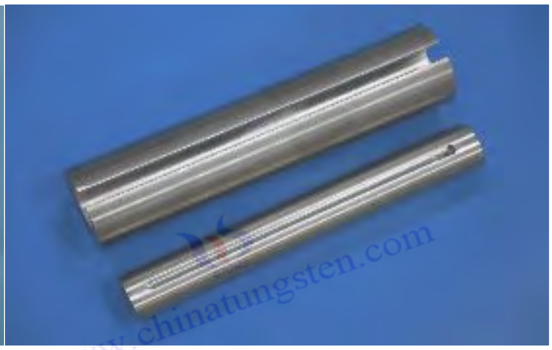

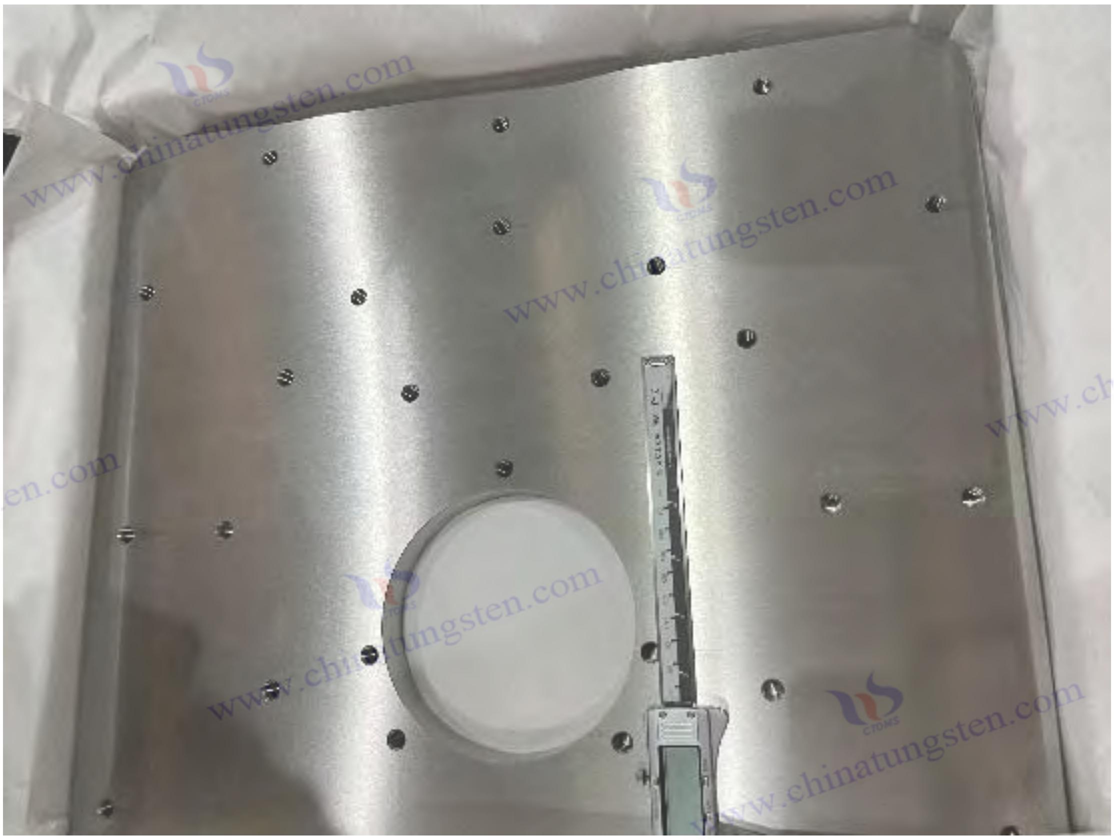

Chapter 10 Research Frontiers and Development Directions of Tungsten Alloy Plates

10.1 Densification Mechanism of Ultra-High Density Tungsten Alloy Plate

With the extreme pursuit of material density in the fields of nuclear energy protection, high-energy particle absorption, inertial counterweight, high-precision medical equipment, etc., ultra-high density tungsten alloy plates (density ≥ 18.5 g/cm³) are becoming a new focus of tungsten material research. Tungsten itself has an extremely high intrinsic density (19.25 g/cm³), but in the process of alloying and plate forming, the final product density is often lower than the theoretical value due to factors such as organizational porosity, impurity inclusions or unreasonable bonding metal ratio. Achieving **the ultimate densification (near-full densification) of** tungsten alloy plates is one of the key bottlenecks in the industrial application of high-end tungsten plates.

This section will systematically discuss the microscopic mechanism, influencing factors, main methods and latest research progress of tungsten alloy plate densification.

1. Basic principles and definitions of densification

Densification refers to the process of eliminating pores between particles and reducing the distance between atoms through heating and pressurization during the powder metallurgy forming process, thereby improving the volume density and structural integrity of the material.

Relative Density is an important indicator to measure the quality of tungsten alloy plate. The calculation method is as follows:

Density (%) = actual density / theoretical density × 100%

In tungsten alloy plates, the theoretical density depends on the ratio of tungsten to bonding metal (such as Ni, Cu), while the actual density is affected by factors such as particle morphology, sintering shrinkage, and residual pores.

2. Microscopic mechanism of densification process

1. Powder particle rearrangement and contact optimization

During the pressing process, the gaps between particles are minimized through molding or isostatic pressing, the contact angle between particles is optimized, and a preliminary structural framework is formed.

2. Surface diffusion and neck formation

At the beginning of heating, diffusion occurs on the particle surface to form a "sintering neck", and atoms migrate along the surface to the low-energy area, shrinking the pores.

3. Interparticle bonding and bulk diffusion

In the high temperature stage, grain boundary diffusion and bulk diffusion occur, the pores shrink, intermetallic bonds are formed between particles, and a dense structure is gradually established.

4. Pore closure and contraction

In the further sintering stage, the closed pores diffuse gas outward, the micropores shrink, the organization becomes homogenous, and a microstructure close to the theoretical density is formed.

3. Key factors affecting densification

1. Powder characteristics

- **Particle size distribution** : fine powder is more conducive to high densification, but is easily oxidized; coarse powder reduces sintering activity;
- **Morphology and structure** : Spherical powder has good fluidity, which is conducive to pressing and forming and uniform density;
- **Oxygen content and impurities** : High oxygen will form WO_3 residues , hindering densification and affecting tissue stability.

2. Binder phase ratio

- Metals such as Ni and Cu as bonding phases can significantly improve density and plasticity, but too high a proportion will reduce the final density;
- The optimal ratio requires a balanced design of board strength, ductility and density.

3. Suppression pressure and methods

- Good initial density can be obtained by controlling the molding pressure at 150~300 MPa ;
- Isostatic pressing (CIP) can effectively eliminate forming directionality and improve the consistency of density.

4. Sintering temperature and atmosphere

- tungsten alloy plate is 1350~1550°C, and it needs to be carried out in high-purity hydrogen or vacuum environment;
- Sintering time affects pore closure and microstructure uniformity.

5. Post-processing

- Hot isostatic pressing (HIP) further improves the densification rate after sintering;
- Intermediate rolling + re-annealing helps to eliminate micropores and improve grain density.

4. Main technical paths to improve the level of densification

Technical Path	Advantages	Key Points
CIP	Uniform pressure and high tolerance for shape complexity	High-strength mold + precise powder packaging technology
Liquid Phase Sintering	Add low melting point bonding metal to help diffusion	Bond metal ratio control + temperature window optimization
Hot Isostatic Pressing (HIP)	Eliminate residual micropores and improve microscopic uniformity	High temperature and high pressure environment control + airtight cavity design
Nano powder homogenization + ultra-fine	Increase the diffusion rate and improve the neck formation efficiency	Nano-agglomeration control + surface treatment to inhibit oxidation
Multiple cold rolling + intermediate annealing	Reduce porosity and enhance texture density	Controlled deformation rate + residual stress release
Laser remelting/electroslag remelting and other new processes	Surface densification + microstructure remodeling	Heat input uniformity + surface grain control

5. Latest Research and Future Directions

1. Multiscale sintering modeling

Finite element method (FEM), molecular dynamics (MD), phase field simulation (Phase-Field) and other technologies are used to simulate the pore evolution and stress conduction path during the sintering process of tungsten alloy plates and optimize the densification path.

2. Rapid consolidation technology (such as SPS)

Spark Plasma Sintering has the advantages of high thermal effect and high compression rate, and can achieve close to theoretical density in a short time, which is suitable for rapid preparation and experimental screening of tungsten plates.

3. Development of high-density composite structural panels

Develop gradient density structure, sandwich tungsten alloy plate (high density in the middle, toughness on the surface) or coated plate to achieve a balance of multiple properties.

4. Research on high densification + low deformation process path

Through the combination of medium-low temperature and high-pressure pre-sintering with secondary vacuum annealing, auxiliary pressure sintering and other composite processes, the contradiction between ultra-high density and deformation stability is solved, which is suitable for the preparation of ultra-large area plates.

VI. Summary

tungsten alloy plates is not only a key path to improving their structural strength, radiation resistance, and thermal management properties, but also represents the core competitiveness of tungsten alloy processing technology. In the future, in-depth research on the densification mechanism will continue to promote technological breakthroughs in key links such as powder property control, sintering physical models, and composite pressing processes, thereby enabling the wider application of tungsten alloy plates in extreme environments and high-end equipment.

10.2 Additive Manufacturing and Intelligent Tungsten Alloy Plate

As the manufacturing industry evolves from traditional batch processing to digitalization, customization, and intelligence, additive manufacturing (AM) technology is gradually penetrating high-performance material systems, including tungsten alloys. In particular, for tungsten alloy plate components with complex structures, customized requirements, and demanding high performance, AM offers a new path to overcome the limitations of conventional processes. Furthermore, with the development of Industry 4.0, intelligent manufacturing systems integrating intelligent sensing, data-driven development, and closed-loop control are establishing the next-generation production paradigm for tungsten alloy plates.

This section will systematically discuss the disruptive changes brought about by intelligence and additive manufacturing to the field of tungsten alloy plates from the aspects of additive manufacturing technology principles, adaptability of tungsten alloy plates, intelligent manufacturing system integration and its industrial prospects.

1. Application potential of additive manufacturing technology in tungsten alloy plates

1. Introduction to Additive Manufacturing

Additive manufacturing is a **layer-by-layer** manufacturing process that builds a three-dimensional structure according to a digital model through laser, electron beam, jetting, molten deposition, etc. It is suitable for the manufacture of metal sheets, complex shells, inner cavity structures, and functional integrated parts.

2. Challenges and progress of AM in tungsten alloys

Tungsten alloy’s high melting point (>3400°C), high thermal conductivity, and low plasticity lead to the following challenges in traditional AM technology:

- Cracks are prone to occur and warping and deformation are serious;
- Laser/electron beam has high reflectivity and low energy absorption rate;
- The powder is difficult to spheroidize and has poor fluidity.

However, with the maturity of the following technologies, AM has made breakthroughs in the preparation of tungsten alloy plates:

- **Electron beam melting (EBM)** : melts tungsten powder in a vacuum to reduce oxidation and crack formation;
- **Directed Energy Deposition (DED) : Suitable for repair** and near-net forming of large-sized tungsten alloy plates ;
- **Laser Powder Bed Fusion (LPBF) :** Excellent density (>98%) in the preparation of small high-density tungsten parts ;
- **Plasma cladding** : realize the composite of functionally graded tungsten layer and substrate.

2. Advantages of Additive Manufacturing in Improving the Performance of Tungsten Alloy Plates

Limitations of traditional processes	Additive manufacturing brings breakthrough
Difficult to control the consistency of plate thickness	Can be printed in layers, with precise control of thickness and texture
Complex structures are difficult to process	Porous structures and functional cavities can be constructed at one time
High material waste rate	Near net shape , high material utilization rate (up to 90%)
Long cycle mold design depends on	Eliminate mold steps and quickly iterate prototypes
The uniformity of ingredients is difficult to control	Customized ingredients and gradient composition construction can be achieved

functional structures such as **heat conduction channels, microstructure layers, and cooling systems** into the plate to achieve the "structure-function integration" evolution of tungsten alloy plates.

3. Integration trend of intelligent manufacturing in tungsten alloy plate production

1. Data-driven quality control system

The sintering/rolling process is controlled through sensor monitoring (temperature field, laser power, molten pool morphology) and digital twin model feedback, which significantly improves the manufacturing consistency of tungsten plates.

2. Autonomously optimize manufacturing processes

additive parameters (scanning path, laser power), etc. based on historical data and self-learning algorithms to achieve adaptive manufacturing.

3. Production line integration and flexible manufacturing units

Through the integration of MES (Manufacturing Execution System), ERP, and CAM systems, we have built a full-process intelligent manufacturing production line of "tungsten powder → tungsten plate → precision components" to meet the needs of small-batch, high-variety, and high-precision orders.

4. AI-driven material design and defect identification

- Use **machine learning algorithms** to predict the impact of alloy formulation on performance and accelerate the material design cycle;
- Use image recognition models to analyze CT or metallographic images to achieve rapid non-destructive detection of defects such as microcracks and inclusions.

4. Key technical bottlenecks and countermeasures for additive manufacturing of tungsten alloy plates

Technical Difficulties	Cause Analysis	Response Path
Difficult to prepare powder	High melting point metals are not easy to atomize and have poor sphericity	Developed inert gas atomization and plasma spheroidization equipment
Cracks are prone to occur and thermal stress is large	Large high temperature gradient + poor ductility	Optimized scanning strategy + heat treatment + nano alloying
Difficult to control plate deformation	The material shrinkage rate is large and the forming layer is thin	Apply support structures, optimize scan paths, and print with sandwich panels
AM product consistency is unstable	Powder batch variation + narrow process window	Introducing online monitoring system + data closed-loop feedback
Lack of standards and testing methods	AM tungsten alloy plate industry is still in the early stages of development	Promote the formulation of ISO/ASTM related standards + construction of process database

5. Future Trends and Frontier Directions

1. Hybrid manufacturing: traditional rolling + additive reconstruction

By rolling the large plate matrix, AM constructs functional local areas to achieve the unity of structural strength and functional requirements.

2. Multi-material collaborative manufacturing

Laser synchronous powder feeding is used to manufacture multifunctional composite tungsten plates such as **tungsten-copper** and **tungsten-ceramic** , which can adapt to complex loads and extreme working conditions.

3. Digital twins and material genetic engineering

By integrating the additive manufacturing parameter database, organizational performance big data and performance prediction model, a full-cycle intelligent control closed loop of tungsten alloy plates with the concept of "design-manufacturing-performance" is constructed.

4. Design of tungsten powder for additive manufacturing

Developing high sphericity, high fluidity, and low oxygen content tungsten alloy powder specifically for additive manufacturing will greatly improve product consistency and forming quality.

VI. Summary

Additive manufacturing and intelligent manufacturing are becoming the key engines for the transformation and upgrading of the tungsten alloy plate industry . It not only expands the boundaries of plate structure complexity and performance integration, but also promotes a comprehensive leap in production efficiency, material utilization, and personalized manufacturing capabilities. With the deep integration of lasers, control systems, AI algorithms, and powder metallurgy, a new generation of high-performance, customizable, intelligently controllable tungsten alloy plates will emerge in the future, fully meeting the multiple demands of nuclear energy, high-end equipment, aerospace, and other fields for "light, precise, strong, and intelligent" materials.

10.3 Integration and Application Expansion of Multifunctional Composite Panels

In the context of the development of high-end manufacturing, extreme environment equipment and multi-field coupling functional devices, metal plates with single performance can no longer meet the diversified and systematic engineering needs. **Multifunctional Tungsten -based Composite Plates**, as a new generation of engineering structural materials, are promoting the evolution of tungsten alloy plates from "structural support" to "structure + function" through structural design, interface engineering and functional integration .

This section will explore in depth the types, interface connection mechanisms, preparation methods, and expansion potential of multifunctional composite panels in different application scenarios, and analyze the current technical challenges and future development trends.

1. **Types and design concepts of multifunctional composite panels**

multiple functional properties such as heat, force, electricity, magnetism, and radiation protection in a tungsten alloy matrix through structural design or material introduction . Its basic categories include:

type	Composition structure	Main features
Tungsten-copper composite plate (W-Cu)	Tungsten matrix + copper network /interlayer	High thermal conductivity, low thermal expansion, anti-corrosion, anti-arcing
Tungsten-steel composite plate (W-SS)	Tungsten matrix + stainless steel base/surface	Strong and tough combination, impact resistance, good machinability
Tungsten-ceramic composite plate (W- Al_2O_3 , etc.)	Tungsten + ceramic particles/coating	Anti-wear, anti-corrosion, high temperature oxidation resistance
Tungsten-polymer/composite resin laminates	Tungsten layer + carbon fiber reinforced polymer layer	Lightweight, shielding electromagnetic interference, improving shock absorption and energy absorption capabilities
Functionally graded materials (FGM)	Composition or microstructure changes along the thickness gradient	Stress relief, thermal stress balance, multi-layer functional integration

This type of composite structure is widely needed in nuclear fusion devices, plasma thermal control elements, aviation radiators, protective covers, etc.

2. Interface bonding mechanism and key control factors of tungsten alloy composite plates

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The performance of composite plates depends on the quality of the interface between the different materials. Due to differences in thermal expansion coefficients and atomic diffusion capabilities between tungsten alloy and other materials (such as copper, steel, and ceramics), interfacial stress concentration, delamination, and microcracks are prone to occur. Therefore, strengthening the metallurgical bond through interface engineering is essential.

1. Interface bonding method

- **Mechanical bite type** : enhance interface friction through rough surface;
- **Intermetallic diffusion bonding** : Atomic interdiffusion under heating conditions forms a transition layer;
- **Reaction diffusion bonding (such as Ti, Cr intermediate layer)** : Introducing active elements between tungsten and other metals to form intermetallic compounds to improve bonding strength;
- **Surface metallurgical cladding** : A transition layer is locally formed by laser/arc melting to achieve metallurgical connection between layers.

2. Key influencing factors

- Thermal matching: The thermal expansion coefficients of the two materials are close, reducing thermal fatigue;
- Interfacial activity: forming a benign interfacial reaction layer rather than a brittle interphase;
- Pretreatment methods: including oxide film removal, roughening treatment, and alloy layer plating;
- Process path: Pressing sequence, sintering atmosphere and temperature curve need to be coordinated.

3. Main preparation methods of tungsten-based composite plates

Preparation process	Principle Introduction	Application Features
Explosion compounding method (EXW)	The explosion shock wave drives the metals to collide at high speed to achieve metallurgical bonding	High interlayer bonding strength, suitable for large-area cladding of tungsten steel and tungsten copper plates
Hot Isostatic Pressing (HIP) Composite Process	Powder pressing and diffusion bonding under high temperature and high pressure	High density, suitable for the fusion of heterogeneous powders and grid structures
Hot rolling composite method	Multilayer composite materials are heated and rolled to form metallurgical bonds	Applicable to multi-metal gradient layer composite, strong control uniformity
Laser Cladding /Directional Deposition	-situ deposition of functional layers or buffer interlayers on the tungsten plate surface	The thickness can be precisely controlled, suitable for customized

		manufacturing of small batches of high-performance components
Cold Spray	High-speed carrier gas pushes the micropowder to hit the substrate to form a mechanical bond	Gentle process, suitable for heat-sensitive composite systems (such as tungsten + polymer)
Bonding/cladding + sintering composite	Outsourcing/ embedding a variety of materials, improving overall density and bonding strength through vacuum sintering	Flexible process, suitable for complex shapes or microstructured composite panels

4. Typical application expansion of multifunctional tungsten composite plates

1. Nuclear industry protection and structural components

- **the first wall structure** in nuclear fusion devices ;
- Tungsten-copper composite plates are used for **plasma-facing thermal components in fusion reactors** and have excellent thermal conductivity and ablation resistance.

2. Aerospace

- W-Cu high thermal conductivity composite plates are used in satellite radiators and spacecraft propulsion systems;
- Functionally graded tungsten plate structures exhibit multi-layer energy absorption advantages in anti-micrometeor/anti-impact armor.

3. Medical equipment field

- Tungsten-polymer composite plates are used in lightweight and adjustable shielding structures for **radiotherapy devices ;**
- Composite tungsten plates are used for scatter suppression and image enhancement in high-resolution SPECT/PET equipment.

4. High temperature industry and thermal control engineering

- Tungsten-ceramic composite plates are widely used in vacuum furnace reflective layers, high-temperature thermal field structural parts, and linings for crystal growth;
- Microchannel composite plates are used for rapid heat transfer in laser and electron beam equipment.

V. Current Challenges and Future Development Directions

Key Questions	**Corresponding Challenges**	**Potential solutions**
Thermal mismatch of dissimilar materials	Interface debonding, thermal fatigue cracks	Introduce gradient transition layer and design buffer structure
Composite process parameters are difficult to standardize	Each composite system needs to be adjusted independently	Advancing database construction and interface thermodynamic modeling
Composite interface quality is difficult to monitor	Internal microcracks and inclusions are difficult to detect nondestructively	Introducing CT, phased array ultrasound, and artificial intelligence defect recognition technologies

High cost and complex preparation	High-end applications are limited	Modular production + precision manufacturing + batch equipment forming
Long application reliability verification cycle	Especially in scenarios with high reliability requirements such as nuclear energy and aerospace	Establish a long-term service behavior simulation and environmental adaptability experimental system

VI. Summary

Multifunctional tungsten alloy composite plates are a key advancement in the expansion of tungsten materials from structural support to multi-field coupling applications. Through composite design and interface control, tungsten alloy plates can combine multiple properties, including mechanical strength, thermal conductivity, radiation resistance, and corrosion resistance, meeting the comprehensive performance requirements in complex environments. In the future, with the advancement of material simulation, additive manufacturing , and high-throughput process platforms, multifunctional composite tungsten plates will serve a wide range of strategic industries, including defense, energy, aerospace, healthcare, and electronics, with a superior performance combination, higher reliability, and more flexible manufacturing paths.

10.4 Study on the Evolution of Service Performance in Extreme Environments (Irradiation, High Temperature, Corrosion)

Tungsten alloy plates are widely used in **extreme service environments** such as nuclear energy, aerospace, thermal control systems, and military protection due to their high melting point, high density, low vapor pressure, and excellent thermal stability . However, under harsh working conditions such as strong radiation, high temperature alternation, and strong corrosive atmosphere (such as halogen gas, molten salt, and plasma), their performance may undergo complex changes, including organizational evolution, performance attenuation, and interface degradation. Therefore, in-depth research on the service behavior of tungsten alloy plates in extreme environments is of great significance for improving their long-term reliability and engineering applicability.

This section will systematically analyze the radiation effect, high temperature thermal load response, degradation mechanism under corrosive environment, and targeted design and evaluation methods to construct a "panoramic picture of performance evolution" of tungsten alloy plates under extreme conditions.

1. Microstructural changes and mechanical effects under strong irradiation environment

1. Radiation sources and typical energy levels

- Neutron irradiation (nuclear fission/fusion reactors): $>10^{18}$ n/ cm^2 ;
- Ion implantation (He^+, H^+, Fe^+): can simulate displacement damage and bubble effects;
- Gamma rays/X-rays: simulate the thermal and ionization effects of radiation.

2. Microstructure evolution

- **Dislocation loops and vacancy aggregation** : forming nanoscale irradiation defects, reducing ductility;

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- **He bubble formation and aggregation** : precipitation at grain boundaries or second phases, easily causing embrittlement and spalling;
- **Irradiation-induced segregation** : local enrichment of alloying elements such as Ni and Fe, changing grain boundary energy;
- **Grain refinement and reorganization** : Nano-recrystallization behavior may be induced under long-term irradiation.

3. Macro performance degradation

- Reduce elongation and impact toughness, and increase brittle fracture sensitivity;
- Elastic modulus and thermal conductivity decrease;
- The thermal fatigue life is shortened and the failure mode changes from plastic failure to brittle fracture.

2. Performance degradation and organizational evolution under high temperature service

tungsten alloy plates serve at temperatures above 1000°C, they face high-temperature induced phenomena such as grain coarsening, interface degradation, and element migration, which affect their structural stability and thermal conductivity.

1. High temperature microscopic mechanism

- **Grain growth** : driven by surface energy, especially in pure tungsten or alloy systems with weak grain boundary energy;
- **Element redistribution** : Alloying elements (such as Ni and Cu) segregate or evaporate at high temperatures;
- **Second phase dissolution/precipitation transformation** : affects hardness and creep behavior;
- **Void and crack growth** : Microvoids driven by thermal stress evolve into microcracks and eventually fail.

2. Degradation of mechanical properties at high temperature

- Yield strength decreases (creep initiation temperature decreases);
- The creep rate increases and the creep life shortens;
- Thermal fatigue cycles lead to grain boundary sliding and interlaminar delamination.

3. Thermal load coupling behavior

- High frequency heat-cool cycles accelerate interface fracture;
- Thermal gradient induces component migration and internal stress accumulation;
- The thermal shock tolerance under transient high-temperature pulses (such as spacecraft return and pulse discharge of fusion devices) needs to be considered.

3. Failure Paths and Protection Strategies in Corrosive Environments

Tungsten alloy may face serious corrosion risks in certain media, especially in environments **such as halogen gas, high-temperature water vapor, acidic molten salt, and electrolyte .**

1. Corrosion type and medium

- **Gas phase corrosion** (Cl_2 , H_2O , O_2) : causes the oxide layer to form and peel off;
- **Molten salt corrosion** (NaCl- KCl , LiF-BeF $_2$): penetrates grain boundaries and forms a brittle layer;

- **Electrochemical corrosion** : Especially in medical electronic components, electrodes and other applications, the tungsten-Cu system is more sensitive;
- **Plasma corrosion** : High temperature excites particles to bombard the surface, causing ablation and atomic desorption.

2. Corrosion failure mechanism

- Local anodic dissolution or grain boundary oxidation leads to grain shedding;
- After the surface passivation film breaks down, corrosion intensifies;
- The alternating oxidation-reduction process weakens the surface density;
- When coupled with high temperature/irradiation, the corrosion rate increases significantly.

3. Protective measures

- **Surface coating** (CrN , Al_2O_3 , SiC): provides high temperature passivation protection ;
- **Alloy element optimization** : Introduce anti-corrosion elements (Re, Ta, Mo) to enhance solid solution oxidation resistance;
- **Composite structure design** : using W-SS/W-Cu composite plates to inhibit the expansion of the corrosion layer;
- **Surface densification process** : laser cladding, PVD, etc. are used to reduce surface porosity.

4. Progress in Testing Methods and Simulation Research in Extreme Environments

1. Accelerated life test and simulation test platform

- Use reactor external irradiation and ion implantation equipment to simulate nuclear environment;
- High-frequency cycle heating table and transient thermal shock device simulate aerospace thermal loads;
- High temperature salt spray, electrochemical corrosion chamber, and hydrofluoric acid spray chamber simulate industrial corrosion environments.

2. Multi-field coupling simulation study

- Establish a multi-field numerical model of heat-mechanics-irradiation-corrosion to predict performance evolution;
- Use **phase field method, molecular dynamics, Monte Carlo** , etc. to simulate grain boundary behavior;
- Combining fracture mechanics and fatigue theory, a life prediction model is constructed.

3. Online monitoring and damage assessment

- Laser interferometer to measure strain;
- Infrared thermography to assess thermal gradients;
- Non-destructive testing (ultrasound, X-ray CT) to monitor internal damage evolution;
- AI image recognition is used to track microcracks and quantify corrosion progression.

V. Future Development Direction and Engineering Response Strategies

Development direction	Engineering significance

Extreme Service Database Construction	Provide data basis for material selection and service life prediction
Intelligent perception + feedback control system	Form a real-time damage monitoring and performance self-adjustment system to improve the safety of materials in service
Development of multifunctional composite structures	Integrate corrosion resistance, radiation resistance, thermal shock resistance and other capabilities to improve service performance in extreme environments
High reliability life design method for fusion/aerospace	Meet the strict requirements of tungsten plate life for strategic projects such as ITER, space exploration, and ultra-high temperature propulsion

VI. Summary

tungsten alloy plates in extreme environments such as high irradiation, high temperature gradients and strong corrosion is controlled by complex microscopic mechanisms, and its structural stability and performance evolution laws directly determine its engineering reliability. By deeply understanding the irradiation-induced microstructural changes, grain evolution and interface damage mechanisms at high temperatures, and failure paths in corrosive environments, the development of new material systems and the design of new structures can be guided. In the future, we should strengthen interdisciplinary integration, numerical modeling and field verification linkage to promote tungsten alloy plates towards the goal of "extreme environment adaptive structural materials."

10.5 High-Performance Alternative Materials and Future Sustainable Strategies for Tungsten Plates

As the global industry develops towards lighter weight, higher performance, and green environmental protection, tungsten alloy plates have unique advantages such as extremely high density, melting point, and radiation protection capabilities, but their high cost, resource scarcity, processing difficulty, and environmental sensitivity also limit their larger-scale applications. In order to achieve functional equivalence or partial substitution, while alleviating dependence on tungsten resources , the materials science community is actively exploring a variety of **high-performance alternative material systems** and thinking about **the sustainable development path of** tungsten plates themselves .

This section will discuss the four aspects of material substitution path, green manufacturing technology, recycling system and industry sustainable strategy, and propose feasible solutions for tungsten alloy plates to continue to maintain their competitiveness in future high-end manufacturing.

1. Development direction of high-performance functional alternative materials

Although tungsten alloy plates are difficult to completely replace in many situations, there are already several material systems with competitive performance and cost advantages in some applications. The main alternative types include:

1. High melting point metal material system

- **Molybdenum alloy plate (Mo, TZM)** : slightly lower density (10.2 g/cm³), good thermal conductivity, better processability than tungsten, suitable for hot field environment;
- **Hafnium and niobium-based alloys** : excellent high-temperature strength, but poor corrosion resistance;
- **Rhenium -based materials** : They have excellent stability in ultra-high temperature environments (>2000°C), but are extremely expensive and are only used in special aerospace devices.

2. High-density composite materials

- **Tungsten polymer composite plate (W-polymer)** : Made into lightweight protective plate by injection molding or bonding, suitable for medical and radiation protection scenarios;
- **W-Cu functional composite board** : Combining high density and high thermal conductivity, it is suitable for spacecraft heat dissipation and electronic device thermal management;
- **Rare earth oxide-metal composite plates (such as Gd-W, La_2O_3-W)** : enhance radiation absorption capacity and improve thermal shock toughness.

3. Ceramics and ceramic matrix composites

- **Silicon carbide (SiC) and boron nitride (BN) reinforced ceramic plates** : They have excellent high-temperature oxidation resistance and dielectric properties and can be used for thermal control protection;
- **Intermetallic compounds (such as TiAl, $MoSi_2$) :** lightweight, good high-temperature strength, but limited thermal conductivity.

4. New functionally graded materials (FGMs)

By gradually changing the composition or structure along the thickness direction, thermal stress regulation and interface stress relief can be achieved, partially replacing the multi-layer tungsten plate structure , and having better engineering adjustability.

2. Sustainable manufacturing strategy of tungsten alloy plate

In addition to replacement, the tungsten plate itself needs to be systematically optimized around "energy saving, consumption reduction, and carbon reduction" while maintaining its high performance advantages.

1. Green powder metallurgy technology

- Develop low-temperature, high-density sintering aids;
- Use plasma spheroidization, high-energy ball milling and other methods to improve the yield rate;
- Reduce the proportion of inert gas used in atmosphere sintering and promote clean hydrogen reduction.

2. Additive manufacturing technology (3D printing)

- tungsten structural parts with complex configurations , laser directed energy deposition (DED) and electron beam melting (EBM) are used to manufacture on demand to reduce material waste;

- Effectively improve the manufacturing efficiency of small batch/customized tungsten alloy plates.

3. Energy-saving surface treatment and composite technology

- Use green thin film deposition such as PVD and CVD to replace electroplating;
- Use non-thermal treatment methods such as laser surface modification, cold spraying, plasma spraying, etc. to reduce energy consumption;
- Promote the composite structure of renewable substrate and tungsten surface layer to improve the overall performance/cost ratio.

3. Recycling and Reuse of Tungsten Alloy Plates

Tungsten is a national key strategic metal, and its resource recovery and recycling have become the core link in the sustainable development of the industry.

1. Tungsten plate recycling methods

- Industrial scraps are directly recycled or reprocessed mechanically;
- Extract tungsten metal powder from scrapped devices and prepare new alloy plates;
- The surface coating is stripped and then pressed/sintered to form a secondary sheet.

2. Remanufacturing and “zero waste” process chain

- To address the performance degradation problem during the regeneration of tungsten plates , microalloy regulation was introduced;
- Restoring the crystal integrity of tungsten using plasma lysis/heat treatment technology;
- Promote the pilot project of recycling tungsten alloy plates in nuclear power and military retired equipment.

3. Establishment of national and international recycling standards

- Establish a certification system for recycling tungsten-based materials (such as GRS, ISO 14021);
- Promote the extension of “green recycling” responsibilities in key use areas such as medical and aviation equipment;
- Use blockchain and big data platforms to track the entire life cycle of tungsten materials.

4. Low carbonization and strategic prospects of tungsten alloy plates in the future

Sustainable development path	Key Objectives	Potential Implementations
Reduce carbon footprint and total emissions	Meeting global carbon peak /carbon neutrality policy constraints	Use green electricity for smelting , introduce low-carbon technology, and embed carbon trading mechanism into the industrial chain
Open up the “green closed loop” of the industrial chain	Construct a complete cycle path of resources → products → recycling → regeneration	Establish industry standards, support recycling platforms, and set recycling quotas
Development of functional customized	Meeting new demands for structural-functional	Promote "tungsten +" cross-border composite, modular structural plates,

panels for high-end manufacturing	integration in extreme service environments	and multifunctional additive manufacturing
Diversification, security and stability of global supply chains	Reduce dependence on a single resource/origin	Develop overseas resources and build local refining + intelligent manufacturing production lines

V. Summary

tungsten alloy plates still occupy an irreplaceable position in high-end manufacturing. However, in the face of the new situation of global resource shortages, stricter environmental protection requirements and accelerated technological progress, exploring alternative materials, optimizing tungsten plate manufacturing processes, and promoting recycling and green manufacturing will become the only way to achieve its long-term sustainable development. The future of tungsten alloy plates is no longer a single material competition, but a comprehensive competition of "material system + process system + industrial path". Only by continuing to work hard in the direction of green, low-carbon, high-performance and intelligent, can tungsten plates continue to play an important role in the future manufacturing system.

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Appendix

Appendix 1 : Common physical/mechanical parameters of tungsten alloy plates

Project Name	unit	Pure tungsten plate (W)	W-Ni-Fe alloy plate	W-Ni-Cu alloy plate	W-Cu composite board
Theoretical density	g/cm³	19.25	17.0～18.5	17.0～18.2	14.5～17.0
Melting point	°C	3410	3300～3400	3200～3400	~3000 (approximate)
Specific heat (normal temperature)	J/(kg·K)	134	140～160	140～160	170～180
Thermal conductivity (25°C)	W/(m·K)	170～180	70～110	80～120	180～220
Coefficient of thermal expansion	10^{-6} /K	4.5～5.0	5.0～8.0	6.0～8.5	6.5～10.0
Resistivity (20°C)	μΩ·cm	5.4～5.7	15～35	20～40	2～4
tensile strength	MPa	700～1000	700～1000	600～900	400～600
Yield Strength	MPa	600～850	600～900	550～850	300～500
Elongation	%	＜3	10～30	10～30	5～15
Brinell hardness (HB)	-	>300	200～300	180～280	120～220
Shore hardness (HRB)	-	>100 (approximate HRC)	80～95	75～90	60～85
Corrosion resistance (in normal temperature atmosphere)	-	excellent	good	good	generally
magnetic	-	none	have	Low magnetic properties (some have)	none
Radiation shielding performance (gamma rays)	d=10mm blocking rate	>85%	>80%	>80%	>75%

illustrate:

- Pure tungsten plate (W): has the highest density, melting point and hardness, and is often used in extreme working conditions such as high-temperature thermal control and radiation protection. The disadvantage is that it is difficult to process and is brittle.
- W-Ni-Fe alloy plate: It is a representative of high-density alloys, has good mechanical toughness and balanced density, and is widely used in inertial parts and protective plates;

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- W-Ni-Cu alloy plate: has good thermal conductivity and is non-magnetic, suitable for electromagnetic shielding and high-density counterweight;
- W-Cu composite board: It has the advantages of thermal conductivity, electrical conductivity and density, and is often used in electronic thermal management structures and microwave component supports.

Appendix 2: Comparison table of tungsten alloy grades and chemical compositions

Brand/standard code	Country/Standard	Alloy type	Main chemical components (mass fraction, %)	Features
W1 (ASTM B760)	ASTM	Pure Tungsten	W ≥ 99.95	High purity tungsten sheet, used for thermal field, vacuum devices, etc.
W-3Ni-7Fe (heavy tungsten alloy)	Common industrial nomenclature	W-Ni-Fe alloy	W ≈ 90, Ni ≈ 3, Fe ≈ 7	High density tungsten alloy, with both structural strength and toughness
W-7Ni-3Cu	Common industrial nomenclature	W-Ni-Cu alloy	W ≈ 90, Ni ≈ 7, Cu ≈ 3	Non-magnetic tungsten alloy, suitable for electronics and protection fields
WCu75 (or WCu25)	Common industrial nomenclature	Tungsten copper composite material	W ≈ 75, Cu ≈ 25	High thermal conductivity tungsten copper plate for heat dissipation and grounding structure
YW1 (YS/T 798)	China Nonferrous Industry Standards	Tungsten Nickel Iron	W ≥ 90, Ni:Fe ≈ 7:3	General grade for military inertial components and counterweight plates
YW2 (YS/T 798)	China Nonferrous Industry Standards	Tungsten - nickel-copper system	W ≥ 90, Ni:Cu ≈ 7:3	Non-magnetic high specific gravity sheet, used in medical treatment, instruments, etc.
G26F (MIL-T-21014)	US Military Standard MIL	W-Ni-Fe alloy	W ≈ 90, Ni ≈ 6, Fe ≈ 4	Military standard tungsten alloy, armor-piercing projectile, missile tail compartment, etc.
W90NiFe (ISO 3767)	ISO International Standards	W-Ni-Fe alloy	W ≈ 90, Ni + Fe ≈ 10	Standard description of general high-density alloys
K20W (DIN EN)	German DIN/EN standards	W-Cu composites	W ≈ 80, Cu ≈ 20	European standard high conductivity tungsten

				copper alloy , suitable for thermal control devices
WL10 (pure tungsten doped)	Internationally used (ASTM/ISO)	Doped tungsten	W ≥ 98.5 , La_2O_3 ≈ 1.0～1.2	Lanthanum -doped tungsten material improves thermal stability and crack resistance
WD100 (company brand)	CTIA GROUP LTD(internal code)	Microalloyed tungsten plate	W ≥ 92, total of microalloying elements such as Ni, Re, Ta ≤ 5	Self-developed alloy, taking into account strength, radiation resistance and thermal conductivity
TCW6025	Japanese corporate brand	W-Cu alloy	W ≈ 60, Cu ≈ 40	Suitable for microwave components, heat sink plates, etc.
WC20 (for electrodes)	ISO 6848	Doped Tungsten	W ≥ 98, CeO_2 ≈ 2.0	doped tungsten is usually used for welding electrodes, but some plates also use

illustrate:

- W-Ni-Fe / W-Ni-Cu series tungsten alloy plates are the most commonly used high specific gravity tungsten alloy types;
- WCu series is mainly used for thermal and electrical conductive structures, such as electronic packaging and heat dissipation modules;
- **Tungsten doping (such as La_2O_3, CeO_2)** can improve thermal shock toughness while maintaining high temperature strength;
- Although the standards of different countries are slightly different, they can be compared and identified through the component interval and brand logic;
- The company's own brands (such as CTIA GROUP LTDWD series) are usually customized and used to meet special demand scenarios.

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Appendix 3: Tungsten Alloy Plate Standard Documents and Main Reference Materials

1. Domestic Standards and Industry Regulations

1. GB/T 18928-2017 National standard for technical conditions of tungsten and tungsten alloy plates specifies
   the technical requirements, test methods and inspection rules for tungsten and tungsten alloy plates.
2. YS/T 798-2012 Technical Specifications for Tungsten Alloy Rods
   is a non-ferrous metal industry standard that covers the composition, properties, and testing methods of tungsten alloy materials.
3. Technical Specification for
   High Density Tungsten Alloy Plates for Nuclear Power Plants Standardizes the material requirements and application standards of tungsten alloy plates for the nuclear power industry.
4. Q/ZW 001-2020 CTIA GROUP LTDTungsten Alloy Plate Enterprise Standard is
   an internal standard of the company, covering the design, manufacturing and quality control of tungsten alloy plates.

II. International Standards and Norms

1. ASTM B760-17 Standard Specification for Tungsten and Tungsten Alloy Plate
   American Society for Testing and Materials standard, which specifies the properties and test methods of tungsten and tungsten alloy plates in detail.
2. ISO 3767-1:2017 Tungsten and Tungsten Alloys — Part 1: Plate and Sheet
   was published by the International Organization for Standardization and covers the classification and technical requirements of tungsten alloy plates.
3. MIL-T-21014D Military Specification: Tungsten Heavy Alloy Plate, Bar, and Rod
   US military standard for military use and quality control of tungsten heavy alloys .
4. EN 1654-1:2018 High Density Heavy Metals and Alloys — Technical Delivery Conditions — Part 1: Tungsten Heavy Alloy Products
   is a European standard covering the delivery conditions and test specifications for tungsten alloys.

3. Important technical books and documents

1. "Technical Handbook of Tungsten and Tungsten Alloys", Metallurgical Industry Press, 2020
   Comprehensively introduces the physical properties, manufacturing processes and application technologies of tungsten and tungsten alloys.
2. Tungsten and Tungsten Alloys, Metals Handbook, Volume 2, ASM International, 1990International
   authoritative metal handbook, tungsten alloy material basics and performance analysis.
3. “Development and Application of Tungsten Heavy Alloys in Aerospace”, Journal of Materials Science, 2018

, details the latest research and development progress of tungsten heavy alloys in the aerospace field.

4. Case Study on Tungsten Alloy Powder Metallurgy Technology and Industrial Application, Issue 5, 2019 .

IV. Typical Patent Literature

1. CN101234567B The invention discloses a method for preparing a tungsten alloy plate with high densification,
   and relates to a tungsten alloy plate preparation technology of a novel powder metallurgy process.
2. US9876543B2 Tungsten Alloy Sheet with Enhanced Thermal Conductivity
   Composite material design with improved thermal conductivity of tungsten alloy sheet.
3. EP3456789A1 Coating Method for Tungsten Alloy Plates
   Surface coating and anti-wear treatment technology of tungsten alloy plates.

5. Academic conferences and industry reports

1. International Tungsten Conference
   bring together the latest technologies and industry trends in the field of tungsten materials.
2. The proceedings of the annual meeting of the Tungsten and Molybdenum Branch of the China Nonferrous Metals Society
   focused on the technological progress and market analysis of China's tungsten alloys.
3. "Tungsten Alloy Plate Market Trend Analysis Report", CTIA GROUP LTD, 2024
   industry report, details the global tungsten alloy plate production and sales and future trends.

Appendix 4: Tungsten Alloy Glossary and English Abbreviations

Terminology (Chinese)	Terminology (English)	Interpretation and explanation
Tungsten Alloy	Tungsten Alloy	with tungsten as the main component and added metals such as nickel, iron, and copper.
Powder Metallurgy	Powder Metallurgy	The process of preparing metal materials by powder forming and sintering.
sintering	Sintering	The process of densifying powder particles at high temperatures.
Isostatic Pressing	Isostatic Pressing	A technology that uses uniform pressure to press powder into shape.
Heat treatment	Heat Treatment	A method of changing the structure and properties of materials by heating, insulation and cooling.
Microstructure	Microstructure	The internal structural characteristics of a material under a microscope.
density	Density	Mass per unit volume, usually expressed in g/cm³.
tensile strength	Tensile Strength	The maximum stress of a material under tension.
Yield Strength	Yield Strength	The stress at which a material begins to deform plastically.
Elongation	Elongation	The ability of a material to deform plastically before breaking, expressed as a percentage.
hardness	Hardness	The ability to resist local deformation is often measured using indicators such as Brinell hardness (HB) and Rockwell hardness (HR).
Coefficient of thermal expansion	Coefficient of Thermal Expansion	The rate at which a material expands in response to a change in temperature.
Thermal conductivity	Thermal Conductivity	The ability of a material to transfer heat, measured in W/(m·K).
Resistivity	Electrical Resistivity	The current resistance of a material, measured in μΩ·cm .
Corrosion resistance	Corrosion Resistance	The ability of a material to resist chemical or electrochemical corrosion.
Gamma ray shielding	Gamma Ray Shielding	Tungsten alloy's ability to absorb and block high-energy gamma rays.
Nondestructive Testing	Non-Destructive Testing (NDT)	Testing methods that do not destroy the integrity of the material, such as ultrasonic, X-ray, and magnetic particle testing.
Particle size	Particle Size	The size of powder particles affects the densification and performance of the material.

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PVD	Physical Vapor Deposition	Physical vapor deposition, a surface coating technology.
Additive Manufacturing	Additive Manufacturing (AM)	The technology of manufacturing parts by stacking materials layer by layer is commonly known as 3D printing.
AS9100	Aerospace Quality Management	Quality management system standards for the aerospace industry.
ISO 13485	Medical Devices Quality System	Medical device quality management system standards.
RoHS	Restriction of Hazardous Substances	EU Directive on the restriction of the use of certain hazardous substances.
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals	EU Registration, Evaluation, Authorisation and Restriction of Chemicals regulations.
MSDS	Material Safety Data Sheet	Material Safety Data Sheets provide information on safe use of chemicals.

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