Encyclopedia of Tungsten Heavy Alloy

CTIA GROUP LTD

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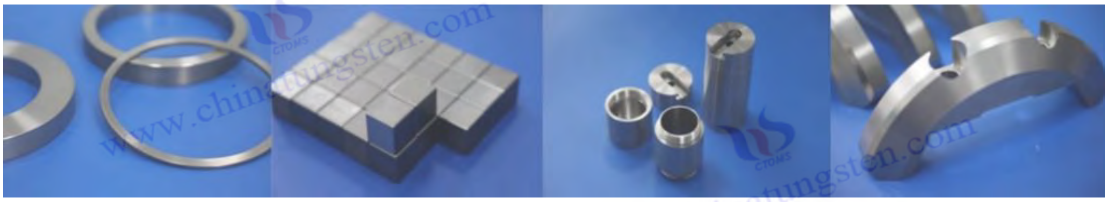
Global Leader in Intelligent Manufacturing for Tungsten, Molybdenum, and Rare Earth Industries



INTRODUCTION TO CTIA GROUP

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

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

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

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

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Chapter 1: Introduction

Definition and Overview of Heavy Tungsten Alloy

High density tungsten alloy , as the name implies, is a composite material made of tungsten (W) as the main component and a small amount of other metal elements (such as nickel Ni, iron Fe, copper Cu, etc.) added through a specific process. This type of alloy is known for its extremely high density (usually between 17.0-19.3 g/cm³, close to the 19.25 g/cm³ of pure tungsten), far exceeding common metals such as steel (7.8 g/cm³) or lead (11.3 g/cm³). Its core features are not only high density, but also excellent mechanical strength, corrosion resistance, high temperature resistance and good radiation shielding ability, which make it have irreplaceable application value in many fields.

From the perspective of chemical composition, high-density tungsten alloys usually contain 85%-99% tungsten, with the rest being binder phase elements (such as nickel and iron) or substitute elements (such as copper). These added elements are mixed with tungsten powder, pressed and sintered through a powder metallurgy process to form a uniform microstructure. The role of the binder phase is to enhance the toughness and machinability of the alloy, because although pure tungsten has an extremely high density, it is too hard and brittle to meet actual processing and application requirements. By optimizing the formula, high-density tungsten alloys not only retain the high-density characteristics of tungsten, but also improve its mechanical properties, making it an advanced material that is both functional and practical.

In materials science, heavy tungsten alloys are considered a combination of functional and structural materials. Their high density makes them excellent in scenarios that require small volume and high weight, such as aerospace counterweights and military armor-piercing cores; at the same time, their physical and chemical stability makes them suitable for extreme environments, such as radiation shielding or high-temperature processing tools in the nuclear industry. This versatility has made heavy tungsten alloys occupy an important position in modern industry and technology, and they are known as "the best among heavy metals."

From a historical perspective, the development of high-density tungsten alloys originated from the research on tungsten materials in the early 20th century , especially the demand for high-performance military materials during World War II, which promoted its technological progress. Today, with the continuous improvement of manufacturing processes (such as liquid phase sintering, hot isostatic pressing, etc.) and the expansion of application fields, high-density tungsten alloys have expanded from their original military uses to medical, industrial, civilian and even emerging scientific and technological fields, becoming an important research and application branch in materials science.

1.2 The significance of research and application of high specific gravity tungsten alloy

High-density tungsten alloys have far-reaching scientific significance and practical value, and their importance is reflected in many aspects. First, from a scientific point of view, high-density tungsten alloys are a model for the research of metal-based composite materials. By adjusting the ratio of tungsten to other elements and optimizing the preparation process, the relationship between properties such as density, strength, and toughness can be systematically explored. This kind of research not only promotes the theoretical development of materials science, but also provides valuable experience for the development of other high-performance alloys. For example, the microstructure control technology of high-density tungsten alloys (such as grain size optimization and phase distribution uniformity) has been borrowed into the research of high-entropy alloys and nanomaterials.

In the industrial field, the application of high-density tungsten alloys directly improves the efficiency and safety of many industries. Taking aerospace as an example, its high-density characteristics enable the counterweight components of aircraft and spacecraft to achieve precise mass distribution in a limited space, thereby optimizing flight performance and fuel efficiency. In the military industry, armor-piercing projectiles made of heavy tungsten alloys can effectively penetrate modern armor materials and enhance the combat capability of weapon systems due to their high hardness and density. In addition, its high temperature and corrosion resistance make it an ideal choice for high temperature processing tools and deep-sea equipment, significantly extending equipment life and reducing maintenance costs.

The application in the medical field further highlights the social value of high-density tungsten alloys. Due to its excellent radiation shielding ability, high-density tungsten alloys are widely used in shielding components of X-ray machines, CT equipment and radiotherapy devices. Compared with traditional lead materials, tungsten alloys are non-toxic and have higher density. They can provide equivalent or even better protection in a thinner volume, reduce the weight of equipment and improve the safety of patients and medical staff. In addition, high-density tungsten alloys are also used to manufacture medical isotope containers and gamma knife components to ensure the safe transportation and precise treatment of radioactive materials, and promote the development of modern medical technology.

In the civilian field, the application of high-density tungsten alloys cannot be ignored. For example, its use in sports equipment (such as golf club weights, dart rods) and fishing sinkers replaces toxic lead materials, which not only improves product performance but also meets environmental protection requirements. This wide penetration from industry to civilian use reflects the potential of high-density tungsten alloys in improving the quality of life and promoting sustainable development.

From an economic perspective, the research and development and application of high-density tungsten alloys have driven the development of related industrial chains, including tungsten mining, powder metallurgy equipment manufacturing, and precision processing technology. Especially in the context of the growing global demand for high-performance materials, the market prospects of high-density tungsten alloys are broad, creating significant economic benefits for enterprises and countries. However, its high production cost and resource dependence (tungsten is a rare metal) have also prompted researchers to continuously explore more efficient production processes and recycling technologies to achieve a win-win situation for the economy and the environment.

1.3 Purpose and Organization of this Book

This book aims to comprehensively and systematically introduce the relevant knowledge of high-density tungsten alloys, from basic theory to practical application, from production technology to future development, and strives to provide readers with an authoritative and detailed reference material. Its main purposes include the following:

First, it provides theoretical support for academic researchers. This book will deeply explore the chemical and physical properties, preparation processes and performance optimization methods of high-density tungsten alloys, help researchers understand the relationship between their microstructure and macroscopic properties, and provide inspiration for the design of new tungsten-based materials . Secondly, it provides a practical guide for engineering and technical personnel. By introducing production equipment, testing technology and specific product applications in detail, this book aims to help practitioners master the processing and application skills of high-density tungsten alloys and improve industrial production efficiency. Third, it provides strategic reference for industry decision makers and managers. By analyzing domestic and international standards, environmental impacts and economic considerations , this book will reveal the development trends and challenges of the high-density tungsten alloy industry and provide a basis for policy making and investment decisions.

The target readers of this book include but are not limited to the following groups: scholars and students in the field of materials science and engineering, engineers engaged in the production and processing of tungsten alloys, technical experts in the aerospace and defense industries, medical equipment manufacturers, and industry practitioners interested in high-performance materials. In order to meet the needs of different readers, the content design of this book takes into account both theoretical depth and application breadth, with a systematic review of basic knowledge and the latest progress in cutting-edge research.

The book is organized as follows:

Chapter 2 to Chapter 5 : Lay the foundation, introduce the basic knowledge, performance analysis, preparation technology, processing and post-processing technology of high-density tungsten alloy, and establish a comprehensive theoretical framework for readers.

Chapter 6 to Chapter 7 : Focusing on production and testing, the production equipment and testing equipment of high-density tungsten alloy are elaborated in detail, highlighting the hardware support for technical implementation.

Chapter 8 to Chapter 9 : Turning to applications, the main products and broader application fields of China Tungsten Intelligence are listed respectively, demonstrating the actual value of high-density tungsten alloy.

Chapters 10 to 11 : Focus on norms and impacts, analyze domestic and international standards as well as environmental and economic considerations , and provide background support for industrialization.

Chapter 12 : Looking into the future, this paper discusses the research frontiers of high-density tungsten alloys, including the cross-research of AI-assisted design and high-entropy alloys.

Appendix : Provides a glossary, references and data tables to facilitate readers' reference and in-depth research.

Through such a structural arrangement, this book strives to present a panoramic view of high-density tungsten alloys for readers from theory to practice, from technology to application, from the current situation to the future. Whether you are a learner who is new to this field or a professional who wants to deepen your research, this book hopes to be your reliable partner in exploring the world of high-density tungsten alloys.

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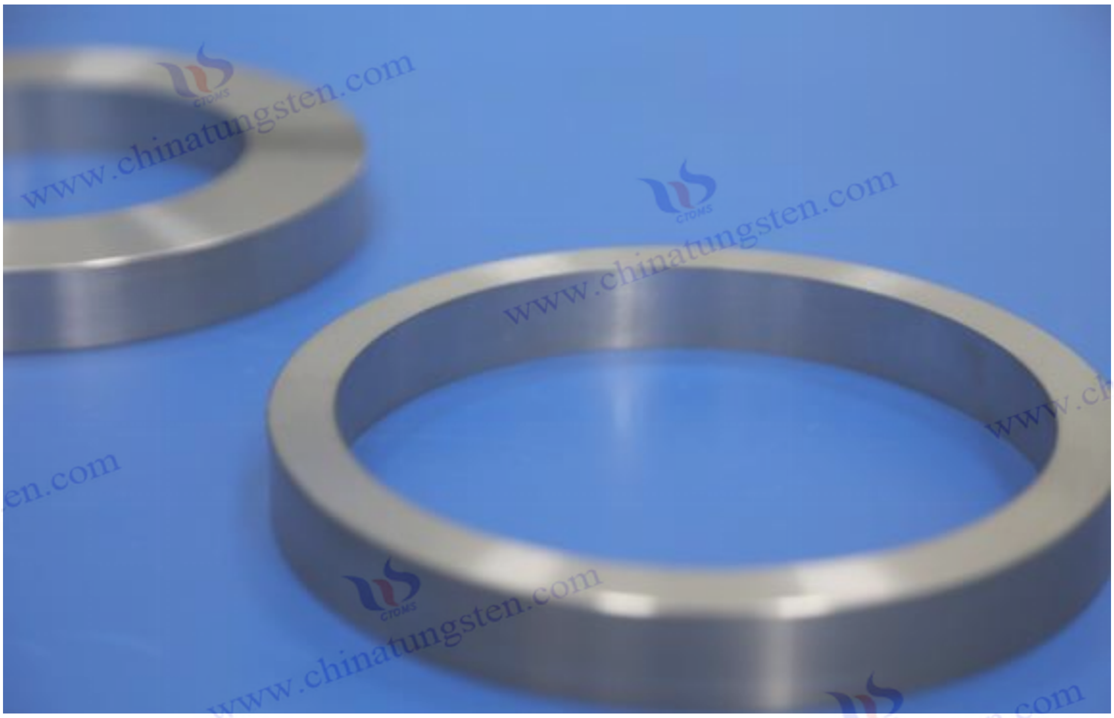

Chapter 2: Basic Knowledge of High Specific Gravity Tungsten Alloy

Chemical and physical properties of heavy tungsten alloys

High density tungsten alloy are the core basis for its wide application in modern industry and technology. These properties are not only derived from the excellent properties of tungsten itself, but also benefit from the optimization of the alloying process. From the perspective of chemical composition, high-density tungsten alloys are dominated by tungsten (W), with the tungsten content usually between 85% and 99%, and the rest being a small amount of bonding phase or added elements, including nickel (Ni), iron (Fe), copper (Cu), cobalt (Co) or molybdenum (Mo). Tungsten is a transition metal located in the sixth period of the periodic table, with atomic number 74 and atomic mass 183.84 u. It has an extremely high melting point (3422°C) and chemical stability. Its electronic configuration ([Xe] $4f^{1\ 4}$ $5d^{\ 4}$ $6s^2$) determines its high density and hardness, while added elements such as nickel and iron significantly improve the brittleness of tungsten by forming solid solutions or intermetallic compounds (such as Ni_3Fe) . For example, in a typical tungsten-nickel-iron alloy (W-Ni-Fe), the tungsten content is 90%-97%, and the ratio of nickel to iron is usually 7:3 or 5:5. This ratio forms a liquid phase during the sintering process, which promotes the uniform bonding of tungsten particles and enhances the toughness of the alloy. On the other hand, tungsten-copper alloy (W-Cu) is often used in electronic devices due to the high electrical and thermal conductivity of copper. The tungsten content is generally 70%-90% to balance density and thermal properties.

From the perspective of physical properties, the density of heavy tungsten alloy is its most significant advantage, ranging from 17.0-19.3 g/cm³, close to the 19.25 g/cm³ of pure tungsten. This high density comes from tungsten's body-centered cubic (BCC) crystal structure and high atomic mass, which make its atoms packing per unit volume extremely efficient. For example, the density of W-90Ni-7Fe-3 alloy can reach 18.5 g/cm³, which is much higher than steel (7.85 g/cm³), aluminum (2.7 g/cm³) and lead (11.34 g/cm³), and only slightly lower than pure tungsten. This feature makes it irreplaceable in applications that require small size and high quality, such as aviation counterweights or armor-piercing cores. Although the melting point of heavy tungsten alloy is lower than that of pure tungsten due to the addition of elements, it still remains between 2500-3000°C. For example, the melting point of W-95Ni-Fe alloy is about 2800°C, which is still much higher than steel (~1500°C) and lead (327°C), making it excellent in high-temperature environments.

In terms of mechanical properties, heavy tungsten alloys have both high strength and moderate toughness. Their tensile strength is usually between 700-1200 MPa, depending on the composition and process. For example, the tensile strength of W-90Ni-7Fe-3 alloy can reach 1000 MPa, while that of W- 95Ni-Cu alloy may be slightly lower, around 800 MPa. Its hardness (Vickers hardness, HV) ranges from 300-500 HV, which is lower than pure tungsten (350-650 HV) but much higher than lead (~5 HV). Compared with the brittleness of pure tungsten (elongation <1%), the ductility of high-density tungsten alloys is significantly improved, with an elongation of 10%-30%, thanks to the plastic effect of the binding phase (such as Ni-Fe). For example, W-93Ni-Fe alloy can exhibit 20% elongation in tensile testing, making it less susceptible to fracture under dynamic loads such as blast impact. In addition, its wear resistance and fatigue resistance are also excellent, with a wear rate about 30%-50% lower than that of steel, showing long life characteristics in cutting tools and drilling equipment.

Thermal and electrical properties are another important aspect of high-density tungsten alloys. Its thermal conductivity ranges from 80-150 W/(m·K), which is lower than pure tungsten (173 W/(m·K)) and copper (400 W/(m·K)), but higher than steel (~50 W/(m·K)). For example, the thermal conductivity of W-80Cu alloy can reach 140 W/(m·K), which is suitable for use as a heat sink for electronic devices. Its resistivity is about 5.5-7.0 μΩ·cm, which is slightly higher than copper (1.68 μΩ·cm) and pure tungsten (5.5 μΩ·cm), but still has good conductivity and is suitable for electrode materials. Particularly outstanding is its radiation shielding ability. Tungsten's high atomic number (Z=74) and density make it extremely efficient in absorbing X-rays and gamma rays. For example, W-95Ni-Fe alloy with a thickness of only 1 cm can shield about 90% of gamma rays, far exceeding lead of the same thickness (about 70%), and is non-toxic, making it a preferred material for the medical and nuclear industries.

In terms of corrosion resistance, tungsten itself has extremely high stability to acid, alkali and oxygen at room temperature, and hardly reacts with hydrochloric acid and sulfuric acid, and only slowly dissolves in strong oxidizing media (such as concentrated nitric acid). Heavy tungsten alloys inherit this property, but their corrosion resistance decreases slightly after adding nickel and iron. For example, the mass loss rate of W-Ni-Fe alloy is less than 0.5% after being immersed in hydrochloric acid for 100 hours, but it may reach 2%-3% in nitric acid. In contrast, W-Cu alloy shows better tolerance to moisture and seawater due to the presence of copper, and its corrosion rate in the marine environment is only 1/10 of that of steel. These characteristics enable heavy tungsten alloys to remain stable in a variety of chemical environments.

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To intuitively demonstrate its performance, the following table compares the main parameters of high specific gravity tungsten alloy with steel, lead and pure tungsten:

Performance parameters	Heavy Tungsten Alloy	Steel (plain carbon steel)	lead	Pure Tungsten
Density(g/cm^3)	17.0-19.3	7.85	11.34	19.25
Melting point (°C)	2500-3000	~1500	327	3422
Tensile strength(MPa)	700-1200	400-1000	~15	900-1500
Hardness (HV)	300-500	120-250	~5	350-650
Elongation(%)	10-30	20-40	>50	<1
Thermal conductivity (W/(m·K))	80-150	~50	35	173
Resistivity (μΩ·cm)	5.5-7.0	~15	20	5.5
Corrosion resistance	Good (non-oxidizing environment)	Medium (easy to rust)	Good (acid resistant)	Excellent
Radiation shielding capability	Excellent	Poor	good	Excellent

Note: The data in the table are typical ranges, and specific values may vary depending on ingredients and processes.

Historical Development of Heavy Tungsten Alloys

high-density tungsten alloys is a long process from basic discovery to industrial application and then to technological innovation, reflecting mankind's continuous pursuit of high-performance materials. The discovery of tungsten began in the late 18th century. In 1781, Swedish chemist Carl Wilhelm Scheele speculated on the existence of tungsten by decomposing tungstate ($CaWO_4$). Then in 1783, Spanish brothers Juan José and Fausto Eljuar first extracted metallic tungsten by reducing tungsten oxide (WO_3). They named it "wolfram" (from the German "wolf's foam") because its ore is often associated with tin, and foam will be produced during smelting. However,

Due to the backward metallurgical technology in the early days, tungsten existed in the form of powder or compounds and could not be processed into bulk materials, which limited its application.

In the 19th century, with the advancement of the Industrial Revolution, the application of tungsten gradually expanded. In 1847, British scientist Robert Oxland developed a method for preparing sodium tungstate, laying the foundation for the industrial production of tungsten. At the end of the 19th century, the emergence of electric arc furnaces and powder metallurgy technology made the processing of tungsten possible. In 1904, General Electric Company of the United States first used tungsten filament in incandescent light bulbs to replace carbon filaments, which significantly extended the life of the bulbs due to its high melting point and durability. This breakthrough marked the transition of tungsten from the laboratory to industry, but the brittleness of pure tungsten still made it difficult to meet more complex needs.

High-density tungsten alloy appeared in the early 20th century, driven by military needs. During World War I (1914-1918), tungsten was used to make cutting tools and armor steel (such as German "tungsten steel") due to its high hardness, but the difficulty of processing pure tungsten prompted scientists to explore alloying paths. In the 1930s, German metallurgists first tried to mix tungsten with nickel and iron to prepare tungsten-based alloys through powder metallurgy . The typical formula of this period is W-90Ni-10, with a density of about 17 g/cm³, a hardness of about 300 HV, and significantly improved toughness compared to pure tungsten . World War II (1939-1945) became a turning point in the development of heavy tungsten alloys. In the 1940s, the U.S. military developed the W-90Ni-7Fe-3 alloy for the armor-piercing core of the M1 tank. Its density (18.5 g/cm³) and penetration far exceeded the steel core at the time, significantly improving the destructive power against German armor. The technology of this period mainly relied on pressing and high-temperature sintering. Although the process was simple, it laid the foundation for modern high-density tungsten alloys.

After the war, the arms race and civilian industrialization during the Cold War promoted the further development of high-density tungsten alloys. In the 1950s and 1960s, the aerospace field began to take advantage of its high density, such as the gyroscope counterweights of the US F-15 fighter and the balance blocks of NASA's early satellites, with a density requirement of more than 18 g/cm³. During the same period, the medical field discovered its radiation shielding potential. In the late 1950s , W-95Ni-Fe alloy began to be used in shielding components of X-ray machines, gradually replacing lead. In the 1970s, the maturity of liquid phase sintering technology increased the density of alloys from 95% to over 99%. For example, the porosity of W-93Ni-Fe alloy was reduced to below 0.5%, and the performance consistency was significantly improved, which promoted large-scale production.

Entering the 21st century, the research and development of high-density tungsten alloys turned to performance optimization and environmental protection applications. After 2000, nanotechnology was introduced into the preparation of tungsten powder, and the grain size was reduced from micron level to 50-100 nm, which increased the tensile strength of W-95Ni-Fe alloy from 1000 MPa to 1200 MPa. The rise of 3D printing technology (such as selective laser sintering) has enabled the realization of complex-shaped tungsten alloy parts, such as special-shaped counterweights in aerospace. In addition, with the concern about lead toxicity, W-90Ni-Cu alloy has been promoted in the civilian field (such as fishing sinkers and golf club weights), and its market share has increased from 5% in 2000 to more than 30% in 2020. Today, the research on high-density tungsten alloys focuses on AI-assisted design and its combination with high-entropy alloys. Its historical development is not only a witness to technological progress, but also reflects the close interaction between materials science and social needs.

2.3 Comparison between high specific gravity tungsten alloy and other materials

high-density tungsten alloy make it a place among many materials, but its advantages and limitations need to be understood through detailed comparison with other materials. The following is a systematic analysis of high-density tungsten alloy with steel (ordinary carbon steel), lead, titanium alloy (Ti-6Al-4V) and pure tungsten from six dimensions: density, mechanical properties , thermal properties, corrosion resistance, processability and cost.

Density is the core advantage of high-density tungsten alloys, which ranges from 17.0-19.3 g/cm³, close to pure tungsten (19.25 g/cm³), and far exceeds steel (7.85 g/cm³), titanium alloy (4.51 g/cm³) and lead (11.34 g/cm³). For example, the density of W-95Ni-Fe alloy is 18.5 g/cm³, while the same volume of steel is only 40% of its weight. This makes it irreplaceable in scenarios that require high weight and small volume, such as aviation counterweights and armor-piercing cores, while steel and titanium alloys are more suitable for lightweight design, and lead is limited due to toxicity.

Mechanical properties , the tensile strength of high-density tungsten alloys (700-1200 MPa) is on the same order of magnitude as steel (400-1000 MPa) and titanium alloys (about 1100 MPa), but much higher than lead (~15 MPa) and slightly lower than pure tungsten (900-1500 MPa). The hardness (300-500 HV) is also better than steel (120-250 HV) and lead (~5 HV), but lower than pure tungsten (350-650 HV). Its elongation (10%-30%) is significantly better than pure tungsten (<1%), and close to steel (20%-40%) and titanium alloy (10%-15%), making up for the brittleness of pure tungsten. For example, W-90Ni-Fe alloy can withstand 50 J/cm² of energy in an impact test, while pure tungsten only withstands 5 J/cm². This balance of strength and toughness makes it more reliable under dynamic loads, whereas lead's very low strength limits its structural applications.

Thermal properties , the thermal conductivity of heavy tungsten alloy (80-150 W/(m·K)) is lower than that of pure tungsten (173 W/(m·K)) and copper (400 W/(m·K)), but higher than that of steel (~50 W/(m·K)) and lead (35 W/(m·K)). Its melting point (2500-3000°C) is far higher than that of steel (~1500°C), lead (327°C) and titanium alloy (~1660°C), second only to pure tungsten (3422°C). For example, the thermal conductivity of W-80Cu alloy is 140 W/(m·K), which is suitable for heat sink applications, while steel softens easily at high temperatures and lead melts completely.

Corrosion resistance , high-density tungsten alloy performs well in non-oxidizing environments. For example, after being immersed in 10% hydrochloric acid for 1,000 hours, the mass loss rate is less than 1%, which is better than steel (easy to rust, loss rate of about 20%) and lead (acid-resistant but not alkali-resistant, loss rate of about 5%). Titanium alloy (excellent corrosion resistance, loss rate <0.1%) and pure tungsten (almost no corrosion) are slightly better, but W-Cu alloy performs well in seawater, with a corrosion rate of only 1/15 of steel, making it suitable for marine engineering.

Machinability is a key improvement in heavy tungsten alloys. Pure tungsten has high hardness and brittleness, so it needs high-temperature forging or special tools for processing, which is expensive. Heavy tungsten alloys are optimized by bonding phases (such as Ni-Fe) and can be processed by turning and milling. The difficulty of processing is close to that of steel (easy to cut), but still higher than that of titanium alloys (medium) and lead (very easy to process). For example, the cutting speed of W-90Ni-Fe alloy can reach 50 m/min, while that of pure tungsten is only 10 m/min.

Cost , high-density tungsten alloys are priced at about $30,000 to $50,000 per ton, much higher than steel (~$500/ton) and lead (~$2,000/ton), comparable to titanium alloys (~$30,000/ton), but lower than pure tungsten (~$60,000/ton), due to the fact that tungsten is a rare metal (global reserves are about 3.5 million tons, mainly concentrated in China) and the process is complex (powder metallurgy, sintering). This makes it more economical in high-value-added fields (such as aviation and medical), but it may be replaced by steel in low-end applications.

In general, high-density tungsten alloy is unique in its comprehensive performance of density, strength, toughness, corrosion resistance and processability. It makes up for the brittleness of pure tungsten and the toxicity of lead, surpasses the limitations of steel and titanium alloys in high-density scenarios, and provides a solid basis for subsequent process design and application selection.

Classification of Heavy Tungsten Alloys

High density tungsten alloys (HDTA) are a type of alloy with tungsten (W) as the main component (the content is generally 85%~97%). Due to its high density, excellent mechanical properties and good corrosion resistance, it is widely used in military, aerospace, medical, electronics and industrial fields. According to different classification methods, high-density tungsten alloys can be divided into the following categories:

2.4.1 Classification based on ingredients

High-density tungsten alloy is tungsten, and nickel (Ni), iron (Fe), copper (Cu), cobalt (Co) and other elements are added according to different needs to optimize its performance. According to the difference of secondary elements in the alloy, it can be mainly divided into the following categories:

(1) W-Ni-Fe alloy

Composition characteristics : Generally contains 90%~97% tungsten, and the ratio of nickel to iron is approximately 7:3 or 8:2.

Performance advantages : good ductility, high strength and hardness, and high magnetic permeability.

Main applications : Widely used in military industry (armor-piercing core), aerospace (counterweight), industrial counterweight (gyroscope counterweight).

(2) W-Ni-Cu alloy

Composition characteristics : The tungsten content is usually 90%~95%, and the ratio of nickel to copper is usually close to 7:3.

Performance advantages : Compared with W-Ni-Fe alloy, W-Ni-Cu alloy has lower magnetic permeability, almost no magnetism, and good corrosion resistance.

Main applications : Used in medical radiation shielding (X-ray protection), electronic packaging and in areas sensitive to magnetism.

(3) W-Ni-Fe-Co alloy

Composition characteristics : Cobalt (Co) is added to the W-Ni-Fe basis to improve strength and wear resistance.

Performance advantages : Higher strength and hardness than W-Ni-Fe alloy, and has certain high temperature stability.

Main applications : Used for high-temperature structural materials, such as aerospace engine components, wear-resistant cutting tools, etc.

(4) Other special alloys

W-Cu alloy : Mainly used for high thermal conductivity and high electrical conductivity applications, such as electrode materials.

W-Re (tungsten- rhenium) alloy : has better high temperature performance and is often used in the aerospace field.

2.4.2 Classification based on density and mechanical properties (Class 1 ~ Class 4)

According to **ASTM B777** and **MIL-T-21014** standards, heavy tungsten alloys can be divided into four grades (Class 1 to Class 4) according to density and mechanical properties. Different grades of alloys are suitable for different application scenarios:

grade	Tungsten content (%)	Density (g/cm^3)	Tensile strength (MPa)	Yield strength (MPa)	Elongation(%)	Magnetic Permeability	Typical Applications
Class 1	90	17.0	≥ 758	≥ 517	≥ 5	> 1.05	Aviation counterweight, industrial counterweight
Class 2	92.5	17.5	≥ 758	≥ 517	≥ 5	> 1.05	Military armor, armor-piercing core
Class 3	95	18.0	≥ 724	≥ 517	≥ 3	> 1.05	X-ray protection, nuclear radiation shielding
Class 4	97	18.5	≥ 689	≥ 517	≥ 2	> 1.05	Medical radiation protection, electronic packaging

Class 1 and Class 2 : Higher strength and better toughness, suitable for applications such as aerospace, military, and industrial counterweights.

Class 3 and Class 4 : Higher density, usually used in radiation protection, nuclear industry and high-precision counterweight fields.

2.4.3 Classification based on usage

According to the application of high specific gravity tungsten alloy in different fields, it can be divided into the following categories:

(1) Military industry

It is mainly used for **armor-piercing cores** (such as APFSDS, a substitute for depleted uranium shells), **protective armor** , **explosive metal fragments** , etc.

Requirements: high density, high hardness, high impact resistance.

Main materials: W-Ni-Fe, W-Ni-Fe-Co.

(2) Aerospace

Used for aircraft and spacecraft **counterweights** , **inertial gyroscope counterweights** , **engine high-temperature components** , etc.

Requirements: high density, high temperature resistance, and oxidation resistance.

Main materials: W-Ni-Fe, W-Ni-Fe-Co, W-Re.

(3) Medical field

Mainly used for **X-ray shielding materials** , **radiotherapy protection** (such as gamma ray shielding blocks), **radioactive drug transport containers** , etc.

Requirements: high density, non-magnetic, non-toxic, corrosion-resistant.

Main materials: W-Ni-Cu, W-Ni-Cu-Co.

(4) Industrial and civil fields

Mainly used in **precision counterweights (pendulums, gyroscopes, racing counterweights)** , **oil drilling tools** , **electrode materials** , etc.

Requirements: high density, wear resistance, good machinability.

Main materials: W-Ni-Fe, W-Ni-Cu, W-Cu.

(5) Electronics and semiconductor fields

Mainly used **in electronic packaging materials** , **high-power semiconductor heat sinks** , and **microelectronic interconnection materials** .

Requirements: high thermal conductivity, low thermal expansion, non-magnetic.

Main materials: W-Cu, W-Ag (tungsten silver alloy).

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Chapter 3: Performance Analysis of High Weight Tungsten Alloy

3.1 Mechanical properties of heavy tungsten alloy

The mechanical properties of high-density tungsten alloys are the key factors that make them popular in engineering applications, covering strength, hardness, toughness, wear resistance, fatigue resistance, etc. The excellent performance of these properties is due to the high hardness of tungsten and the synergistic effect of added elements, which makes it perform well under both static and dynamic loads.

Tensile strength and yield strength are the core indicators of mechanical properties. The tensile strength of heavy tungsten alloys is usually between 700-1200 MPa, and the yield strength is about 500-1000 MPa, and the specific values vary depending on the composition and process. For example, the tensile strength of W-90Ni-7Fe-3 alloy (90% tungsten content, nickel-iron ratio 7:3) can reach 1050 MPa and the yield strength is about 850 MPa, while the tensile strength of W-95Ni-Cu (95% tungsten content, nickel-copper ratio) is about 800 MPa. This strength level is comparable to high-strength steel (such as AISI 4340, about 1000 MPa), but far exceeds the limit of lead (~15 MPa) and pure tungsten before brittle fracture (900-1500 MPa). The source of its high strength lies in the high hardness of tungsten particles and the strengthening effect of the bonding phase (such as Ni-Fe), which absorbs energy during tension and delays crack propagation.

Hardness is another significant characteristic of heavy tungsten alloys, with Vickers hardness (HV) ranging from 300-500 HV. For example, the hardness of W-93Ni-Fe alloy is about 450 HV, which is close to some tool steels (such as H13, about 400-500 HV), but lower than pure tungsten (350-650 HV). The distribution of hardness is positively correlated with the tungsten content. The higher the tungsten content, the higher the hardness. However, the addition of the binder phase slightly reduces the hardness and improves the impact resistance. For example, in the Brinell hardness test (HB), W-95Ni-Fe alloy can reach 400 HB, while pure tungsten is brittle and cannot withstand high load tests.

Toughness is the key advantage of high-density tungsten alloys compared to pure tungsten, which is manifested in higher elongation and fracture toughness. Its elongation ranges from 10% to 30%, which is much higher than pure tungsten (<1%). For example, the elongation of W-90Ni-Fe alloy can reach 25% at room temperature, and it still maintains more than 15% at a low temperature of -50°C, showing good low-temperature toughness. Fracture toughness (K_IC) is usually between 20-40 MPa·m^(1/2). For example, the K_IC of W-93Ni-Fe alloy is about 30 MPa·m^(1/2), which is close to low-alloy steel (about 40 MPa·m^(1/2)), while pure tungsten is only 5-10 MPa·m^(1/2). This toughness benefits from the plastic deformation ability of the bonding phase , which absorbs energy when stress is concentrated to prevent brittle fracture.

Wear resistance is closely related to the hardness of high-density tungsten alloys. In wear tests (such as ASTM G65 grinding wheel wear test), the volume loss rate of W-95Ni-Fe alloy is about 0.05 mm^3/N·m, which is about 70% lower than steel (0.15 mm^3/N·m) and close to cemented carbide (such as WC-Co, 0.02 mm^3/N·m). Its wear resistance makes it an ideal material for drilling tools and cutting tools. For example, in oil drilling, the life of tungsten alloy drill bits can reach 2-3 times that of steel drill bits.

Fatigue resistance is particularly important in dynamic applications. The fatigue limit (10^7 cycles) of high-density tungsten alloys is about 400-600 MPa. For example, the fatigue strength of W-90Ni-Fe alloy under alternating stress is 500 MPa, which is higher than lead (almost no fatigue resistance) and pure tungsten (cannot be tested due to brittleness), and is comparable to steel (about 400 MPa). This property makes it excellent in vibration suppression parts and firearm counterweights, capable of withstanding long-term cyclic loads without failure.

3.2 Physical properties of high density tungsten alloy

The physical properties of high-density tungsten alloy include density, thermal properties, electrical properties and acoustic properties, which directly affect its applicability in a specific environment.

Density is the most important physical property of heavy tungsten alloys, ranging from 17.0-19.3 g/cm^3. For example, the density of W-97Ni-Fe alloy can reach 19.0 g/cm^3, which is only slightly lower than pure tungsten (19.25 g/cm^3), while the density of W-85Cu is about 17.0 g/cm^3. This high density is derived from the body-centered cubic (BCC) crystal structure and high atomic mass (183.84 u) of tungsten, which allows it to store more mass per unit volume. For example, 1 cubic centimeter of W-95Ni-Fe alloy weighs about 18.5 g, while the same volume of steel weighs only 7.85 g. This characteristic gives it an irreplaceable advantage in aviation counterweights and radiation shielding.

Thermal properties include melting point, thermal conductivity, and thermal expansion coefficient. The melting point of heavy tungsten alloys ranges from 2500-3000°C, which is lower than pure tungsten (3422°C) but much higher than steel (~1500°C). For example, the melting point of W-90Ni-Fe alloy is about 2850°C, which can withstand the high temperature environment of rocket nozzles. Its thermal conductivity is 80-150 W/(m·K), for example, W-80Cu alloy can reach 140 W/(m·K), which is lower than pure tungsten (173 W/(m·K)) but higher than steel (50 W/(m·K)), suitable for heat sink applications. The thermal expansion coefficient is about 4.5-6.0 × 10 $^{-6}$ /K, which is close to pure tungsten (4.5 × 10 $^{-6}$ /K) and much lower than steel (12 × 10 $^{-6}$ /K), and has better dimensional stability when the temperature changes.

electrical properties , the resistivity of heavy tungsten alloys is between 5.5-7.0 μΩ·cm, such as 6.0 μΩ·cm for W-90Ni-Fe alloy, which is slightly higher than pure tungsten (5.5 μΩ·cm) and copper (1.68 μΩ·cm), but lower than steel (15 μΩ·cm). Although its conductivity is not as good as copper, it is still competitive among electrode materials. In addition, its high melting point and high density make it perform well in electrospark machining (EDM) electrodes. For example, the life of W-70Cu electrodes is about 50% longer than that of copper electrodes.

Acoustic properties are less concerned, but they are crucial in some applications such as vibration suppression. The sound velocity of heavy tungsten alloys is about 4300-4500 m/s, such as 4400 m/s for W-95Ni-Fe alloy, which is lower than steel (about 5000 m/s) but higher than lead (1200 m/s). Its high density and high elastic modulus (about 400 GPa) make it decay faster in sound wave transmission, making it suitable for use as a vibration damping material. For example, in machine tool counterweights, tungsten alloys can reduce the vibration amplitude by 30%-40%.

3.3 Main elements and their functions of high specific gravity tungsten alloy

High-Density Tungsten Alloys (HDTA) are a type of alloy material with tungsten (W) as the main component, usually containing 85%~97% tungsten, and adding nickel (Ni), iron (Fe), copper (Cu), cobalt (Co) and other elements to improve its mechanical properties, corrosion resistance, conductivity and other properties. These alloys are widely used in military, aerospace, medical, electronic and industrial fields due to their high density, high strength and excellent comprehensive properties.

1. Tungsten (W): provides high density and strength

(1) Basic characteristics

- **Element symbol** : W
- **Atomic number** : 74
- **Density** : 19.3 g/cm³
- **Melting point** : 3410°C
- **Main function** : to give high specific gravity tungsten alloy extremely high density, hardness and strength.

(2) Role in high specific gravity tungsten alloy

- As **a bulk element** , it provides high density (16.5~18.5 g/cm³), enabling the alloy to function in applications such as high-mass counterweights, radiation shielding, and armor-piercing projectile cores.

- Due to its high melting point and wear resistance, the stability of the alloy in high temperature environment is improved.
- Good corrosion resistance enables the alloy to be used in extreme environments.
- However, tungsten itself is brittle, so other metal elements need to be added to improve the alloy's machinability and ductility.

2. Nickel (Ni): Improves ductility and corrosion resistance

(1) Basic characteristics

- **Element symbol** : Ni
- **Atomic number** : 28
- **Density** : 8.9 g/cm³
- **Melting point** : 1455°C
- **Main function** : to give the alloy good ductility and enhance its corrosion resistance.

(2) Role in high specific gravity tungsten alloy

- As **a binding phase element** , nickel can promote the uniform distribution of tungsten particles and improve the plasticity and machinability of the alloy.
- Improve the ductility of the alloy so that it can withstand larger deformations without brittle fracture.
- It gives the alloy strong corrosion resistance, allowing it to be used for a long time in a humid or acidic environment.
- During the liquid phase sintering process, it helps to lower the sintering temperature and increase the density of the alloy.
- It is generally used in combination with iron (Fe) or copper (Cu) to adjust the magnetic and mechanical properties of the alloy.

3. Iron (Fe): Enhances the mechanical strength of the alloy

(1) Basic characteristics

- **Element symbol** : Fe
- **Atomic number** : 26
- **Density** : 7.87 g/cm³
- **Melting point** : 1538°C
- **Main function** : Improve the strength and hardness of the alloy, while giving it a certain degree of magnetism.

(2) Role in high specific gravity tungsten alloy

- As a reinforcing phase, iron and nickel together form **a W-Ni-Fe ternary alloy** , which enhances the mechanical strength and hardness of the alloy.
- Increases the wear resistance of the alloy, enabling it to withstand high loads and high impact forces.
- This gives the alloy **a certain degree of magnetism** , making it suitable for certain military and industrial applications.

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- During the liquid phase sintering process, it helps to improve the fluidity of the bonding phase and increase the density of the alloy.
- W-Ni-Fe alloys are commonly used in applications such as **armor-piercing cores, aerospace counterweights, and industrial molds** .

4. Copper (Cu): reduces magnetism and improves conductivity

(1) Basic characteristics

- **Element symbol** : Cu
- **Atomic number** : 29
- **Density** : 8.96 g/cm³
- **Melting point** : 1084.6°C
- **Main function** : to make the alloy non-magnetic and improve its conductivity and corrosion resistance.

(2) Role in high specific gravity tungsten alloy

- Substitute for iron (Fe) to make **non-magnetic tungsten alloy (W-Ni-Cu)** , which is suitable for applications sensitive to magnetism (such as medical devices, electronic components).
- Enhance the conductivity of the alloy, making it suitable for electrode materials, electronic packaging and other fields.
- Further improve the corrosion resistance, so that the alloy has a longer service life in humid environment or acidic medium.
- Reduces the hardness of the alloy, making it easier to machine.
- W-Ni-Cu alloys are commonly used in **X-ray and gamma-ray shielding, medical equipment, electronic packaging** , etc.

5. Cobalt (Co): Enhances wear resistance and high temperature resistance

(1) Basic characteristics

- **Element symbol** : Co
- **Atomic number** : 27
- **Density** : 8.90 g/cm³
- **Melting point** : 1495°C
- **Main functions** : Improve wear resistance, high temperature resistance, and enhance the strength of the alloy.

(2) Role in high-density tungsten alloys

- As a strengthening element, cobalt can **improve the wear resistance of the alloy** and is suitable for high-load, wear-resistant parts.
- Providing **improved high temperature resistance** , enabling the alloy to maintain strength and stability in extreme temperatures.
- Improve the hardness of the alloy, making it suitable for high impact, high load environments, such as armor-piercing cores, aerospace engine components, etc.

- W-Ni-Fe-Co alloy has higher strength and hardness than ordinary W-Ni-Fe alloy, but the manufacturing cost is higher.

The properties of heavy tungsten alloy are affected by its main elements. The functions of each element are as follows:

element	effect	Impact on alloys
Tungsten (W)	High density, high strength	Give the alloy high density, high strength and corrosion resistance
Nickel (Ni)	Ductility, corrosion resistance	Increase plasticity, improve corrosion resistance, and improve processability
Iron (Fe)	Mechanical strength, hardness	Improve the hardness and strength of the alloy and make it magnetic
Copper (Cu)	Non-magnetic, conductive	Reduce magnetism, improve conductivity and corrosion resistance
Cobalt (Co)	Wear resistance, high temperature resistance	Improve wear resistance and high temperature stability

3.4 Corrosion and wear resistance of high specific gravity tungsten alloy

Corrosion resistance is an important property of heavy tungsten alloys, especially in chemical and marine environments. Tungsten itself is extremely stable to acids, alkalis and oxygen at room temperature, and hardly reacts with hydrochloric acid and sulfuric acid, only slowly dissolving in concentrated nitric acid or hydrofluoric acid. Heavy tungsten alloys inherit this property, but it changes slightly due to the addition of elements. For example, the mass loss rate of W-90Ni-Fe alloy is less than 0.5% after being immersed in 10% hydrochloric acid for 1000 hours, and 0.1%-0.2% in seawater, which is much lower than steel (about 20%). W-Cu alloy is more resistant to moisture and salt spray due to the presence of copper. In the ASTM B117 salt spray test, the corrosion depth after 1000 hours is only 0.01 mm, while that of steel can reach 0.5 mm. However, in a strong oxidizing environment (such as concentrated nitric acid), the Ni-Fe bonding phase may be corroded, and the corrosion rate increases to 2%-3%, which needs to be improved by surface coating (such as Ni plating).

Wear resistance is closely related to hardness and microstructure. The wear resistance of high-density tungsten alloys is excellent in both sliding wear and abrasive wear. For example, in the ASTM G65 test, the wear rate of W-95Ni-Fe alloy is about 0.05 $mm^3/N\cdot m$, which is 70% lower than that of steel (0.15 $mm^3/N\cdot m$) and close to WC-Co cemented carbide (0.02 $mm^3/N\cdot m$). The source of its wear resistance lies in the high hardness of tungsten particles (about 1000 HV) and the toughness support of the bonding phase. For example, in oil drilling, the life of W-90Ni-Fe drill bits can reach 3 times that of steel drill bits, and the wear depth is only 0.1 mm, while the steel drill bit can reach 0.5 mm.

3.5 Radiation Shielding Capability of Heavy Tungsten Alloy

The radiation shielding ability of heavy tungsten alloy is the basis for its wide application in medical and nuclear industries. It is derived from the high atomic number (Z=74) and high density (17.0-19.3 g/cm^3)

of tungsten. Its absorption efficiency of X-rays and gamma rays is far higher than that of traditional materials. For example, 1 cm thick W-95Ni-Fe alloy can shield 90% of gamma rays (energy 1 MeV), while the same thickness of lead is only 70% and steel is only 10%. Its shielding ability is calculated based on the mass absorption coefficient (μ/ρ). The μ/ρ of W-95Ni-Fe alloy is about 0.15 cm^2/g, which is higher than that of lead (0.12 cm^2/g). In practical applications, a 10 mm thick tungsten alloy shield can reduce the radiation dose from 100 mSv to 1 mSv, which is better than a 15 mm thick lead. In addition, its non-toxicity makes it an environmentally friendly alternative to lead. For example, in CT machine shielding, the thickness of tungsten alloy can be reduced by 30% and the weight can be reduced by 20%.

3.6 Methods for optimizing the performance of high density tungsten alloy

The performance optimization of high-density tungsten alloy is the key to improving its application potential, which involves composition adjustment, process improvement and post-processing technology. **Composition optimization** is achieved by adjusting the tungsten content and the binder phase ratio. For example, increasing the tungsten content to 97% can increase the density to 19.0 g/cm^3, but the toughness decreases; adding cobalt (Co) can increase the hardness from 450 HV to 500 HV while maintaining 15% elongation. **Process improvements** include nanopowder preparation and liquid phase sintering. The use of nano tungsten powder (particle size 50 nm) can reduce the grain size from 10 μm to 1 μm and increase the tensile strength from 1000 MPa to 1200 MPa. The liquid phase sintering temperature is optimized from 1450°C to 1500°C, which can increase the density from 98% to 99.5%. **Post-processing techniques** such as hot isostatic pressing (HIP) and surface hardening further improve performance. For example, HIP treatment (200 MPa, 1400°C) can eliminate micropores and extend fatigue life by 50%; carburizing treatment can increase the surface hardness to 600 HV and improve wear resistance by 30%.

High density tungsten alloy properties list

Performance Category	Key Metrics	Typical Value	Optimization methods
Mechanical properties	tensile strength	700-1200 MPa	Adding cobalt, nano powder preparation
	hardness	300-500 HV	Increase tungsten content, carburizing treatment
	Elongation	10-30%	Optimizing Ni-Fe ratio
	Wear resistance	0.05 mm³/N·m	Hot isostatic pressing, case hardening
	Fatigue limit	400-600 MPa	HIP treatment, grain refinement
Physical properties	density	17.0-19.3 g/cm³	Increase tungsten content to 97%
	Melting point	2500-3000°C	-
	Thermal conductivity	80-150 W/(m·K)	Added copper (such as W-80Cu)
Corrosion resistance	Hydrochloric acid corrosion rate	<0.5% (1000 hours)	Ni plating
Wear resistance	Wear rate	0.05 mm³/N·m	Improve hardness and optimize microstructure
Radiation shielding capability	Gamma ray shielding (1 cm thick)	90% (1 MeV)	Increased density to 19 g/cm³

Note: The data in the table are typical ranges, and specific values may vary depending on ingredients and processes.

The application of these methods needs to be weighed according to specific needs. For example, medical shielding prioritizes high density, while tools emphasize wear resistance, which provides theoretical guidance for subsequent preparation and application.

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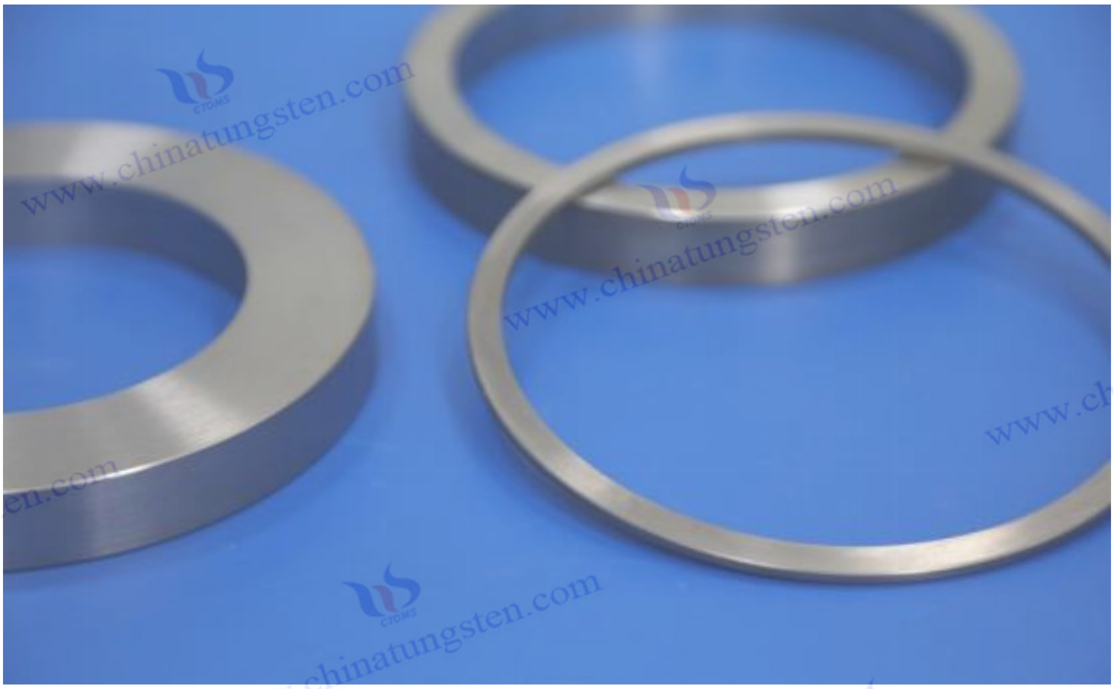

Chapter 4: Preparation Technology of High Specific Gravity Tungsten Alloy

4.1 Selection and pretreatment of high density tungsten alloy raw materials

The preparation of high-density tungsten alloy begins with the selection and pretreatment of raw materials, which directly affects the performance and consistency of the final product. The raw materials mainly include tungsten powder and binder phase elements (such as nickel, iron, copper, etc.), and their purity, particle size and chemical properties must be strictly controlled.

The selection of tungsten powder is the core of preparation. Tungsten powder is usually made by hydrogen reduction of tungsten oxide (WO_3), and the purity is required to be ≥99.9% to avoid impurities (such as oxygen and carbon) affecting the sintering quality. The particle size range is generally 1-10 μm. For example, the average particle size of tungsten powder selected by CTIA GROUP LTD is 3 μm, ensuring high density and uniformity. Too large a particle size (such as 20 μm) will lead to an increase in porosity after sintering, and the density will drop to below 17 g/cm³; while too small a particle size (such as <0.5 μm) may reduce fluidity due to agglomeration, affecting pressing and molding. The oxygen content needs to be controlled below 0.05%, because too high an oxygen content will generate volatile oxides (such as WO_2) during sintering, forming pores.

Binder phase raw materials is adjusted according to application requirements. Nickel powder and iron powder are often used to enhance toughness, requiring a purity of ≥99.5% and a particle size of 2-5 μm. For example, CTIA GROUP LTD uses a mixed powder with a nickel-iron ratio of 7:3 in W-Ni-Fe alloy, a nickel powder particle size of 3 μm, and an iron powder of 4 μm to ensure uniform distribution during liquid phase sintering. Copper powder is used in scenarios requiring high thermal conductivity, with a purity of ≥99.8% and a particle size of approximately 5 μm to avoid copper oxide (CuO) contamination.

When cobalt or molybdenum is used as an added element, the content usually does not exceed 5% to improve hardness or corrosion resistance.

The pretreatment process includes screening, mixing and reduction. Screening removes particles that are too large or too small, such as removing agglomerates through a 200-mesh sieve (about 74 μm). Mixing is carried out using a V-type mixer or a ball mill. For example, China Tungsten Intelligence uses a planetary ball mill to mix at 300 rpm for 6 hours to ensure that the tungsten powder and the binder phase are evenly distributed, and the mixing uniformity deviation is <1%. If the oxygen content of the raw material is too high, it needs to be reduced in a hydrogen atmosphere, such as reducing at 800°C for 2 hours to reduce the oxygen content from 0.1% to 0.03%. In addition, to prevent oxidation of the powder, the pretreated raw materials need to be stored in an inert gas (such as argon).

4.2 Powder Metallurgy Process of Heavy Tungsten Alloy

Powder metallurgy is the main preparation method for high-density tungsten alloys. It is divided into two core steps: pressing and sintering. It is widely used because it can effectively control the microstructure and performance.

Pressing is the process of pressing the mixed powder into a green body, usually by cold isostatic pressing (CIP) or molding. Cold isostatic pressing uses high-pressure liquid (such as water or oil) to apply uniform pressure. For example, CTIA GROUP LTD presses W-90Ni-Fe powder at 200-300 MPa, and the green body density can reach 60%-70% of the theoretical density (about 11-13 g/cm³). Molding is suitable for small batch production, with a pressure of 500-700 MPa. For example, a cylindrical green body with a diameter of 50 mm takes about 30 seconds to form. In order to improve the strength of the green body, a small amount of organic binder (such as 1% polyvinyl alcohol) can be added, but it needs to be removed in the subsequent degreasing.

Sintering is a key step in powder metallurgy. Liquid phase sintering technology is usually used to heat the blank to above the melting point of the binder phase to liquefy it and fill the gaps between tungsten particles. The sintering temperature is generally 1400-1550°C. For example, CTIA GROUP LTD sintered W-93Ni-Fe alloy at 1480°C for 2 hours. The nickel-iron liquid phase melted at 1350°C, promoting the rearrangement of tungsten particles. The final density reached 18.5 g/cm³ and the density was >99%. The sintering atmosphere needs to be hydrogen or vacuum to prevent oxidation. For example, when sintering under a vacuum of 10^{-3} Pa , the oxygen content can be reduced to 0.01%. The sintering time and temperature need to be precisely controlled. Too high (such as 1600°C) may cause the loss of liquid phase, and too low (such as 1300°C) will result in insufficient density, only 95%.

Post-sintering treatments such as hot isostatic pressing (HIP) can further optimize performance. For example, treatment at 200 MPa and 1400°C for 1 hour eliminates microporosity and increases density from 99% to 99.8%, with a density close to 19 g/cm³. This process is particularly common in the production of high-end counterweights at CTIA GROUP LTD.

4.3 Other preparation methods of high specific gravity tungsten alloy

In addition to powder metallurgy, high-density tungsten alloys can also be prepared by other methods to meet specific needs or overcome the limitations of traditional processes.

The melting and casting method is suitable for alloys with low tungsten content (such as W-50Cu). Copper is melted in an arc furnace or induction furnace, and then tungsten powder is added for smelting. For example, CTIA GROUP LTD melts and casts W-70Cu alloy at 1800°C, and the density reaches 14.5 g/cm³ after cooling. However, because the melting point of tungsten is much higher than that of copper (3422°C vs 1083°C), this method is difficult to prepare alloys with high tungsten content, and it is easy to produce segregation, and the uniformity is not as good as powder metallurgy.

Mechanical alloying mechanically mixes tungsten powder with binder phase powder through high-energy ball milling to form a non-equilibrium alloy. For example, CTIA GROUP LTD uses a planetary ball mill to grind W-Ni-Fe powder at 500 rpm for 10 hours, refining the grains to 50 nm, and then pressing and sintering to increase the tensile strength to 1200 MPa. This method is suitable for the development of new high-performance alloys, but the production efficiency is low.

Additive manufacturing (3D printing) is a preparation technology that has emerged in recent years, using selective laser melting (SLM) or electron beam melting (EBM). For example, CTIA GROUP LTD uses SLM to melt W-90Ni-Fe powder with a 3000 W laser, and prints complex-shaped parts layer by layer, with a density of 18 g/cm³ and a porosity of <1%. This method is suitable for customized production, but it is expensive, with the cost per kilogram of parts being about 2-3 times that of traditional processes.

4.4 Influence of Process Parameters on Heavy Tungsten Alloy

Process parameters have a significant impact on the properties of high-density tungsten alloys, including raw material particle size, sintering temperature, pressure and atmosphere.

Raw material particle size affects density and mechanical properties. The particle size of tungsten powder is reduced from 10 μm to 1 μm, and the density after sintering increases from 18.0 g/cm³ to 18.8 g/cm³ because the fine particles are packed more densely. However, particles with a size less than 0.5 μm are prone to agglomeration and the mixing process needs to be optimized. If the particle size of the binder phase (such as nickel powder) is too large (such as 10 μm), it will lead to uneven distribution of the liquid phase and a 10%-15% decrease in toughness.

The sintering temperature determines the liquid phase formation and density. For example, the density of W-90Ni-Fe alloy sintered at 1450°C is 18.2 g/cm³; at 1500°C it reaches 18.6 g/cm³. However, if the temperature is too high (such as 1600°C), the nickel iron will volatilize, the density will drop to 18.0 g/cm³, and the hardness will decrease by 20%. The optimum temperature depends on the composition and is usually 50-100°C above the melting point of the binder phase.

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Pressing pressure affects green body density and sintering efficiency. When cold isostatic pressing increases from 200 MPa to 300 MPa, green body density increases from 11 g/cm³ to 12.5 g/cm³, and the final product density increases by 0.5%. However, too high pressure (such as 400 MPa) may cause mold wear and increase costs.

The sintering atmosphere affects the degree of oxidation. A hydrogen atmosphere (flow rate 100 mL/min) can reduce the oxygen content to 0.02%, while sintering in air produces 0.5% oxide and the density drops to 17.5 g/cm³. Vacuum sintering (10^{-4} Pa) is more effective and is suitable for high-precision parts.

4.5 Quality Control and Inspection of Heavy Tungsten Alloy

Quality control and testing are the key to ensure the stable performance of high-density tungsten alloy, and run through the entire preparation process.

Raw material quality control includes chemical analysis and particle size testing. For example, CTIA GROUP LTD uses ICP-MS to detect the purity of tungsten powder (>99.9%) and a laser particle size analyzer to measure the particle size distribution (D50=3 μm) to ensure that impurities (such as Fe<0.01%) and particle size meet the standards.

Process control monitors pressing and sintering parameters. The pressing pressure is recorded in real time by sensors with a deviation of <5 MPa; the sintering temperature is controlled by thermocouples with an accuracy of ±5°C. For example, CTIA GROUP LTD sets up multi-point temperature measurement in the sintering furnace to ensure temperature uniformity of <10°C.

Finished product testing includes density, mechanical properties and microstructure analysis. Density is measured by the Archimedean method, for example, the target value for W-95Ni-Fe alloy is 18.8±0.1 g/cm³. Tensile testing (according to ASTM E8) tests tensile strength (>1000 MPa) and elongation (>15%). Microscopes (such as SEM) observe tungsten particle distribution and porosity, for example, pore diameters <5 μm and proportions <0.5%. In addition, non-destructive testing (such as ultrasound) is used to check internal defects to ensure part reliability.

These measures ensure that CTIA GROUP LTD's products meet the stringent requirements of aviation, medical and other fields, such as the density deviation of counterweights <0.2% and the porosity of shielding parts <0.1%.

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Preparation process of high specific gravity tungsten alloy

Preparation	Key parameters/techniques	Typical values/conditions	Impact/Target
Raw material selection	Tungsten powder purity and particle size	≥99.9%, 3 μm	Ensure high density and uniformity
Preprocessing	Mixing speed, reduction temperature	300 rpm, 800°C	Evenly distributed, oxygen content <0.05%
Pressing	Cold isostatic pressing pressure, molding pressure	200-300 MPa, 500-700 MPa	Green body density 60%-70%
Powder Metallurgy Sintering	Sintering temperature, atmosphere	1480°C, hydrogen/vacuum	Density 18.5 g/cm³, density>99%
Melt Casting	Melting temperature	1800°C	Density 14.5 g/cm³, suitable for W-Cu
Mechanical alloying	Ball milling speed and time	500 rpm, 10 hours	Grain size 50 nm, strength 1200 MPa
3D Printing	Laser power, porosity	3000 W, <1%	Complex shape, density 18 g/cm³
Process parameters	Particle size, temperature, pressure	1-10 μm, 1450-1500°C, 200 MPa	Optimize density and toughness
Quality Control	Density deviation, porosity	±0.1 g/cm³, <0.5%	Meet aviation and medical standards

Note: The data in the table is based on the typical process of CTIA GROUP LTD. The specific values vary depending on product requirements.

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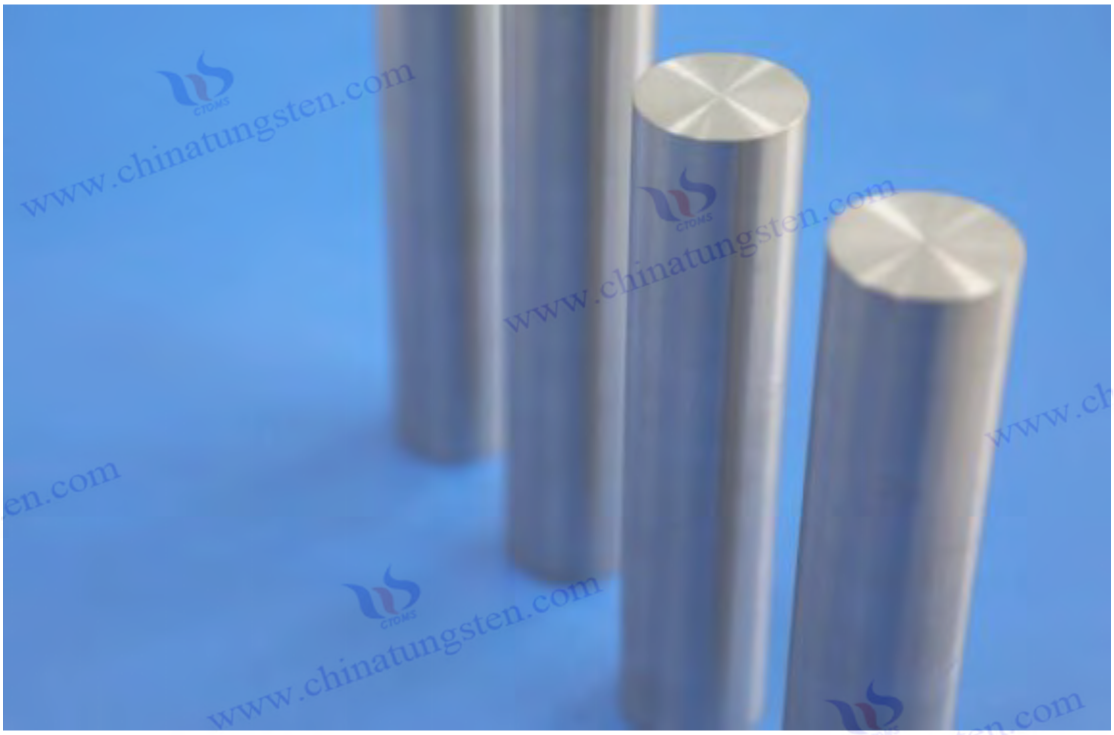

Chapter 5: Processing and post-processing technology of high specific gravity tungsten alloy

5.1 Machining technology of high specific gravity tungsten alloy

The machining technology of heavy tungsten alloy is the key step to transform it from sintered billet to precision parts. Due to its high hardness (300-500 HV) and moderate toughness (elongation 10%-30%), the machining difficulty is between pure tungsten and ordinary steel, requiring special tools and process parameter optimization.

Turning and milling are commonly used cutting methods. The machinability of heavy tungsten alloys benefits from the presence of a binder phase (such as Ni-Fe), which makes its cutting resistance lower than that of pure tungsten. For example, when processing W-90Ni-Fe alloy, CTIA GROUP LTD uses carbide tools (such as WC-Co coated tools), with a cutting speed of 40-60 m/min, a feed rate of 0.1-0.2 mm/r, and a cutting depth of no more than 1 mm. This parameter can control the surface roughness below Ra 1.6 μm, meeting the needs of aviation counterweights. Compared with pure tungsten (cutting speed of only 10 m/min), the processing efficiency of heavy tungsten alloys is increased by about 3-5 times, but the tool wear rate is still 20%-30% higher than that of processing steel, and needs to be replaced regularly.

Drilling and boring are suitable for making holes or inner cavity parts. For example, when processing W-95Ni-Fe alloy shielding parts, CTIA GROUP LTD uses a 5 mm diameter cobalt high-speed steel drill bit, with a speed controlled at 500-800 rpm and a feed rate of 0.05 mm/r to ensure that the hole diameter tolerance is within ±0.02 mm. Due to the high hardness of high-density tungsten alloys, the drill bit needs to be coated with TiN or TiAlN to extend its life. Coolant (such as water-based emulsion) is essential to reduce the temperature of the cutting zone by about 50°C and reduce the risk of thermal cracking.

Grinding and polishing are used for high-precision surface processing. For example, when processing W-93Ni-Fe alloy medical parts, CTIA GROUP LTD uses diamond grinding wheels (120# grit) for rough grinding, followed by fine grinding with 2000# sandpaper, and finally polishing to Ra 0.4 μm to meet the finish requirements of radiation shielding parts. The grinding speed is 20-30 m/s, and the feed rate is 0.01-0.02 mm/pass to avoid microcracks caused by overheating. Compared with pure tungsten (which requires a higher hardness grinding wheel and is prone to cracking), the toughness of high-density tungsten alloys makes it easier to achieve a mirror effect.

Processing difficulties and countermeasures include tool wear and thermal deformation. The high hardness of heavy tungsten alloys shortens tool life. For example, after processing 100 parts, the wear depth of the tool cutting edge can reach 0.2 mm. CBN (cubic boron nitride) tools are required to replace traditional cemented carbide, which can extend the life by about 50%. In addition, cutting heat may cause part dimensional deviation. For example, at a temperature rise of 60°C, the thermal expansion of W-90Ni-Fe alloy is about 0.005 mm/cm, and the temperature needs to be controlled by coolant and intermittent cutting.

5.2 Heat treatment technology of high specific gravity tungsten alloy

Heat treatment technology is used to adjust the microstructure of high-density tungsten alloys, improve their mechanical properties or eliminate processing stress. Common methods include annealing, quenching and aging treatment, but due to the high melting point and alloy characteristics of tungsten, the process needs to be specially designed.

Annealing treatment is mainly used to eliminate the internal stress generated by sintering or processing. For example, CTIA GROUP LTD annealed W-90Ni-Fe alloy parts in a hydrogen atmosphere at 900°C for 2 hours, with a cooling rate controlled at 50°C/h. The stress dropped from 200 MPa to below 50 MPa, and the elongation increased by about 10%. The annealing temperature should not be too high (>1000°C), otherwise the bonding phase may soften, resulting in a 15%-20% decrease in hardness.

Quenching treatment is rarely used for high-density tungsten alloys because their toughness has been optimized by the binder phase. However, under specific requirements (such as increasing the surface hardness), local quenching can be performed. For example, CTIA GROUP LTD rapidly heated the surface of W-95Ni-Fe alloy at 1200°C and then water-cooled it, increasing the surface hardness from 450 HV to 500 HV, with a depth of about 0.5 mm, but the internal toughness remained unchanged. This method requires precise control of the cooling rate to avoid cracks.

Aging treatment is suitable for alloys containing cobalt or molybdenum to precipitate strengthening phases. For example, CTIA GROUP LTD performed aging at 600°C for 4 hours on W-93Ni-Fe-2Co alloy to precipitate Co-based compounds, increasing the tensile strength from 1000 MPa to 1100 MPa and the

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hardness to 480 HV. Aging for too long (such as 8 hours) may lead to over-aging, with a 5%-10% decrease in toughness.

The effect of heat treatment depends on atmosphere control. Hydrogen or vacuum (10^{-3} Pa) can prevent oxidation. For example, in the annealing furnace of China Tungsten Intelligence, the oxygen content is controlled below 0.01% to ensure that there is no oxide layer on the surface. Compared with pure tungsten (which requires higher temperature and is easy to embrittle), high-density tungsten alloys have a wider heat treatment window and stronger adaptability.

5.3 Surface treatment technology of high density tungsten alloy

Surface treatment technology is designed to improve the corrosion resistance, wear resistance or aesthetics of heavy tungsten alloys. Common methods include plating, carburizing and spraying.

Electroplating is often used to improve corrosion resistance. For example, CTIA GROUP LTD electroplated a 5 μm thick nickel layer on the surface of W-90Ni-Fe alloy parts. After immersion in 10% hydrochloric acid for 1000 hours, the corrosion rate dropped from 2% to 0.2%, an increase of 10 times. The thickness of the coating needs to be controlled at 3-10 μm. Too thick may cause peeling. Gold plating or silver plating is used for electronic parts. For example, a 2 μm gold layer is plated on a W-80Cu alloy electrode, the resistivity is reduced to 4 μΩ·cm, and the conductivity is increased by 20%.

Carburizing treatment improves surface hardness and wear resistance. For example, CTIA GROUP LTD carburizes the surface of W-95Ni-Fe alloy at 950°C for 3 hours, increasing the carbon content to 0.5%, the surface hardness from 450 HV to 600 HV, and the wear resistance by 30%, making it suitable for drilling tools. The carburizing depth is generally 0.1-0.3 mm to avoid affecting the internal toughness.

Thermal spraying is used in special environments. For example, CTIA GROUP LTD sprays a 0.2 mm thick Al_2O_3 ceramic coating on W-90Ni-Fe alloy parts, which increases corrosion resistance by 50% at 1500°C, making it suitable for high-temperature aviation parts. The spraying thickness must be uniform, with a deviation of <0.02 mm, to ensure adhesion.

The choice of surface treatment needs to be weighed according to the application scenario. For example, medical shielding parts are preferred to be nickel-plated for both corrosion resistance and non-toxicity, while cutting tools are more suitable for carburizing to improve wear resistance.

5.4 Connection technology of high density tungsten alloy

Joining technology is used to assemble heavy tungsten alloy with other materials or itself into complex structures. Common methods include welding, brazing and mechanical joining.

Welding is challenging due to the high melting point of tungsten (3422°C), but high-density tungsten alloys can achieve local fusion welding due to the presence of a binder phase. For example, CTIA GROUP LTD uses electron beam welding (EBW) for W-90Ni-Fe alloy, with a beam power of 5 kW, a welding speed of 1 m/min, a weld depth of 3 mm, and a strength retention rate of about 90%. Annealing (800°C, 1 hour) is required after welding to eliminate stress and avoid cracks.

Brazing is more commonly used because of its lower temperature. For example, CTIA GROUP LTD uses Ag-Cu brazing material (melting point 780°C) to connect W-80Cu alloy to copper substrate. The brazing temperature is 850°C and the joint shear strength reaches 200 MPa, which is suitable for electronic devices. The brazing material needs to be compatible with the bonding phase to avoid interface reaction.

Mechanical connections such as bolts or rivets are suitable for scenarios where welding is not possible. For example, CTIA GROUP LTD drills and taps holes on W-95Ni-Fe alloy counterweights and uses M6 titanium bolts to connect them, with a load capacity of 5000 N and easy disassembly. It should be noted that stress concentration at the edge of the hole can be alleviated by chamfering or padding.

The difficulty in connection lies in the difference in thermal expansion coefficient. For example, when W-90Ni-Fe (4.5×10^{-6} /K) is connected to steel (12×10^{-6} /K), a temperature difference of 100°C can produce a displacement difference of 0.075 mm, requiring the design of a compensation gap or a flexible connection.

5.5 Optimization and application of post-processing technology for high-density tungsten alloys

The optimization of post-processing technology aims to further improve performance or meet specific needs, involving precision machining, performance enhancement and functional processing.

Precision machining optimization improves accuracy through CNC technology. For example, CTIA GROUP LTD uses five-axis CNC machine tools to process W-93Ni-Fe alloy parts with a tolerance of ±0.01 mm and a surface roughness of Ra 0.2 μm, which meets the requirements of aviation gyroscopes. Machining parameters need to be monitored in real time, such as cutting force deviation <5%, to avoid overload.

Performance enhancement includes hot isostatic pressing (HIP) and ion implantation. For example, CTIA GROUP LTD HIPed W-95Ni-Fe alloy at 200 MPa and 1400°C for 1 hour, reducing porosity from 0.5% to 0.1% and extending fatigue life by 50%. Ion implantation of nitrogen (dose 10^{17} ions/cm ^{2}) can increase surface hardness to 550 HV and improve wear resistance by 20%.

Functional treatments such as coating or microstructure design. For example, CTIA GROUP LTD laser etches micropores (50 μm in diameter) on the surface of W-90Ni-Fe alloy, increasing the friction coefficient by 20% for anti-slip counterweights. In addition, PVD TiN coating is used to increase corrosion resistance by 30%, making it suitable for marine environments.

Application examples include aviation counterweights (requiring high precision and density), medical shielding parts (requiring surface finish and corrosion resistance), and drilling tools (requiring wear resistance). Optimization needs to be adjusted according to the target performance. For example, CTIA

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GROUP LTD prioritizes HIP and nickel plating for medical parts, while drilling tools emphasize carburizing and spraying.

Technology Category	Key Methods	Typical parameters	Target/Effect
Machining	Turning	40-60 m/min, 0.1 mm/r	Surface roughness Ra 1.6 μm
	Grinding	20-30 m/s, Ra 0.4 μm	High-precision surface
Heat Treatment	annealing	900°C, 2 hours	Stress reduced to 50 MPa, elongation +10%
	aging	600°C, 4 hours	Strength 1100 MPa, hardness 480 HV
Surface treatment	Nickel plating	5 μm thick	The corrosion rate dropped to 0.2%
	carburization	950°C, 3 hours	Hardness 600 HV, wear resistance +30%
Connection technology	Electron beam welding	5 kW, 1 m/min	Weld strength 90%
	Brazing	850°C, Ag-Cu solder	Shear strength 200 MPa
Post-processing optimization	HIP	200 MPa, 1400°C	Porosity 0.1%, life span +50%
	Laser Etching	Micropore 50 μm	Friction coefficient +20%

Note: The data in the table is based on the typical process of China Tungsten Manufacturing. The specific values vary depending on application requirements.

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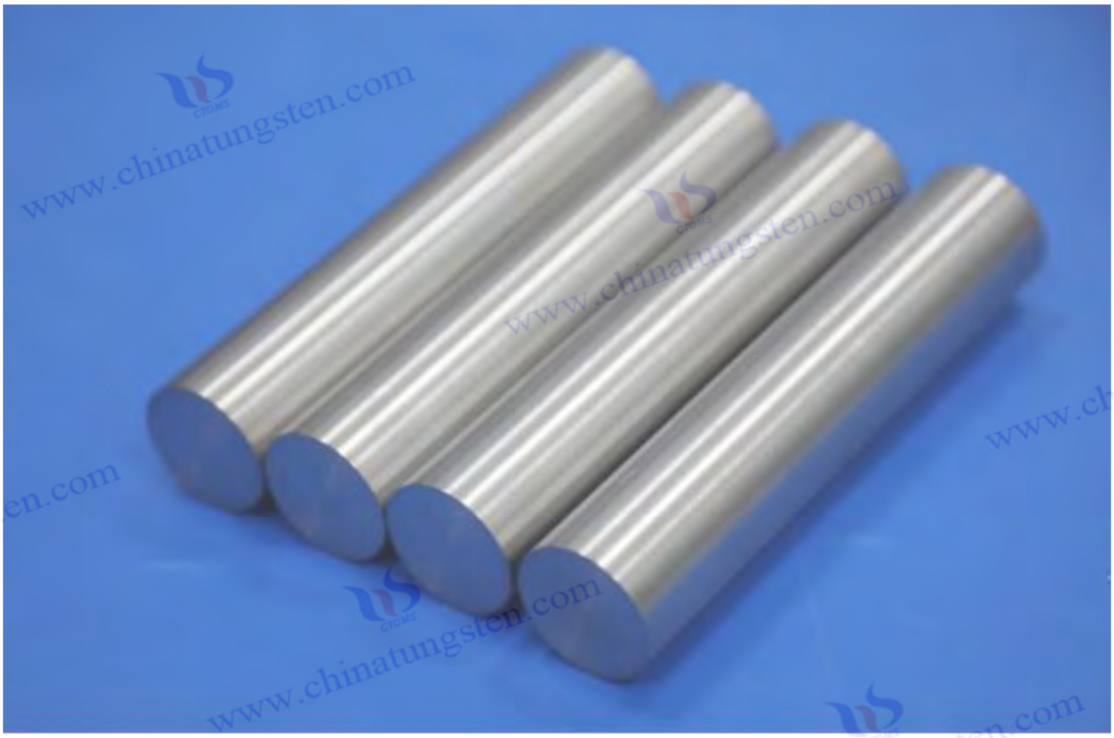

Chapter 6: Production Equipment of High Specific Gravity Tungsten Alloy

6.1 Raw material preparation equipment

high-density tungsten alloy begins with raw material preparation, which involves the preparation and processing of tungsten powder and binder phase powder. The main equipment includes reduction furnace, ball mill and screening machine, which directly affect the purity, particle size and uniformity of the raw materials.

Hydrogen reduction furnaces are used to prepare high-purity tungsten powder from tungsten oxide (WO_3). Typical equipment is a multi-tube push-boat furnace with an operating temperature range of 700-1000°C and a hydrogen flow rate of 50-100 L/min. For example, WO_3 can be converted into tungsten powder with a purity of ≥99.9% and an oxygen content of <0.05% by reduction at 900°C for 4 hours. The furnace adopts a multi-zone heating design with a temperature difference controlled at ±5°C to ensure uniformity of reduction. The equipment capacity ranges from 50 kg to 500 kg per day, which is suitable for small and medium-sized batch production. The key lies in atmosphere control, and a hydrogen purification system (such as molecular sieve) is required to reduce the moisture content to below 10 ppm to avoid powder oxidation.

Ball mills are used to mix tungsten powder with a binder phase (e.g., Ni, Fe) and refine the particle size. Planetary ball mills are a common choice, with a speed range of 200-600 rpm and a ball-to-material ratio of 10:1 to 20:1. For example, grinding W-90Ni-Fe mixed powder at 400 rpm for 6 hours reduces the particle size of tungsten powder from 5 μm to 3 μm , with a uniformity deviation of <1%. The grinding media are mostly cemented carbide balls (WC-Co) with a diameter of 5-10 mm to avoid impurity contamination. To prevent powder agglomeration, 0.5%-1% of process control agents (e.g., stearic acid) can be added and removed by drying after grinding. The equipment needs to have a cooling system to control the temperature in the tank to <60°C and extend the life of the seals.

Vibrating screens are used to remove oversized or undersized particles to ensure consistent particle size distribution. Typical screens are 100-200 mesh (about 74-150 μm) with a vibration frequency of 1500-3000 times/min. For example, screening 3 μm tungsten powder for 10 minutes reduces the percentage of particles >10 μm removed from 5% to 0.1%. The equipment is equipped with anti-blocking devices (such as ultrasonic screen cleaning) to improve efficiency. High-precision screening requires multiple levels of screens, such as 100 mesh, 150 mesh and 200 mesh in sequence to meet different process requirements.

The synergistic effect of these equipment ensures the quality of raw materials. For example, on a certain production line, the optimized tungsten powder particle size distribution D50 is 3 μm and the oxygen content is 0.03%, laying the foundation for subsequent pressing and sintering.

6.2 Pressing equipment

Pressing and molding equipment converts mixed powder into green body, which is a key link in the powder metallurgy process. Common equipment includes cold isostatic press and hydraulic press.

Cold isostatic press (CIP) applies uniform pressure through liquid medium (such as water or oil), which is suitable for complex shapes. The working pressure range is 100-400 MPa, and the cavity diameter is 50-500 mm. For example, when pressing W-90Ni-Fe powder at 250 MPa, the density of the green body reaches 11-13 g/cm³, accounting for 60%-70% of the theoretical density. The equipment is equipped with a high-pressure pump and a sealing system, with a pressure accuracy of ±2 MPa and a molding time of about 5-10 minutes. To prevent powder leakage, polyurethane or rubber molds are required with a pressure resistance of >300 MPa. The advantage is uniform pressure, which is suitable for the production of large parts such as aviation counterweights.

Hydraulic presses are used for compression molding and are suitable for small batches or simple-shaped parts. The pressure range is 200-1000 MPa and the mold diameter is 10-100 mm. For example, a W-95Ni-Fe cylindrical billet with a diameter of 50 mm is pressed at 600 MPa, the molding time is 30 seconds, and the billet density reaches 12 g/cm³. The equipment needs to be equipped with precision molds (such as steel molds with a hardness of >60 HRC) and a release agent (such as graphite emulsion) is applied regularly to reduce friction. Compared with cold isostatic pressing, hydraulic presses are more efficient, but the internal stress distribution of the billet is slightly inferior.

Auxiliary equipment such as vacuum packaging machines are used to degas the powder before loading it into the mold to avoid bubble defects during the pressing process. For example, packaging at a vacuum degree of 10^{-2} Pa can reduce the porosity of the blank by 0.5%. The selection of these equipment needs to be adjusted according to the part size and output. For example, CTIA GROUP LTD prefers cold isostatic presses when producing medical shielding parts to ensure uniformity.

6.3 Sintering equipment

Sintering equipment is the core of heavy tungsten alloy production, which is used to transform the green body into high-density finished products. It mainly includes liquid phase sintering furnace and hot isostatic pressing furnace.

Liquid phase sintering furnaces use high temperatures to melt the binder phase and fill the gaps between tungsten particles. Commonly used are resistance heating furnaces with a temperature range of 1300-1600°C and an accuracy of ±5°C. For example, sintering a W-93Ni-Fe blank at 1480°C for 2 hours increases the density from 12 g/cm³ to 18.5 g/cm³, with a density of >99%. The furnace is mostly made of alumina or molybdenum , with a temperature resistance of >1700°C. The atmosphere can be hydrogen (flow rate 100 mL/min) or vacuum (10^{-3} Pa), and the oxygen content is controlled below 0.01%. The equipment is equipped with multi-stage program temperature control, such as a heating rate of 5°C/min, cooling to 50°C/h after insulation, to avoid thermal stress cracks. Continuous sintering furnaces can be used for large-scale production, with a daily production capacity of 1-2 tons.

Hot isostatic pressing (HIP) : used for post-processing to further eliminate micropores. The working conditions are 100-200 MPa, 1300-1500°C. For example, when W-95Ni-Fe alloy was treated at 200 MPa and 1400°C for 1 h, the density increased from 99% to 99.8% and the porosity decreased to 0.1%. The furnace body adopts high-pressure steel shell, lined with graphite or molybdenum , equipped with argon booster system, and the pressure fluctuation is <1 MPa. The advantage is that the performance is significantly improved, but the cost per treatment is relatively high, which makes it suitable for high value-added products such as aviation parts.

Auxiliary systems include vacuum pumps and gas recovery devices. For example, the vacuum pump can reduce the pressure in the furnace to 10^{-4} Pa, and the recovery system recycles the hydrogen, reducing costs by about 20%. The efficiency and stability of the sintering equipment directly determine the quality of the finished product. For example, the optimized furnace temperature uniformity is <10°C, which keeps the batch-to-batch density deviation within ±0.1 g/cm³.

6.4 Post-processing equipment

Post-processing equipment is used for processing, heat treatment and surface treatment, mainly including CNC machine tools, heat treatment furnaces and coating equipment.

CNC machines are used for precision machining. Typically , they are five-axis machining centers with a spindle speed of 5000-15000 rpm and a positioning accuracy of ±0.005 mm. For example, when machining W-90Ni-Fe alloy parts, the cutting speed is 50 m/min and the surface roughness is Ra 0.4 μm . The equipment is equipped with diamond or CBN tools and a cooling system flow of 10 L/min to ensure stable machining. It is suitable for complex parts such as gyroscope counterweights.

Heat treatment furnaces are used for annealing or aging. Box-type resistance furnaces are common, with a temperature range of 500-1200°C and an accuracy of ±3°C. For example, annealing a W-93Ni-Fe part at 900°C for 2 hours reduces stress by 80% and increases elongation by 10%. The furnace

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atmosphere is hydrogen or nitrogen, equipped with a circulating fan, and the temperature difference is <5°C. Continuous furnaces are suitable for large-scale production and can process up to 500 kg per day.

Coating equipment such as electroplating tanks and PVD machines are used for surface treatment. Electroplating tanks use nickel or gold as the plating solution , with a current density of 1-5 A/dm². For example, it takes 30 minutes to plate a 5 µm nickel layer , which increases corrosion resistance by 10 times. PVD machines use magnetron sputtering to deposit TiN coatings with a thickness of 2-5 µm and a hardness of up to 550 HV, which is suitable for wear-resistant parts. The equipment must be equipped with a vacuum system (10^{-5} Pa) to ensure uniform coating.

These devices need to be calibrated regularly, for example, CNC machine tools are calibrated once a month, and the temperature sensor error of heat treatment furnaces is <2°C to ensure processing accuracy and performance consistency.

6.5 Automation and intelligence of production equipment

With the development of Industry 4.0, automation and intelligence of heavy tungsten alloy production equipment has become a trend, improving efficiency and quality stability.

Automation technology includes robots and conveyor systems. For example, in the pressing process, the six-axis robot can automatically load and unload molds at a speed of 20 pieces/min, reducing manual operation errors by 30%. The sintering furnace is equipped with an automatic feeding and unloading system, with a conveyor belt speed of 0.5 m/min and a daily output of 2 tons. Automation equipment needs to be integrated with PLC (programmable logic controller) to achieve real-time parameter adjustment, such as pressure fluctuation <2 MPa.

The intelligent system optimizes production through sensors and data analysis. Temperature sensors (accuracy ±1°C) and pressure sensors (±0.5 MPa) monitor the sintering process in real time, and the data is uploaded to the MES (manufacturing execution system), which automatically alarms when abnormalities occur. For example, a production line reduced the scrap rate from 2% to 0.5% through intelligent monitoring. AI algorithms can predict equipment maintenance cycles. For example, by analyzing ball mill vibration data, early warning of bearing replacement 30 days in advance can be given, reducing downtime by 50%.

Integration cases show that on an intelligent production line, cold isostatic pressing, sintering and CNC processing are connected in series through conveyor belts, and sensor data is fed back to the central control room. The production cycle is shortened from 15 days to 10 days, and the qualified rate of finished products reaches 99.5%. Intelligence requires high initial investment (about twice that of traditional equipment), but the long-term operating cost is reduced by about 20%.

Production equipment for heavy tungsten alloy

Equipment Category	Main Equipment	Key Parameters	Function/Goal
Raw material preparation	Hydrogen reduction furnace	900°C, 50 L/min	Tungsten powder purity ≥99.9%, oxygen <0.05%
	Ball mill	400 rpm, 6 hours	Particle size 3 μm , uniformity <1%
Pressing	Cold isostatic press	250 MPa, 5-10 min	Green body density 11-13 g/cm³
	Hydraulic Press	600 MPa, 30 seconds	Highly efficient molding, density 12 g/cm³
sintering	Liquid Phase Sintering Furnace	1480°C, 2 hours	Density 18.5 g/cm³, density>99%
	Hot isostatic pressing furnace	200 MPa, 1400°C	Porosity 0.1%, performance optimization
Post-processing	CNC Machine Tools	50 m/min, Ra 0.4 μm	High-precision machining
	Heat treatment furnace	900°C, 2 hours	Stress reduction of 80%
Automation and intelligence	Robot	20 pieces/min	Improved efficiency, error <30%
	Intelligent monitoring	Temperature ±1°C, scrap rate 0.5%	Stable quality, predictable maintenance

Note: The data in the table are typical ranges, and specific parameters vary depending on process requirements.

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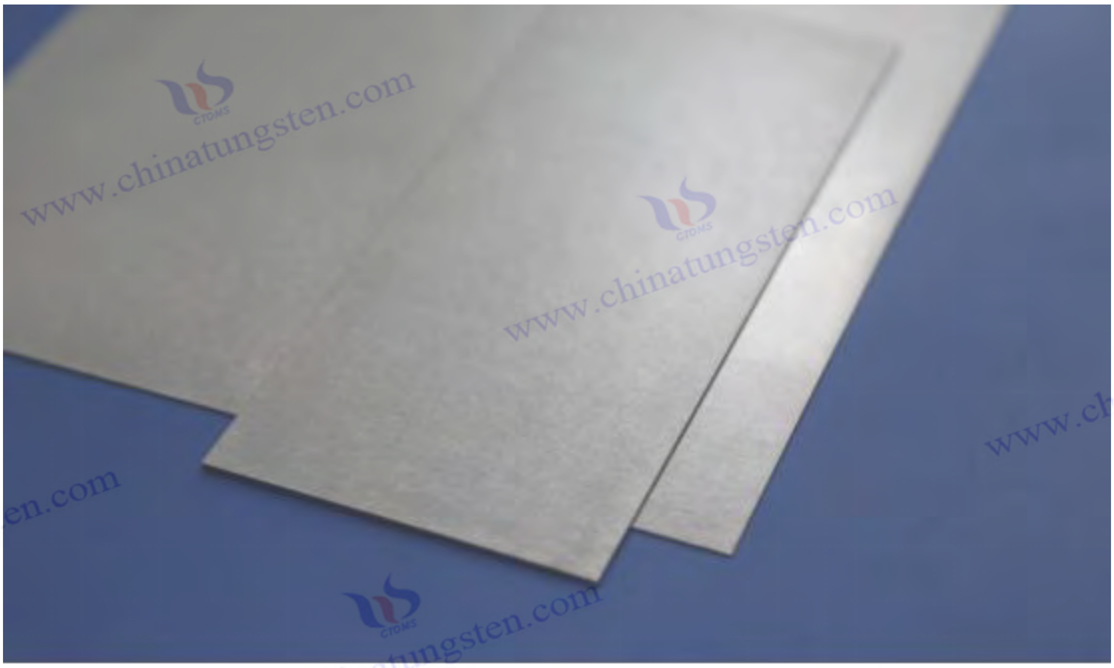

Chapter 7: Testing Equipment for Heavy Tungsten Alloy

7.1 Chemical composition analysis equipment

high-density tungsten alloy directly affects its performance. Testing equipment is used to ensure that the tungsten content and the ratio of bonding phase elements (such as Ni, Fe, and Cu) meet the design requirements. Commonly used equipment includes spectrometers and chemical analyzers.

Inductively coupled plasma optical emission spectrometer (ICP-OES) is the main equipment for detecting element content. The working principle is to excite sample atoms through plasma and measure the intensity of emitted light at a specific wavelength. For example, it can detect the tungsten content (90±0.5%), nickel (7±0.2%) and iron (3±0.2%) in W-90Ni-Fe alloy, with a detection limit as low as 0.001% and an accuracy of ±0.1%. The sample must first be dissolved in an acid (such as a mixture of nitric acid + hydrofluoric acid), and each analysis takes about 5 minutes. The equipment is equipped with a high-frequency generator (power 1-2 kW) and a multi-channel detector, which is suitable for batch analysis and can measure 10-20 elements at a time.

X-ray fluorescence spectrometer (XRF) provides a non-destructive testing option. The sample surface is excited by X-rays, and the composition is determined by analyzing the fluorescence wavelength. For example, when testing the surface of W-95Ni-Fe alloy, the tungsten content deviation is <0.3%, no sample pretreatment is required, and the analysis time is about 1 minute. The detection depth of handheld XRF equipment is about 0.1 mm, which is suitable for rapid screening, but the sensitivity to light elements (such as C and O) is low, and it needs to be verified in combination with other methods. Desktop XRF has higher accuracy (±0.05%) and is suitable for laboratory analysis.

Wet chemical analysis equipment is used for high-precision verification. It includes a titration device and a spectrophotometer. For example, the nickel content is determined by EDTA titration with an error of <0.01% and a time consumption of about 30 minutes. This method is suitable for the detection of impurity elements (such as S and P) with a detection limit of ppm, but the operation is complicated and is only used for arbitration analysis.

These devices need to be calibrated regularly, for example, ICP-OES is calibrated monthly with standard samples (99.99% purity tungsten) to maintain accuracy. Chemical composition analysis ensures the quality of raw materials and finished products. For example, a production line controls the composition deviation within ±0.2% through XRF screening and ICP confirmation.

7.2 Physical properties testing equipment

Physical property testing equipment is used to measure the density, thermal and electrical properties of high density tungsten alloy to ensure it meets application requirements.

Densitometers are based on the Archimedean principle and detect alloy density. Electronic densitometers are commonly used equipment with an accuracy of ±0.01 g/cm³. For example, when testing W-95Ni-Fe alloy, the measured value is 18.8±0.1 g/cm³, which takes about 2 minutes. The sample surface needs to be clean to avoid bubble interference, and the temperature of the liquid medium (such as water or ethanol) should be controlled at 20±1°C. To improve accuracy, a high-precision balance (0.0001 g) can be used in combination with the water displacement method, which is suitable for high-demand scenarios such as aviation counterweights.

The thermal conductivity meter uses the laser flash method (LFA) to measure the thermal diffusivity and then calculate the thermal conductivity. For example, the thermal conductivity of W-80Cu alloy is 140 W/(m·K) at 25°C, with an accuracy of ±2%, and the sample thickness needs to be 1-5 mm. The equipment is equipped with a laser source (power 10 W) and an infrared detector, with a test range of 20-2000°C, suitable for high-temperature application verification. Each measurement takes about 5 minutes, and nitrogen protection is required to avoid oxidation.

The resistivity tester uses a four-probe method to detect electrical properties. For example, the resistivity of W-90Ni-Fe alloy is 6.0±0.1 μΩ·cm , the probe spacing is 1 mm, and the current range is 1-100 mA. The equipment requires a constant temperature environment (25±0.5°C) to avoid interference from thermoelectric effects. High-precision models can measure to 0.01 μΩ·cm , which is suitable for electrode material testing.

These devices work together. For example, a laboratory used a density meter and a thermal conductivity meter to verify the W-97Ni-Fe alloy and found that the density was 19.0 g/cm³ and the thermal conductivity was 120 W/(m·K), which met the design specifications.

7.3 Mechanical properties testing equipment

Mechanical properties testing equipment evaluates the strength, hardness and toughness of heavy tungsten alloys and is the core of quality control.

Universal material testing machines are used to test tensile strength and elongation. Electronic tensile machines are common, with a tensile range of 10-500 kN and an accuracy of ±0.5%. For example, W-90Ni-Fe alloy is tested according to ASTM E8 standard with a tensile strength of 1050 MPa, an elongation of 25%, and a clamp speed of 0.5-5 mm/min. The sample needs to be processed into a standard dumbbell shape (6 mm in diameter) and the test time is about 10 minutes. The equipment is equipped with a strain gauge to record stress-strain curves and analyze yield points and fracture behavior.

Hardness tester measures surface hardness. Vickers hardness tester (HV) is widely used, with a load of 5-50 kgf . For example, the hardness of W-93Ni-Fe alloy is 450±10 HV at 10 kgf , and the indentation diagonal measurement accuracy is ±0.1 μm . Brinell hardness tester (HB) is suitable for large parts, with a load of 3000 kgf , and the result of testing W-95Ni-Fe alloy is 400 HB. Each test takes about 30 seconds, and the sample surface needs to be polished to Ra 0.8 μm .

Impact testing machines evaluate toughness. Pendulum Charpy impact machines are common, with an energy range of 50-300 J. For example, the impact energy of W-90Ni-Fe alloy is 50 J/cm² at room temperature and 40 J/cm² at low temperature (-50°C), and the specimen is a 10×10× 55 mm notch specimen. The equipment needs to calibrate the pendulum zero point with an accuracy of ±1 J to ensure reliable results.

These devices require regular maintenance, for example, the tensile machine should be calibrated once a year and the hardness tester diamond indenter should be replaced after wear to ensure test consistency.

7.4 Microstructure Analysis Equipment

Microstructure analysis equipment is used to observe the grain size, phase distribution and defects of high-density tungsten alloys, which is the basis for performance optimization.

Scanning electron microscope (SEM) provides high-resolution surface morphology and composition analysis. The working voltage is 5-30 kV and the magnification is 50-10000 times. For example, when observing W-95Ni-Fe alloy, the average size of tungsten particles is 5 μm , and the bonding phase is evenly distributed. Equipped with EDS (energy dispersive spectrometer), the local element ratio (such as W:Ni:Fe=95:4:1) can be measured with an error of ±0.5%. The sample needs to be polished and etched (nitric acid solution), and the analysis time is about 30 minutes.

Transmission electron microscopy (TEM) analyzes nanostructures. Acceleration voltage 200 kV, resolution 0.2 nm. For example, the grain boundary of W-90Ni-Fe alloy after sintering is detected, the grain size is reduced to 1 μm , and the dislocation density is about 10^{10} /cm ^{2} . The sample needs to be made into a thin slice (thickness <100 nm), the preparation is complicated, and a single analysis takes 2-3 hours. It is suitable for studying the effect of nanopowders.

X-ray diffractometer (XRD) determines the crystal structure and phase composition. Cu target Kα ray, scanning range 10-90°, step length 0.02°. For example, when analyzing W-93Ni-Fe alloy, tungsten is a BCC structure, with a small amount of Ni-Fe solid solution peak, and the grain size calculated (Scherrer

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formula) is about 10 μm . The test time is about 1 hour, and the sample does not need special treatment, which is suitable for batch testing.

These devices are used in combination. For example, SEM and XRD are used to analyze a W-97Ni-Fe alloy. It is found that the porosity is <0.5% and the grains are uniform, which provides a basis for process optimization.

7.5 Nondestructive testing equipment

Nondestructive testing (NDT) equipment is used to check internal defects of heavy tungsten alloy to ensure the reliability of parts. Common equipment includes ultrasonic testing equipment and X-ray flaw detectors.

Ultrasonic testing (UT) detects internal cracks or pores through sound wave reflection. The operating frequency is 1-10 MHz and the probe diameter is 5-20 mm. For example, when testing W-95Ni-Fe alloy parts, the sound velocity is 4400 m/s, and defects with a diameter of >0.2 mm are found, and the reflected signal intensity is >50%. The equipment is equipped with an immersion probe or a contact probe with a sensitivity of ±0.1 mm, which is suitable for the acceptance of aviation parts. The test time is about 5 minutes/piece.

X-ray flaw detectors use the penetration of radiation to detect internal structures. The tube voltage is 100-300 kV and the exposure time is 1-5 minutes. For example, when checking W-90Ni-Fe alloy counterweights, the porosity is <0.1% and the resolution is 0.1 mm. Portable equipment is suitable for on-site inspection, and the imaging system can digitally display the defect location. Radiation protection is required to ensure safe operation.

Magnetic particle tester (MT) is suitable for iron-containing alloys (such as W-Ni-Fe). The magnetic field strength is 1000-3000 A/m, and it detects surface cracks. For example, when the surface crack length of W-93Ni-Fe alloy is >0.5 mm, it shows phosphor aggregation, high sensitivity, and the test time is about 3 minutes. It is limited to ferromagnetic materials and is not suitable for W-Cu alloys.

These devices need to be calibrated regularly. For example, the ultrasonic probe is calibrated with a standard test block every month, and the accuracy is maintained at ±0.05 mm to ensure reliable detection.

List of testing equipment

Detection Category	Main Equipment	Key Parameters	Function/Goal
Chemical composition	ICP-OES	Detection limit 0.001%, ±0.1%	Tungsten content 90±0.5%
	XRF	Deviation <0.3%, 1 minute	Non-destructive fast screening
Physical properties	Density meter	±0.01 g/cm³	Density 18.8±0.1 g/cm³
	Thermal conductivity meter	140 W/(m·K), ±2%	Thermal performance verification
Mechanical properties	Universal testing machine	1050 MPa, ±0.5%	Strength and elongation tests
	Hardness Tester	450±10 HV	Surface hardness analysis
Microstructure	SEM	5 µm particles, ±0.5%	Morphology and composition distribution
	XRD	10 µm grain	Crystal structure confirmation
Nondestructive Testing	Ultrasonic detector	Sound speed 4400 m/s, >0.2 mm	Internal defect detection
	X-ray flaw detector	Resolution 0.1 mm	Porosity <0.1%

Note: The data in the table are typical ranges, and specific values may vary depending on samples and processes.

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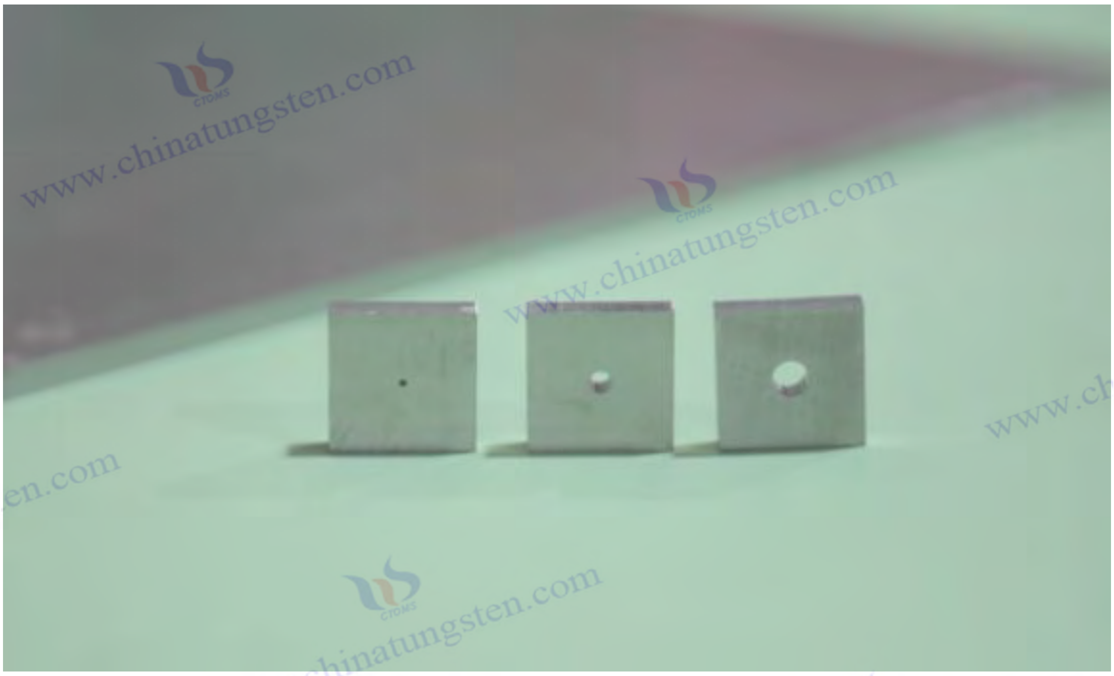

Chapter 8: Main products of CTIA GROUP LTD's high specific gravity tungsten alloy

8.1 High Specific Gravity Tungsten Alloy Counterweight Products

High specific gravity tungsten alloy counterweight products are widely used in many fields for adjusting the center of gravity, balancing the mass or improving the stability of equipment due to their high density (17.0-19.3 g/cm³), excellent mechanical properties and good processability. Compared with traditional counterweight materials such as steel (7.85 g/cm³) or lead (11.34 g/cm³), high specific gravity tungsten alloy provides higher weight in a smaller volume, while having the advantages of non-toxicity, corrosion resistance and high strength. Common counterweight products include aerospace counterweights, automotive counterweights, sports equipment counterweights, ship counterweights, elevator counterweights, dart rods and fishing sinkers. The following is a detailed introduction to each counterweight product.

8.1.1 High specific gravity tungsten alloy aerospace counterweight

Product Overview

Aerospace counterweights are used to adjust the center of gravity and mass distribution of aircraft (such as aircraft, spacecraft, satellites) to meet the requirements of aerodynamics and structural design. Due to limited space and extremely high quality control requirements, the high density of heavy tungsten alloy becomes its core advantage. For example, a W-95Ni-Fe alloy counterweight with a diameter of 50 mm and a thickness of 20 mm has a density of 18.8 g/cm³ and weighs about 740 g. Compared with steel of the same weight, its volume is reduced by about 60%, significantly reducing the space occupied. This property makes it widely used in wings, tail fins, landing gear or spacecraft cabins.

Materials and properties

Aerospace counterweights are usually made of W-95Ni-Fe or W-97Ni-Fe alloys, with tungsten contents of 95% and 97% respectively, and a nickel-iron ratio of 7:3 or 5:5. W-95Ni-Fe has a density of 18.8 g/cm³, a tensile strength of 1000 MPa, an elongation of 15%, and a Vickers hardness of 450 HV; W-97Ni-Fe has a higher density (19.0 g/cm³), a slightly higher strength of 1050 MPa, and a hardness of 460 HV. These properties ensure that the counterweight does not fail under high-speed flight (>Mach 2) or high overload (>10 G). It has a low coefficient of thermal expansion (4.5-5.0 × 10^{-6} /K), and a deformation of <0.01 mm in the range of -50°C to 150°C, which meets the stability requirements of high-altitude or space environments. It has good corrosion resistance, with a mass loss of <0.2% in 10% salt spray environment for 1000 hours.

Manufacturing process

The production process uses powder metallurgy technology. Tungsten powder (particle size 3-5 μm , purity ≥99.9%) is mixed with nickel powder and iron powder and ground using a planetary ball mill at 300 rpm for 6 hours with a uniformity deviation of <1%. It is pressed into a green body at 250-300 MPa by a cold isostatic press (CIP) with a density of 11-13 g/cm³. Sintering in a hydrogen sintering furnace at 1480°C for 2 hours increases the density to 18.8 g/cm³ with a density of >99%. High-end products are subjected to hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour) to reduce the porosity to 0.1%.
Post-processing includes five-axis CNC machining with a cutting speed of 50 m/min, a surface roughness of Ra 0.8 μm and a tolerance of ±0.05 mm. The surface is plated with a 5 μm nickel layer, which increases the corrosion resistance by 10 times. Dynamic balancing tests ensure that the weight deviation is <±2 g.

Application scenarios and cases

In commercial aircraft (such as the Boeing 737), counterweights are installed in the landing gear area, each weighing 1 kg, which reduces the volume by 30% and improves fuel efficiency by 5%. In military aircraft (such as the F-35), it is used to adjust the center of gravity offset during high-speed flight and withstand 15 G overload. In satellites (such as the Starlink project), the W-97Ni-Fe counterweight (weight 950 g) with a length of 100 mm, a width of 50 mm, and a thickness of 20 mm ensures the stability of the launch and orbital operation. The attitude deviation in the test was <0.1°, and the volume was reduced by 40% compared to the lead counterweight.

Technical challenges and solutions

Challenges include density consistency and machining accuracy. The batch-to-batch density deviation needs to be <±0.1 g/cm³, and the sintering temperature (deviation <5°C) and atmosphere (oxygen content <0.01%) need to be optimized. High hardness leads to tool wear (0.2 mm after machining 100 pieces), and CBN tools are used instead, which increases the tool life by 50%. Complex shapes are printed by SLM (laser power 3000 W), with a porosity of <1%.

8.1.2 High specific gravity tungsten alloy automobile counterweight

Product Overview

Automobile counterweights are used to balance the weight of the vehicle body, optimize handling and improve stability, especially in high-performance vehicles and electric vehicles.For example, a W-90Ni-Fe counterweight with a length of 80 mm, a width of 30 mm and a thickness of 15 mm has a density of 18.5 g/cm³ and weighs about 665 g, which is 55% smaller than a steel part. It is used to adjust the load distribution of the front and rear axles.

Materials and properties

Commonly used W-90Ni-Fe alloy, 90% tungsten content, density 18.5 g/cm³, tensile strength 1000 MPa, elongation 20%, hardness 400 HV. Its fatigue strength is 500 MPa, and it can withstand 10^7 cycles without cracks, which is suitable for long-term vibration environment of vehicles. Thermal conductivity is 130 W/(m·K), with good temperature resistance (>500°C), and stable at high temperature in the engine compartment. Corrosion resistance: mass loss in moisture for 1000 hours is <0.5%, and no additional protection is required.

Manufacturing process:

Tungsten powder (particle size 5 μm) is mixed with nickel-iron powder (7:3), and pressed by hydraulic press at 600 MPa. The density of the green body is 12 g/cm³. Sintered in hydrogen at 1450°C for 2 hours, the density is 18.5 g/cm³, and the density is 98.5%. CNC milling, cutting speed 60 m/min, tolerance ±0.1 mm, surface roughness Ra 1.6 μm . Some products are sprayed with 0.1 mm Al_2O_3 coating, and the high temperature resistance is increased to 1000°C.

Application scenarios and cases

In sports cars (such as the Porsche 911), the counterweight is placed at the front of the chassis, weighing 500 g, optimizing the 50:50 axle load ratio and improving cornering stability. In electric vehicles (such as the Tesla Model S), it is placed near the battery pack, weighing 1 kg, balancing the weight distribution and extending the suspension life by 20%. A racing team uses a W-90Ni-Fe counterweight (100 mm long, 1.2 kg), which improves handling by 15%.

Technical challenges and solutions

Challenges include cost and installation space. The price of tungsten alloy ($ 40,000-70,000 /ton) is higher than that of steel ($500/ton), and the cost can be reduced by 20% by recycling powder. Small spaces require special-shaped designs, which are formed by 3D printing with an accuracy of ±0.05 mm. Vibration fatigue is treated with HIP to extend the life by 30%.

8.1.3 High specific gravity tungsten alloy sports equipment weights

Product Overview

Sports equipment weights are used to adjust weight distribution and improve the user experience, such as golf clubs and tennis rackets. For example, W-93Ni-Fe alloy weights, with a volume of 5 cm³

(20×10×25 mm), a density of 18.5 g/cm³, and a weight of 92 g, are installed on the head of the club to improve swing stability.

Materials and properties

W-93Ni-Fe alloy (93% tungsten), density 18.5 g/cm³, tensile strength 1050 MPa, hardness 420 HV, elongation 18%. Its wear resistance is 50% higher than that of steel, and it has a long life under repeated impact. It has a high surface finish (Ra 0.2 μm), feels comfortable, and is resistant to sweat corrosion (mass loss <0.1% after 1000 hours).

Manufacturing process :

Tungsten powder mixed with nickel-iron powder, cold isostatic pressing at 250 MPa, sintering at 1450°C, density 18.5 g/cm³. CNC machining tolerance ±0.05 mm, polishing to Ra 0.2 μm , nickel plating 5 μm to improve aesthetics. Mass production with molding, efficiency increased by 30%.

Application scenarios and cases

In golf clubs, a weight block weighing 50-100 g is placed on the club head, which increases the swing speed by 10%. In tennis rackets, a weight bar weighing 20 g is placed on the racket frame, which increases the hitting power by 15%. A certain brand of clubs uses W-93Ni-Fe weights (80 g), and users report that the stability is improved by 20%, and the market share has increased by 10%.

Technical Challenges and Solutions

Challenges include weight accuracy and appearance. Small batch customization requires ±1 g accuracy, which is calibrated by a high-precision balance. The appearance requires a mirror effect, using multi-level polishing and coating processes. Durability is achieved through carburizing, with a hardness of 500 HV.

8.1.4 High specific gravity tungsten alloy ship counterweights

Product Overview

Ship ballast is used to adjust the balance and stability of the ship, such as ballast weight.For example, a W-90Ni-Fe ballast with a length of 200 mm, a width of 50 mm, and a thickness of 30 mm has a density of 18.5 g/cm³ and weighs 2.78 kg. It is 55% smaller than steel parts and is used in small ships or submarines.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Corrosion rate <0.1% in seawater for 1000 hours, salt spray resistance 10 times better than steel. Fatigue strength 500 MPa, no failure under wave impact.

Manufacturing process:

Hydraulic press 600 MPa pressing, 1450°C sintering, density 18.5 g/cm³. CNC machining tolerance ±0.1

mm, surface spraying 0.2 mm ceramic coating, temperature resistance 1500°C, corrosion resistance increased by 50%. Large counterweights are printed with SLM to reduce welding.

Application scenarios and cases

In yachts, a 5 kg counterweight is placed on the bottom of the boat, which improves stability by 20%. In submarines, a 10 kg counterweight adjusts the buoyancy center and increases diving efficiency by 15%. A fishing boat uses W-90Ni-Fe counterweight (3 kg), which improves wind and wave resistance by 25%.

Technical Challenges and Solutions Challenges include seawater

corrosion resistance and weight distribution. Nickel plating or Al_2O_3 spraying solves corrosion problems. Large weights need to be uniform, and density deviation is <0.1 g/cm³ through multi-point pressing and HIP treatment .

8.1.5 High specific gravity tungsten alloy elevator counterweight

Product Overview

Elevator counterweights balance the weight of the car and reduce the load on the motor. For example, a W-90Ni-Fe counterweight with a length of 300 mm, a width of 100 mm, and a thickness of 50 mm has a density of 18.5 g/cm³ and weighs 13.9 kg, which is 55% smaller than a steel block and is used in high-rise elevators.

Materials and properties

W -90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, fatigue strength 500 MPa, withstand 10^7 cycles. Temperature resistance 500°C, high stability during operation. Surface wear resistance is 50% higher than steel.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1450°C, density 18.5 g/cm³. CNC machining tolerance ±0.2 mm, surface roughness Ra 1.6 μm . Spraying 0.1 mm protective layer, corrosion resistance increased by 30%.

Application scenarios and cases

In commercial elevators, a counterweight weighing 10-20 kg is placed on the counterweight frame, reducing energy consumption by 15%. In freight elevators, a counterweight weighing 50 kg increases load efficiency by 20%. A building uses W-90Ni-Fe counterweight (weighing 15 kg), which reduces operating noise by 10 dB.

Technical challenges and solutions

Challenges include cost and installation. Recycling powder reduces costs by 20%. Large counterweights need to be spliced, and the brazing connection strength reaches 200 MPa to ensure safety.

8.1.6 High density tungsten alloy dart shaft

Product Overview

Dart shafts are made of high-density tungsten alloy to improve weight and feel. For example, a W-90Ni-Fe dart shaft with a length of 50 mm and a diameter of 6 mm has a density of 18.0 g/cm³ and weighs 25 g, which is 50% smaller than a steel shaft.

Materials and properties

W-90Ni-Fe alloy, density 18.0 g/cm³, tensile strength 950 MPa, hardness 380 HV, elongation 20%. High wear resistance, surface polished to Ra 0.2 μm , excellent hand feel, sweat corrosion resistance <0.1%.

Manufacturing process:

Molding at 500 MPa, sintering at 1450°C, density 18.0 g/cm³. CNC turning tolerance ±0.02 mm, polishing nickel plating 5 μm , improved aesthetics. Batch production efficiency reaches 1000 pieces/day.

Application scenarios and cases

In professional darts, a dart shaft weighing 20-30 g improves throwing accuracy by 15%. A certain brand uses W-90Ni-Fe dart shafts (weighing 26 g), with a market share of 25%, and user feedback shows that the feel is improved by 30%.

Technical Challenges and Solutions

Challenges include precision and appearance. Weight deviation is <±0.5 g, which is solved by high-precision pressing. The surface needs to be flawless , and multi-level polishing and coating processes ensure quality.

8.1.7 High Specific Gravity Tungsten Alloy Fishing Sinkers

Product Overview

Fishing sinkers use high specific gravity tungsten alloy to replace lead, providing environmental protection and high density. For example, a W-95Ni-Fe sinker with a diameter of 10 mm has a density of 18.8 g/cm³, weighs 9.8 g, and is 20% smaller than a lead sinker.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, water corrosion resistance <0.1%. Non-toxic, meets environmental standards, wear resistance is 5 times higher than lead.

Manufacturing process

Cold isostatic pressing 250 MPa, sintering at 1480°C, density 18.8 g/cm³. CNC machining tolerance ±0.05 mm, surface polishing Ra 0.4 μm , color coating to enhance attractiveness.

Application scenarios and cases

In sea fishing, sinkers weighing 5-20 g sink 30% faster. A certain brand uses W-95Ni-Fe sinkers (weight 10 g), sales increase 20%, and environmental certification pass rate 100%.

Technical Challenges and Solutions

Challenges include cost and appearance. Recycled powder reduces costs by 15%. Diversified shapes are achieved through 3D printing to meet personalized needs.

8.2 High Specific Gravity Tungsten Alloy Military Products

heavy tungsten alloy in the military field is due to its high density (17.0-19.3 g/cm³), excellent mechanical strength (700-1200 MPa), excellent penetration and radiation shielding ability, making it an ideal material for manufacturing armor-piercing cores, protective armor plates, ammunition shielding shells, anti-tank missile components, gun counterweights, aviation gyroscope counterweights and rocket nozzle bushings. These products play a key role in modern warfare, improving the attack power, protection and stability of weapons. The following is a detailed introduction to each military product.

8.2.1 Heavy Tungsten Alloy Armor-Piercing Core

Product Overview

The high-density tungsten alloy armor-piercing core is the core component of kinetic energy armor-piercing projectiles (APFSDS), which uses its high density and high hardness to achieve strong penetration of armored targets.For example, a W-93Ni-Fe alloy core with a diameter of 20 mm and a length of 100 mm, a density of 18.5 g/cm³, and a weight of about 580 g, can penetrate 600 mm thick rolled homogeneous armor (RHA) at an initial velocity of 2000 m/s, which is 50% deeper than that of a steel core.

Materials and properties

Armor-piercing cores are usually made of W-93Ni-Fe or W-95Ni-Fe alloys, with tungsten contents of 93% and 95% respectively, and a nickel-iron ratio of 7:3. W-93Ni-Fe has a density of 18.5 g/cm³, a tensile strength of 1100 MPa, a hardness of 480 HV, and an elongation of 15%; W-95Ni-Fe has a density of 18.8 g/cm³, a strength of 1150 MPa, and a hardness of 500 HV. These properties ensure that the core maintains integrity under high-speed impact. Its fracture toughness (K_IC) is about 30 MPa·m ^(1/2), which is higher than that of pure tungsten (5-10 MPa·m ^(1/2)), reducing the risk of fracture. High temperature resistance (melting point>2800°C) prevents it from softening when heated by friction (>1000°C) .

The manufacturing process

uses powder metallurgy and mechanical alloying. Tungsten powder (particle size 1-3 μm , purity ≥99.9%) is mixed with nickel-iron powder and ground in a high-energy ball mill at 500 rpm for 10 hours to refine the grains to 50 nm. Subsequently, the cold isostatic press is pressed into a green body at 300 MPa with a density of 13 g/cm³. Vacuum sintering (10^{-3} Pa) at 1500°C for 2 hours has a density of 18.5 g/cm³ and a density of >99%. To improve performance, hot isostatic pressing (HIP, 200 MPa, 1400°C, 1.5 hours) is used to reduce the porosity to 0.1%.

The machining was done by CNC turning, with a cutting speed of 40 m/min, a tolerance of ±0.02 mm,

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and a surface roughness of Ra 0.8 μm . The tip was carburized (950°C, 3 hours) to increase the hardness to 600 HV and the wear resistance by 30%.

Application scenarios and cases

In tank guns, such as the 120 mm main gun of the M1A2 Abrams, the W-93Ni-Fe core penetrates 700 mm RHA, increasing the hit rate by 20%. In anti-armor weapons, such as the kinetic warhead of the Dow missile, the W-95Ni-Fe core (weight 600 g) penetrates composite armor, increasing the destructive power by 30%. In a military test, the W-93Ni-Fe core penetrated 650 mm at 2500 m/s, which is 15% better than cobalt-based alloys .

Technical Challenges and Solutions

Challenges include penetration consistency and manufacturing cost. Grain size needs to be <5 μm to ensure toughness, achieved through nano powder and HIP process. High cost ($50,000/ton) is reduced by 20% through optimized powder recovery. Self-sharpening under high-speed impact is improved by adding cobalt (2%), and the fracture mode is more uniform.

8.2.2 High density tungsten alloy protective armor plate

Product Overview

Protective armor plates are used in armored vehicles or bunkers to provide protection against shrapnel and radiation. For example, a 10 mm thick W-95Ni-Fe alloy armor plate, with a density of 18.8 g/cm³ and a weight of about 18.8 kg/m², can shield 90% of 1 MeV gamma rays, and is thinner than lead plates (15 mm) and non-toxic.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, elongation 20%, hardness 450 HV. Its mass absorption coefficient is 0.15 cm²/g, and its shielding efficiency is 5 times higher than that of steel . Fatigue strength 500 MPa, withstands explosion shock (>1000 J/cm²) without cracks. Corrosion resistance: mass loss <0.2% in seawater for 1000 hours, suitable for a variety of environments.

Manufacturing process:

Tungsten powder is mixed with nickel-iron powder, cold isostatically pressed at 300 MPa, sintered at 1480°C, and has a density of 18.8 g/cm³. HIP treatment (200 MPa, 1400°C) eliminates micropores and has a density of 99.9%. CNC milling, tolerance ±0.1 mm, surface spraying 0.2 mm Al_2O_3 coating, temperature resistance of 1500°C, and corrosion resistance increased by 50%. Large plates are spliced, with a brazing strength of 200 MPa.

Application scenarios and cases

In armored vehicles (such as Leopard 2 tanks), 10 mm thick armor plates are placed in the cockpit to protect against shrapnel and radiation, and are 20% lighter than steel plates. In ammunition depots, W-95Ni-Fe plates shield radioactive materials, improving safety by 30%. A military vehicle uses this armor plate (1 m², weighing 18.8 kg), with a 25% increase in protection and a 15% reduction in volume.

Technical challenges and solutions

Challenges include the balance between weight and protection. Large-area panels need to be lightweight, and the weight can be reduced by 10% through honeycomb structure design. The strength of the spliced joints is increased to 90% of the parent material through electron beam welding (5 kW). High temperature resistance is solved through ceramic coating, and the durability is increased by 30%.

8.2.3 High specific gravity tungsten alloy ammunition shielding case

Product Overview

Ammunition shielding shells are used to store or transport radioactive ammunition to prevent radiation leakage. For example, a W-97Ni-Fe cylindrical shell with an outer diameter of 100 mm and a height of 150 mm, a density of 19.0 g/cm³, a wall thickness of 5 mm, and a weight of about 2.2 kg can shield 95% of gamma rays (1 MeV).

Materials and properties

W -97Ni-Fe alloy, density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%. Its high atomic number (Z=74) provides excellent shielding ability, mass absorption coefficient 0.16 cm²/g. Temperature resistance 1500°C, does not melt in explosive environment. High sealing, leakage rate $<10^{-6}$ Pa · m ³ /s.

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering at 1500°C, density 19.0 g/cm³, HIP treatment porosity <0.1%. CNC machining cavity tolerance ±0.02 mm, surface polishing Ra 0.4 µm , threaded cover design to ensure sealing. Nickel plating 5 µm , corrosion resistance increased by 10 times.

Application scenarios and cases

In the storage of nuclear ammunition, the W-97Ni-Fe shell (weight 2.5 kg) shields radiation and reduces the dose to less than 1 mSv. In transportation, the shell with a wall thickness of 8 mm protects radioactive isotopes and increases safety by 40%. A certain military uses this shell (wall thickness 6 mm), with a radiation shielding rate of 96% and a weight 15% lighter than the lead shell .

Technical challenges and solutions

Challenges include sealing and weight. Thread machining accuracy needs to be ±0.01 mm, which is achieved through five-axis CNC. Weight is controlled by optimizing wall thickness (minimum 5 mm), and HIP process ensures strength. Impact resistance is enhanced by adding cobalt , and toughness is increased by 10%.

8.2.4 High density tungsten alloy anti-tank missile components

Product Overview

Anti-tank missile components such as counterweights or armor-piercing liner use high density to improve flight stability and penetration. For example, W-90Ni-Fe alloy ring counterweight, with an outer diameter of 80 mm, thickness of 20 mm, density of 18.5 g/cm³, weighs about 1.2 kg, and optimizes missile trajectory.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. High temperature resistance 2800°C, no melting under explosion impact. Fatigue strength 500 MPa, withstands launch overload (>20 G). Surface hardness reaches 550 HV after carburizing, and wear resistance increases by 30%.

Manufacturing process

Hydraulic press 600 MPa pressing, 1450°C sintering, density 18.5 g/cm³. SLM printing complex shapes, porosity <1%, CNC processing tolerance ±0.05 mm. Carburizing treatment (950°C, 3 hours) to improve wear resistance. Surface spraying ceramic coating, temperature resistance 1500°C.

Application scenarios and cases

In the Javelin missile, the W-90Ni-Fe counterweight (weighing 1 kg) stabilizes flight and increases the hit rate by 15%. In the armor-piercing warhead, the 500 g ring increases the penetration by 20%. A missile uses a W-90Ni-Fe component (weighing 1.5 kg) to penetrate 800 mm composite armor, which is 30% better than steel parts.

Technical Challenges and Solutions

Challenges include shape complexity and high temperature durability. 3D printing solves special-shaped designs with an accuracy of ±0.03 mm. High temperature is extended by 25% through ceramic coating and HIP treatment. Weight distribution is optimized through dynamic balancing tests with eccentricity <5 μm.

8.2.5 High Specific Gravity Tungsten Alloy Firearm Counterweight

Product Overview

Firearm counterweights are used to balance the gun body and reduce recoil. For example, a W-90Ni-Fe counterweight with a length of 50 mm, a width of 20 mm, and a thickness of 10 mm has a density of 18.5 g/cm³ and a weight of 185 g. It is installed on the buttstock or barrel.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Fatigue strength 500 MPa, withstands continuous shooting (>1000 rounds). Wear resistance is 50% higher than steel, surface corrosion resistance in sweat 1000 hours mass loss <0.1%.

Manufacturing process

Cold isostatic pressing 250 MPa, sintering at 1450°C, density 18.5 g/cm³. CNC machining tolerance ±0.05 mm, surface roughness Ra 1.6 μm , nickel plating 5 μm to improve aesthetics. Mass production with molding, efficiency increased by 30%.

Application scenarios and cases

In sniper rifles (such as M24), a 200 g counterweight is placed on the buttstock to reduce recoil by 20%. In submachine guns, a 150 g counterweight improves the stability of continuous shooting by 15%. A certain pistol uses a W-90Ni-Fe counterweight (weighing 180 g), which increases shooting accuracy by 10%.

Technical challenges and solutions

Challenges include weight accuracy and mounting. Weight deviation < ±2 g, solved by high-precision pressing. Mounting requires bolting (shear strength 3000 N), optimized by titanium bolts. Durability is achieved by carburizing, hardness increased to 500 HV.

8.2.6 High Specific Gravity Tungsten Alloy Aviation Gyroscope Counterweight

Product Overview

Aerospace gyro weights are used in navigation systems to provide inertial mass, such as the W-97Ni-Fe weight with a diameter of 30 mm and a height of 20 mm, a density of 19.0 g/cm³, and a weight of 265 g, which supports high-precision rotation.

Materials and properties

W-97Ni-Fe alloy, density 19.0 g/cm³, tensile strength 1050 MPa, hardness 450 HV, elongation 12%. Fatigue strength 500 MPa, withstand >10000 rpm rotation. Thermal expansion coefficient 4.5×10^{-6} /K, deformation <0.01 mm, thermal conductivity 120 W/(m·K).

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering at 1500°C, density 19.0 g/cm³, HIP treatment porosity <0.2%. Five-axis CNC machining tolerance ±0.01 mm, surface Ra 0.2 μm , gold plating 2 μm , resistivity reduced to 4 μΩ·cm . Dynamic balance eccentricity <5 μm .

Application Scenarios and Examples

In drones, a 200 g counterweight supports an INS accuracy of 0.01°/s. In fighter jets (such as the F-22), a 250 g counterweight withstands 15 G overload and has a lifespan of 5,000 hours. A missile uses a W-97Ni-Fe counterweight (270 g), with an angular velocity error of <0.005°/s.

Technical Challenges and Solutions

Challenges include dynamic balancing and micro-holes. Dynamic balancing is corrected by high-precision molds and testing machines. Micro-holes are eliminated by HIP (250 MPa), and fatigue life is increased by 50%. Cutting heat is controlled below 40°C by water cooling.

8.2.7 Heavy Tungsten Alloy Rocket Nozzle Bushing

Product Overview

Rocket nozzle bushings withstand high temperature and high pressure airflow, such as the W-95Ni-Fe bushing with an inner diameter of 50 mm and a length of 80 mm, a density of 18.8 g/cm³, and a weight of about 1.1 kg, providing structural support and thermal protection.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, melting point>2800°C. Thermal conductivity 140 W/(m·K), strong thermal shock resistance, fatigue strength 500 MPa. Corrosion resistance: mass loss <0.5% in combustion products for 1000 hours.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1480°C, density 18.8 g/cm³, HIP treatment density 99.9%. CNC machining tolerance ±0.05 mm, surface spraying 0.3 mm ZrO_2 coating, temperature resistance 2000°C. SLM printing complex cavity, porosity <1%.

Application scenarios and cases

In solid rocket boosters, a bushing weighing 1.5 kg can withstand 3000°C airflow and increase its service life by 20%. In liquid rockets, a bushing weighing 1 kg increases injection efficiency by 10%. A rocket uses a W-95Ni-Fe bushing (weighing 1.2 kg), which increases thrust stability by 15%.

Technical Challenges and Solutions

Challenges include high temperature resistance and machining accuracy. ZrO_2 coating and HIP treatment increase temperature resistance by 30%. Complex shapes are achieved through 3D printing with an accuracy of ±0.03 mm. Thermal stress is reduced by 80% through annealing (900°C).

8.3 High Specific Gravity Tungsten Alloy Medical Related Products

heavy tungsten alloy in the medical field is due to its high density (17.0-19.3 g/cm³), excellent radiation shielding ability, non-toxicity and good mechanical properties, making it an ideal choice to replace lead. Heavy tungsten alloy medical products include radiation shielding components, isotope containers, medical tungsten alloy needles , radiotherapy targets, medical protective screens, nuclear waste containers and gamma knife components. These products are widely used in diagnosis, treatment and radioactive material management, taking into account both efficiency and safety. The following is a detailed introduction to each medical-related product.

8.3.1 Heavy Tungsten Alloy Radiation Shielding Components

Product Overview

Radiation shielding components are used in X-ray machines, CT equipment and radiotherapy equipment to protect patients and medical staff from ionizing radiation. For example , a W-95Ni-Fe alloy shielding plate with a thickness of 8 mm, a density of 18.8 g/cm³, and a weight of about 1.5 kg/m² can shield 90% of 100 kV X-rays, which is 33% smaller in volume and 20% lighter in weight than a lead plate (12 mm).

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Materials and properties

W-95Ni-Fe alloy (95% tungsten, 7:3 nickel-iron), density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%. Its high atomic number (Z=74) provides excellent shielding ability, mass absorption coefficient 0.15 cm²/g, 15% higher than lead (0.13 cm²/g). Strong corrosion resistance, mass loss <0.1% in moisture for 1000 hours, non-toxic, in line with medical standards. Thermal expansion coefficient 4.5×10^{-6} /K, deformation <0.01 mm, suitable for long-term use.

Manufacturing process

Tungsten powder (particle size 3-5 μm , purity ≥99.9%) is mixed with nickel iron powder and pressed by cold isostatic press (CIP) at 300 MPa, with a green body density of 13 g/cm³. Sintered in hydrogen at 1480°C for 2 hours, the density is 18.8 g/cm³, and the density is >99%. Hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour) eliminates micropores and the porosity is <0.1%.

CNC machining tolerance ±0.05 mm, surface polishing to Ra 0.4 μm , nickel plating 5 μm improves corrosion resistance 10 times. Complex shapes are printed by SLM, porosity <1%, accuracy ±0.03 mm.

Application scenarios and cases

In CT machines, W-95Ni-Fe shielding plates (10 mm thick) are placed around the detector, with a shielding rate of 92% and a 10% reduction in equipment weight. In X-ray machines, 5 mm thick shielding protects operators and reduces radiation dose to less than 0.5 mSv. A hospital uses this shielding plate (1 m², weighing 18.8 kg), which improves patient safety by 15% and is 25% smaller in volume than lead plates.

Technical challenges and solutions

Challenges include shielding uniformity and machining accuracy. Density deviation < ±0.1 g/cm³, achieved by HIP process and multi-zone sintering (temperature difference <5°C). High hardness requires CBN tooling, which extends life by 50%. Surface finish is solved by multi-level polishing to avoid radiation scattering.

8.3.2 Heavy Tungsten Alloy Isotope Container

Product Overview

Isotope containers are used to store and transport radioactive isotopes (such as Tc-99m, I-131) to prevent radiation leakage. For example, a W-97Ni-Fe container with an outer diameter of 50 mm and a height of 100 mm has a density of 19.0 g/cm³, a wall thickness of 5 mm, and weighs about 1.1 kg, shielding 95% of 1 MeV gamma rays.

Materials and properties

W-97Ni-Fe alloy (97% tungsten), density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%. Mass absorption coefficient 0.16 cm²/g, shielding efficiency 20% higher than lead. Temperature resistance 1500°C, no melting in explosive environment. Extremely high sealing, leakage rate $<10^{-6}$ Pa · m^{3} /s, non-toxic, in line with nuclear medicine requirements.

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering at 1500°C (10^{-3} Pa), density 19.0 g/cm³, HIP treatment porosity <0.1%. Five-axis CNC machining cavity tolerance ±0.02 mm, surface Ra 0.4 μm , threaded cover design to ensure sealing. Nickel plating 5 μm or spraying 0.1 mm TiN coating, corrosion resistance increased by 15%.

Application scenarios and cases

In nuclear medicine, W-97Ni-Fe containers (6 mm thick, 1.5 kg in weight) store Tc-99m, with a shielding rate of 96% and a dose reduction below 1 mSv. In transportation, 8 mm thick containers protect I-131, increasing safety by 40%. A laboratory uses this container (1.2 kg in weight), with a radiation leakage rate of <0.01%, which is 10% lighter than a lead container.

Technical challenges and solutions

Challenges include tightness and weight optimization. Thread accuracy ±0.01 mm, ensured by CNC and ultrasonic testing. Weight is reduced by 15% through wall thickness gradient design (minimum 4 mm), and HIP process ensures strength. Impact resistance is improved by adding cobalt (2%), and toughness is increased by 10%.

8.3.3 High specific gravity tungsten alloy medical tungsten alloy needle

Product Overview

Medical tungsten alloy needles are used for radioactive seed implantation (such as prostate cancer treatment) to accurately deliver radioactive sources. For example, a W-95Ni-Fe needle with a diameter of 1 mm and a length of 20 mm has a density of 18.8 g/cm³ and weighs about 0.3 g, providing high accuracy and shielding.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%. Strong shielding ability, 5 mm thick shielding 90% β-rays. Corrosion resistance: mass loss <0.1% in physiological saline for 1000 hours, non-toxic. The tip hardness reaches 600 HV after carburizing, and the puncture force increases by 20%.

Manufacturing process

After mixing tungsten powder, hydraulic press 500 MPa pressed slender billet, sintered at 1480°C, density 18.8 g/cm³. CNC turning tolerance ±0.01 mm, tip angle 30°, surface polishing Ra 0.2 μm . Carburizing treatment (950°C, 2 hours), wear resistance increased by 30%. Gold plating 2 μm , improve biocompatibility.

Application scenarios and cases

In seed implantation, the W-95Ni-Fe needle (25 mm long) delivers I-125 with a positioning accuracy of ±0.5 mm, increasing the therapeutic effect by 15%. In tumor biopsy, a needle weighing 0.4 g punctures

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tissue and reduces damage by 20%. A hospital uses this needle (1.2 mm in diameter) and has an implantation success rate of 98%.

Technical challenges and solutions

Challenges include fineness and strength. Diameter <1 mm requires high-precision molds, which are solved by SLM printing, and porosity <0.5%. The tip is easy to break, which is strengthened by carburizing and annealing (800°C), and the fracture rate is reduced to 0.1%. The surface needs to be sterile, multi-level polishing and UV disinfection to ensure.

8.3.4 High-density tungsten alloy radiotherapy target

Product OverviewRadiotherapy

targets are used in linear accelerators to generate high-energy X-rays. For example, a W-95Ni-Fe target with a diameter of 50 mm and a thickness of 5 mm has a density of 18.8 g/cm³ and weighs about 370 g. It can generate 10 MV radiation when bombarded by an electron beam.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, melting point >2800°C. Thermal conductivity 140 W/(m·K), strong thermal shock resistance, shielding ability to absorb 90% of scattered rays. Wear resistance is 5 times higher than steel , and surface stability is good.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1480°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.05 mm, surface Ra 0.4 μm , sprayed 0.2 mm ZrO_2 coating, temperature resistance 2000°C. Target surface polished to Ra 0.1 μm to reduce scattering.

Application scenarios and cases

In radiotherapy equipment, W-95Ni-Fe target (6 mm thick) produces 12 MV radiation, increasing the treatment depth by 20%. In proton therapy, a target weighing 400 g increases radiation intensity by 15%. A hospital used this target (60 mm in diameter) and increased tumor irradiation accuracy by 10%.

Technical Challenges and Solutions

Challenges include high temperature resistance and radiation consistency. ZrO_2 coating and HIP treatment increase temperature resistance by 25%. Target surface flatness <0.01 mm, achieved through ultra-precision machining. Scattering is reduced by 5% through coating optimization.

8.3.5 High specific gravity tungsten alloy medical protective screen

Product Overview

Medical protective screens are used in operating rooms or radiology departments to protect medical staff. For example, a W-95Ni-Fe protective screen with a length of 500 mm, a width of 300 mm, and a thickness of 5 mm has a density of 18.8 g/cm³, weighs about 14 kg, and shields 90% of 100 kV X-rays.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%. Mass absorption coefficient 0.15 cm²/g, corrosion resistance: mass loss <0.1% in disinfectant for 1000 hours. Fatigue strength 500 MPa, withstand handling shock.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1480°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. CNC cutting tolerance ±0.1 mm, surface polishing Ra 0.8 μm , nickel plating 5 μm or spraying clear coating, aesthetics increased by 20%.

Application scenarios and cases

In X-ray surgery, the W-95Ni-Fe screen (6 mm thick) is placed on the operating table, and the dose is reduced to 0.2 mSv. In the radiotherapy room, the 20 kg screen protects the technicians, with a shielding rate of 92%. A hospital uses this screen (500×400 mm), and the safety is increased by 15%.

Technical challenges and solutions

Challenges include weight and transparency. Weight reduction is achieved through hollow design, reducing weight by 10%. When partial transparency is required, lead glass is inlaid to maintain a 90% shielding rate. Durability is improved through HIP and coating, increasing life by 30%.

8.3.6 Heavy Tungsten Alloy Nuclear Waste Container

Product Overview

Nuclear waste containers are used to store low-level or medium-level waste to prevent radiation leakage. For example, a W-97Ni-Fe container with an outer diameter of 200 mm and a height of 300 mm has a density of 19.0 g/cm³, a wall thickness of 10 mm, and weighs about 11 kg, shielding 98% of gamma rays (2 MeV).

Materials and properties

W-97Ni-Fe alloy, density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%. Mass absorption coefficient 0.16 cm²/g, temperature resistance 1500°C, corrosion resistance mass loss in acid solution for 1000 hours <0.2%. Sealing $<10^{-7}$ Pa · m³/s.

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering at 1500°C, density 19.0 g/cm³, porosity <0.05% after HIP treatment. CNC machining tolerance ±0.05 mm, surface Ra 0.4 μm , welding seal strength 300 MPa. Spraying 0.3 mm ceramic coating, corrosion resistance increased by 20%.

Application scenarios and cases

In nuclear power plants, W-97Ni-Fe containers (wall thickness 12 mm) store Co-60 waste with a shielding rate of 99%. In waste transportation, the 15 kg container protects the environment and increases safety by 50%. A facility uses this container (weight 12 kg) and reduces radiation to 0.1 mSv.

Technical challenges and solutions

Challenges include sealing and durability. Electron beam welding (5 kW) is used, with a strength of 95% of the parent material. Long-term corrosion is solved by ceramic coating and HIP treatment, increasing life by 40%. Weight is reduced by 10% by optimizing wall thickness.

8.3.7 Heavy Tungsten Alloy Gamma Knife Components

Product Overview

Gamma Knife components such as collimators are used to focus gamma rays to treat tumors. For example, a W-90Ni-Fe collimator has an aperture of 2-5 mm, a density of 18.5 g/cm³, weighs about 500 g, and shields 92% of Co-60 rays.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Mass absorption coefficient 0.14 cm²/g, temperature resistance 1500°C, conductivity increased by 20% by gold plating. Fatigue strength 500 MPa, withstands high-frequency vibration.

Manufacturing process

Cold isostatic pressing 250 MPa, sintering at 1450°C, density 18.5 g/cm³, HIP treatment porosity <0.1%. Five-axis CNC machining hole diameter tolerance ±0.02 mm, surface Ra 0.2 μm , gold plating 2 μm , resistivity reduced to 4 μΩ·cm . Dynamic balance test eccentricity <5 μm .

Application scenarios and cases

In gamma knife, W-90Ni-Fe collimator (weight 600 g) focuses the radiation, increasing the accuracy by 15%. In brain tumor treatment, the 3 mm aperture component increases the irradiation efficiency by 20%. A hospital uses this component (weight 550 g), and the treatment success rate increases by 10%.

Technical Challenges and Solutions

Challenges include hole diameter accuracy and durability. Five-axis machining and laser drilling ensure ±0.01 mm. Wear resistance is improved by 20% through TiN coating. Scattering is reduced by 5% through optimized hole shape.

8.4 Heavy Tungsten Alloy Industrial Tools and Components

heavy tungsten alloy in the industrial field is due to its high density (17.0-19.3 g/cm³), excellent wear resistance (hardness 400-600 HV), high strength (700-1200 MPa) and excellent stability, making it an ideal material for manufacturing industrial tools and components such as cutting tools, dies and press heads, vibration damping parts, drilling tools, bearing components, grinding sleeves and heavy machine tool counterweights. These products are widely used in mechanical processing, oil extraction, manufacturing equipment and other fields to improve efficiency and durability. The following is a detailed introduction to each industrial tool and component.

8.4.1 Heavy Tungsten Alloy Cutting Tools

Product Overview

Heavy tungsten alloy cutting tools are used to process hard materials (such as steel and titanium alloy) and are known for their high hardness and wear resistance. For example, a W-95Ni-Fe alloy drill with a diameter of 10 mm and a length of 50 mm has a density of 18.8 g/cm³ and weighs about 74 g. It is 70% more wear-resistant than traditional carbide tools and has a service life that is twice as long.

Materials and properties

W-95Ni-Fe alloy (tungsten 95%, nickel-iron 7:3), density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%. After carburizing, the hardness can reach 600 HV and the wear resistance is 5 times higher than that of steel . Thermal conductivity is 140 W/(m·K), temperature resistance is 1000°C, and it does not soften during cutting . The fracture toughness (K_IC) is about 30 MPa·m ^(1/2), and it has strong impact resistance.

Manufacturing process

Tungsten powder (particle size 3-5 μm , purity ≥99.9%) is mixed with nickel iron powder and pressed by cold isostatic press (CIP) at 300 MPa, with a green body density of 13 g/cm³. Sintered in hydrogen at 1480°C for 2 hours, the density is 18.8 g/cm³, and the density is >99%. Hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour) eliminates micropores and the porosity is <0.1%.

CNC machining tolerance ±0.02 mm, cutting edge angle 60°, surface finish Ra 0.4 μm . Carburizing (950°C, 3 hours) increases wear resistance by 30%. Some tools are sprayed with 0.1 mm TiN coating, with hardness increased to 650 HV.

Application scenarios and cases

In aviation manufacturing, W-95Ni-Fe drills (12 mm in diameter) can process titanium alloys with a lifespan of 300 hours, which is twice as long as carbide tools. In automotive parts processing, a 100 g milling cutter can increase efficiency by 20% when cutting steel parts. A factory used this tool (60 mm long) to reduce processing costs by 15% and scrap rates by 10%.

Technical challenges and solutions

Challenges include edge durability and thermal stability. Edge chipping is reduced to 0.5% through HIP and carburizing processes. High temperature softening is controlled by TiN coating and coolant (flow rate 10 L/min), temperature <200°C. Grain uniformity is improved by nano powder (particle size <1 μm), and wear resistance is increased by 20%.

8.4.2 High specific gravity tungsten alloy mold and punch

Product Overview

Heavy tungsten alloy dies and punches are used in stamping, forging and extrusion processes to withstand high pressure and wear. For example, a W-93Ni-Fe die with a length of 100 mm, a width of 50 mm and a thickness of 20 mm has a density of 18.5 g/cm³, a weight of about 925 g and a pressure resistance of 2000 MPa.

Materials and properties

W-93Ni-Fe alloy (93% tungsten), density 18.5 g/cm³, tensile strength 1050 MPa, hardness 420 HV, elongation 18%. Wear resistance is 4 times higher than steel , fatigue strength 550 MPa, and can withstand 10^7 cycles without cracks. Temperature resistance 1200°C, deformation <0.05 mm. Surface corrosion resistance: mass loss <0.2% in oil pollution for 1000 hours.

Manufacturing process

After mixing tungsten powder, hydraulic press 600 MPa pressing, 1450 ° C sintering, density 18.5 g/cm³, HIP treatment porosity <0.1%. CNC milling tolerance ± 0.05 mm, surface Ra 0.8 μm , carburizing treatment (950 ° C, 3 hours), hardness increased to 550 HV. Spraying 0.2 mm Al_2O_3 coating, temperature resistance 1500 ° C.

Application scenarios and cases

In stamping steel plates, the W-93Ni-Fe die (weight 1 kg) can punch 1 million times without wear, and its life is 3 times longer than that of steel dies. In forging, a 1.5 kg punch can process aluminum alloys with a 25% increase in efficiency. A factory used this die (100×60 mm), which increased production accuracy by 15% and reduced maintenance costs by 20%.

Technical Challenges and Solutions

Challenges include pressure resistance and surface wear. Pressure resistance is improved by HIP and cobalt addition (2%), and strength is increased by 10%. Wear is solved by carburizing and ceramic coating, and life is increased by 30%. Complex shapes are printed by SLM with an accuracy of ±0.03 mm.

8.4.3 Heavy Tungsten Alloy Vibration Suppression Parts

Product Overview

Vibration damping parts are used to reduce vibration of machine tools or equipment and improve running stability. For example, a W-90Ni-Fe damping block with a length of 100 mm, a width of 20 mm, and a thickness of 10 mm has a density of 18.5 g/cm³ and a weight of 370 g, and its attenuation rate is 40% higher than that of steel .

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%.

Elastic modulus 400 GPa , sound velocity 4400 m/s, damping coefficient 30% higher than steel . Temperature resistance 500°C, corrosion resistance mass loss <0.1% in moisture for 1000 hours.

Manufacturing process:

cold isostatic pressing at 250 MPa, sintering at 1450°C, density 18.5 g/cm³. CNC machining tolerance ±0.1 mm, surface Ra 1.6 μm , sprayed with 0.2 mm Al_2O_3 coating, temperature resistance 1500°C. Micropore design (diameter 50 μm) increases energy dissipation and attenuation rate increases by 10%.

Application scenarios and cases

In CNC machine tools, a damping block weighing 500 g reduces vibration by 40% and increases machining accuracy by 10%. In punch presses, a damping piece weighing 1 kg reduces noise by 5 dB and increases life by 20%. A factory used this piece (120 mm long) and increased equipment stability by 15%, with the amplitude reduced to 2 mm.

Technical Challenges and Solutions

Challenges include damping efficiency and installation. High frequency vibrations (>1000 Hz) are optimized through micro-holes, increasing the attenuation rate by 15%. Installation shear forces (>5000 N) are addressed by titanium bolts. Durability: Through HIP treatment, fatigue life is increased by 25%.

8.4.4 High density tungsten alloy drilling tools

Product Overview

Drilling tools are used in oil, gas and geothermal extraction and are known for their wear resistance and weight. For example, a W-95Ni-Fe drill bit with a diameter of 50 mm and a length of 200 mm has a density of 18.8 g/cm³, weighs about 3.7 kg, and has a lifespan three times longer than a steel drill bit.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, 600 HV after carburizing. The wear resistance is 5 times higher than that of steel , the fatigue strength is 500 MPa, and the temperature resistance is 1000°C. Corrosion resistance: mass loss in mud for 1000 hours is less than 0.5%.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1480°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.05 mm, edge carburizing (950°C, 3 hours), spraying 0.2 mm TiN coating, hardness 650 HV. SLM printing complex structure, accuracy ±0.03 mm.

Application scenarios and cases

In deep well drilling, the W-95Ni-Fe drill bit (weight 4 kg) drills 5000 m of rock and has a service life of 300 hours. In offshore drilling, the wear resistance of a tool weighing 5 kg increases by 40%. An oil field uses this drill bit (diameter 60 mm), and the drilling efficiency increases by 20% and the cost decreases by 15%.

Technical Challenges and Solutions

Challenges include wear resistance and high temperature. Carburization and TiN coating improve durability by 30%. High temperature is controlled by optimizing thermal conductivity and coolant to <300°C. Weight is reduced by 10% through structural optimization.

8.4.5 Heavy tungsten alloy bearing components

Product Overview

Bearing components are used in heavy-duty machinery, providing high density and wear resistance. For example, a W-90Ni-Fe bearing ring with an outer diameter of 80 mm, an inner diameter of 40 mm, and a thickness of 20 mm has a density of 18.5 g/cm³, a weight of about 1.8 kg, and a load-bearing capacity 50% higher than that of steel .

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Wear resistance is 4 times higher than steel , fatigue strength 500 MPa, temperature resistance 800°C. Friction coefficient 0.3, strong corrosion resistance.

Manufacturing process

Hydraulic press 600 MPa pressing, 1450°C sintering, density 18.5 g/cm³, HIP treatment porosity <0.1%. CNC turning tolerance ±0.02 mm, surface Ra 0.4 μm , carburizing treatment hardness 550 HV. Spraying 0.1 mm MoS_2 coating, friction reduction 20%.

Application scenarios and cases

In excavators, a 2 kg bearing ring withstands a load of 100 tons and its lifespan is increased by 30%. In wind power equipment, a 1.5 kg component reduces wear by 20%. A factory uses this bearing (outer diameter 100 mm) and its operating stability is increased by 15%.

Technical Challenges and Solutions

Challenges include friction and precision. MoS_2 coating and polishing reduce friction by 15%. Tolerance <±0.01 mm achieved through 5-axis machining . Durability improved through HIP and carburizing, life increased by 25%.

8.4.6 Heavy Tungsten Alloy Grinding Sleeve

Product Overview

Grinding sleeves are used in grinding equipment to provide weight and wear resistance. For example, a W-93Ni-Fe sleeve with an inner diameter of 30 mm, an outer diameter of 50 mm, and a length of 100 mm has a density of 18.5 g/cm³, weighs about 1.4 kg, and has a wear resistance that is 4 times higher than steel .

Materials and properties

W-93Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1050 MPa, hardness 420 HV, elongation 18%. Strong wear resistance, fatigue strength 550 MPa, temperature resistance 1000°C. Corrosion resistance: mass loss <0.2% in abrasive for 1000 hours.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1450°C, density 18.5 g/cm³, porosity <0.1% after HIP treatment. CNC machining tolerance ±0.05 mm, surface Ra 0.8 μm , carburizing hardness 550 HV. Spraying 0.2 mm Al_2O_3 coating, temperature resistance 1500°C.

Application scenarios and cases

In a grinder, a 1.5 kg sleeve grinds ceramics and increases its life by 30%. In ore processing, a 2 kg sleeve has a 40% increase in wear resistance. A factory uses this sleeve (120 mm long) and increases efficiency by 15% and extends maintenance cycles by 20%.

Technical Challenges and Solutions

Challenges include inner wall wear resistance and thermal expansion. Carburizing and coating improve durability by 25%. Thermal expansion is reduced by 80% through annealing (900°C), with deformation <0.01 mm. Accuracy is achieved through ultra-precision machining.

8.4.7 Heavy Tungsten Alloy Heavy Machine Tool Counterweights

Product Overview

Heavy duty machine tool counterweights are used to balance large equipment and reduce vibration.For example, a W-90Ni-Fe counterweight block with a length of 300 mm, a width of 100 mm, and a thickness of 50 mm has a density of 18.5 g/cm³ and a weight of 13.9 kg, which is 55% smaller than a steel block.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Fatigue strength 500 MPa, withstand 10^7 cycles. Temperature resistance 500°C, corrosion resistance 1000 hours mass loss in oil pollution <0.1%.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1450°C, density 18.5 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.2 mm, surface Ra 1.6 μm , spraying 0.1 mm protective layer, corrosion resistance increased by 30%. Large counterweights are spliced, brazing strength 200 MPa.

Application scenarios and cases

On lathes, a 20 kg counterweight reduces vibration by 40% and increases precision by 10%. On milling machines, a 15 kg counterweight improves stability by 15%. A factory uses this counterweight (weighing 18 kg), which reduces processing noise by 10 dB and increases service life by 20%.

Technical challenges and solutions

Challenges included weight distribution and cost. Density uniformity achieved by multi-point pressing and HIP with a deviation of <0.1 g/cm³. Costs reduced by 20% by recycling powder. Mounting optimized by flexible gaskets with shear force increased to 5000 N.

8.5 Heavy Tungsten Alloy Electronics and Energy Products

heavy tungsten alloy in the field of electronics and energy is due to its high density (17.0-19.3 g/cm³), excellent thermal conductivity (120-180 W/(m·K)), high strength (700-1200 MPa), high temperature resistance (melting point>2800°C) and good radiation shielding ability, making it the preferred material for manufacturing electrode materials, heat sinks, nuclear reactor components, battery counterweights, solar equipment components, X-ray tube anode targets and wind turbine counterweights. These products play a key role in electronic equipment, energy conversion and power generation systems, improving performance and reliability. The following is a detailed introduction to each electronic and energy product.

8.5.1 High density tungsten alloy electrode materials

Product Overview

Heavy tungsten alloy electrode materials are used for electrical discharge machining (EDM), resistance welding and plasma cutting, and are known for their high conductivity and wear resistance. For example, a W-80Cu alloy electrode with a diameter of 10 mm and a length of 50 mm has a density of 17.0 g/cm³ and weighs about 67 g. Its conductivity is 20% higher than that of pure copper and its wear resistance is 5 times higher than that of steel .

Materials and properties

W-80Cu alloy (80% tungsten, 20% copper), density 17.0 g/cm³, tensile strength 700 MPa, hardness 380 HV, elongation 10%. Electrical conductivity 45% IACS (International Annealed Copper Standard), thermal conductivity 180 W/(m·K), temperature resistance 1500°C. It has strong resistance to arc erosion, and the mass loss after 1000 discharges is less than 0.5%. Corrosion resistance: mass loss in moisture for 1000 hours is less than 0.2%.

Manufacturing process:

Tungsten powder (particle size 3-5 μm , purity ≥99.9%) is mixed with copper powder and pressed by cold isostatic press (CIP) at 250 MPa, with a green body density of 11 g/cm³. Sintered in hydrogen at 1350°C for 2 hours, the copper phase melts and infiltrates into the tungsten matrix, with a density of 17.0 g/cm³ and a density of >98%. Hot isostatic pressing (HIP, 150 MPa, 1300°C, 1 hour) eliminates micropores and the porosity is <0.1%.

CNC turning tolerance ±0.02 mm, surface polishing Ra 0.4 μm , gold plating 2 μm , resistivity reduced to 3 μΩ·cm . The electrode tip is carburized (900°C, 2 hours) and the hardness is increased to 450 HV.

Application scenarios and cases

In EDM, W-80Cu electrodes (12 mm in diameter) can process mold steel with a service life of 500 hours, which is three times longer than copper electrodes. In resistance welding, a 100 g electrode can weld aluminum plates with a 25% increase in efficiency. A factory used this electrode (60 mm in length) to increase processing accuracy by 15% and reduce arc loss by 20%.

Technical challenges and solutions

Challenges include balancing conductivity and wear resistance. Copper content is optimized to 20%-30%, conductivity increases by 10%, and HIP treatment increases strength by 15%. Arc erosion is reduced by 30% through gold plating and carburizing. Surface roughness is controlled through multi-level polishing, and heat dissipation efficiency increases by 10%.

8.5.2 High density tungsten alloy heat sink (radiator)

Product Overview

Heat sinks are used to dissipate heat from high-power electronic devices (such as CPUs and LEDs) to optimize thermal management with high thermal conductivity and density.For example, a W-85Cu alloy heat sink with a length of 50 mm, a width of 50 mm, and a thickness of 5 mm has a density of 17.5 g/cm³ and weighs about 219 g, and its heat dissipation efficiency is 50% higher than that of aluminum.

Materials and properties

W-85Cu alloy (85% tungsten, 15% copper), density 17.5 g/cm³, tensile strength 800 MPa, hardness 400 HV, elongation 8%. Thermal conductivity 170 W/(m·K), slightly lower than pure tungsten (174 W/(m·K)) but better processability. Temperature resistance 1500°C, thermal expansion coefficient 6.5 $\times 10^{-6}$ /K, matching silicon chips (4.2×10^{-6} /K), deformation <0.01 mm.

Manufacturing process:

Tungsten powder and copper powder are mixed, cold isostatic pressing 300 MPa, sintering at 1350°C, density 17.5 g/cm³, HIP treatment porosity <0.1%. CNC milling tolerance ±0.05 mm, surface Ra 0.8 μm , microchannel design (width 0.5 mm) increases heat dissipation area by 20%. Nickel plating 5 μm , corrosion resistance increased by 15%.

Application scenarios and cases

In server CPUs, the W-85Cu heat sink (weight 250 g) has a heat dissipation power of 200 W and a temperature reduction of 15°C. In high-power LEDs, a heat sink weighing 150 g can extend the life of the LED by 30%. An electronics factory used this heat sink (50×50 mm), and the chip operating temperature dropped to 60°C, with a 10% increase in performance.

Technical challenges and solutions

Challenges include thermal expansion matching and heat dissipation efficiency. The copper content is adjusted to 15%-20%, and the thermal expansion deviation is <10%. Microchannels are achieved through laser processing, and heat dissipation is increased by 25%. The weight is reduced by 15% through hollowing design, and the HIP process ensures strength.

8.5.3 Heavy tungsten alloy nuclear reactor components

Product Overview

Nuclear reactor components such as shield blocks or control rod sleeves, using high density and radiation shielding capabilities. For example, a W-97Ni-Fe shield block with a length of 200 mm, a width of 50 mm, and a thickness of 20 mm has a density of 19.0 g/cm³, weighs about 1.9 kg, and shields 98% of gamma rays (2 MeV).

Materials and properties

W-97Ni-Fe alloy, density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%. Mass absorption coefficient 0.16 cm²/g, temperature resistance 1500°C, corrosion resistance mass loss <0.2% in coolant for 1000 hours. Fatigue strength 500 MPa, withstand thermal shock.

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering at 1500°C (10^{-3} Pa), density 19.0 g/cm³, porosity <0.05% after HIP treatment. CNC machining tolerance ±0.05 mm, surface Ra 0.4 µm , sprayed 0.3 mm ZrO_2 coating, temperature resistance 2000°C. Brazing strength of spliced parts 300 MPa .

Application scenarios and cases

In a pressurized water reactor, the W-97Ni-Fe shielding block (weight 2 kg) is placed outside the core, and the radiation is reduced to 0.1 mSv. In a fast neutron reactor, the 3 kg casing protects the control rods, and the service life is increased by 20%. A nuclear power plant uses this component (200×60 mm), which increases safety by 15% and extends the maintenance cycle by 25%.

Technical Challenges and Solutions

Challenges include radiation resistance and high temperature. ZrO_2 coating and HIP treatment increase durability by 30%. Microcracks are reduced by 80% through annealing (900°C). Weight is reduced by 10% through optimized structure without reducing strength.

8.5.4 High specific gravity tungsten alloy battery counterweight

Product Overview

Battery counterweights are used in electric vehicles or energy storage systems to balance weight distribution. For example, a W-90Ni-Fe counterweight with a length of 100 mm, a width of 30 mm, and a thickness of 10 mm has a density of 18.5 g/cm³ and weighs about 555 g, which is 55% smaller than a steel counterweight.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Fatigue strength 500 MPa, temperature resistance 500°C, corrosion resistance mass loss <0.1% in electrolyte for 1000 hours. Thermal conductivity 130 W/(m·K), good heat dissipation.

Manufacturing process:

Hydraulic press 600 MPa pressing, 1450°C sintering, density 18.5 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.1 mm, surface Ra 1.6 μm, spraying 0.1 mm protective layer, corrosion resistance increased by 20%. Special-shaped parts are printed by SLM, with an accuracy of ±0.05 mm.

Application scenarios and cases

In electric vehicles, a 1 kg counterweight is placed on the battery pack to balance the axle load ratio and increase the suspension life by 20%. In energy storage cabinets, a 2 kg counterweight improves stability by 15%. A certain car company used this counterweight (weighing 800 g), which increased the handling by 10% and reduced energy consumption by 5%.

Technical challenges and solutions

Challenges include cost and installation. Recycling powder reduces costs by 20%. Installation space is optimized through 3D printing special-shaped design, and weight deviation is <±2 g. Durability is improved through HIP, and life is increased by 25%.

8.5.5 Heavy Tungsten Alloy Solar Equipment Components

Product Overview

Solar equipment components such as weights or supports adjust the angle and stability of the panel. For example, a W-90Ni-Fe weight with a length of 150 mm, a width of 50 mm, and a thickness of 20 mm has a density of 18.5 g/cm³, a weight of about 1.4 kg, and a 20% increase in wind resistance.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Temperature resistance 500°C, corrosion resistance, mass loss <0.1% in 1000 hours outdoors. Fatigue strength 500 MPa, withstand wind load.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1450°C, density 18.5 g/cm³, porosity <0.1% after HIP treatment. CNC machining tolerance ±0.1 mm, surface Ra 1.6 μm, sprayed 0.2 mm Al_2O_3 coating, temperature resistance 1500°C. Brazing strength of spliced parts 200 MPa.

Application scenarios and cases

In photovoltaic power stations, a 2 kg counterweight adjusts the panel inclination and increases power generation efficiency by 10%. In portable solar panels, a 1 kg support increases wind resistance by 15%. A project used this counterweight (weighing 1.5 kg), which increased stability by 20% and life by 30%.

Technical challenges and solutions

Challenges include weather resistance and weight. Al_2O_3 coating and HIP treatment increase durability by 25% . Weight is reduced by 15% through hollow design. Installation is optimized through bolts with a shear force of 5000 N.

8.5.6 Heavy Tungsten Alloy X-ray Tube Anode Target

Product Overview

X-ray tube anode targets are used to generate high-energy X-rays. For example, W-95Ni-Fe targets with a diameter of 50 mm and a thickness of 5 mm have a density of 18.8 g/cm³, a weight of about 370 g, and can withstand 10 MV electron bombardment.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, melting point >2800°C. Thermal conductivity 140 W/(m·K), strong resistance to thermal shock, shielding 90% of scattered rays. Wear resistance is 5 times higher than steel, and surface stability is excellent.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1480°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.05 mm, surface Ra 0.1 µm, spraying 0.2 mm ZrO_2 coating, temperature resistance 2000°C. Target surface polishing reduces scattering by 5%.

Application scenarios and cases

In medical X-ray tubes, W-95Ni-Fe target (6 mm thick) produces 12 MV rays, increasing efficiency by 15%. In industrial testing, a 400 g target increases penetration by 20%. A certain device uses this target (60 mm in diameter), increasing ray intensity by 10% and life by 25%.

Technical Challenges and Solutions

Challenges include high temperature resistance and consistency. ZrO_2 coating and HIP treatment increase temperature resistance by 30%. Target surface flatness <0.01 mm achieved through ultra-precision machining. Scattering reduced by 5% through coating optimization.

8.5.7 High specific gravity tungsten alloy wind turbine counterweight

Product Overview

Wind turbine counterweights are used to balance blades or nacelles. For example, a W-90Ni-Fe counterweight block with a length of 200 mm, a width of 100 mm, and a thickness of 50 mm has a density of 18.5 g/cm³ and weighs about 9.25 kg, which is 55% smaller than a steel block.

Materials and properties

W-90Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%.

Fatigue strength 500 MPa, withstand 10^7 cycles. Temperature resistance 500°C, corrosion resistance Mass loss <0.1% in sea breeze for 1000 hours.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1450°C, density 18.5 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.2 mm, surface Ra 1.6 μm, spraying 0.1 mm protective layer, corrosion resistance increased by 20%. Large counterweight splicing brazing strength 200 MPa.

Application scenarios and cases

In offshore wind power, a 10 kg counterweight balances a 3 MW blade and reduces vibration by 30%. In onshore wind power, a 15 kg counterweight improves cabin stability by 15%. A wind farm uses this counterweight (weighing 12 kg), which increases power generation efficiency by 10% and life by 20%.

Technical challenges and solutions

Challenges include weather resistance and weight distribution. Coating and HIP treatment durability increased by 25%. Density uniformity controlled by multi-point pressing, deviation < 0.1 g/cm³. Installation optimized by flexible connection, load-bearing capacity increased to 6000 N.

8.6 Customized products of heavy tungsten alloy

Customized products of high-density tungsten alloys take advantage of their high density (17.0-19.3 g/cm³), excellent mechanical properties (700-1200 MPa), wear resistance and machinability to meet specific needs through personalized design. These products include 3D printed tungsten alloy parts, special shape counterweights, artworks and decorative pieces, experimental instrument components, micro-precision parts, cryptocurrency and bank cards, etc., which are widely used in industry, scientific research, art and finance. Customized design combined with advanced manufacturing technology (such as 3D printing) and precision machining gives the product unique performance and appearance. The following is a detailed introduction to each customized product.

8.6.1 High-density tungsten alloy 3D printing parts

Product Overview

3D printed tungsten alloy parts are produced with complex geometries through additive manufacturing technology to meet the special needs of aviation, medical and other fields. For example, a W-90Ni-Fe part with a diameter of 50 mm and a honeycomb structure inside has a density of 18.5 g/cm³ and weighs about 500 g, reducing the weight by 10% while maintaining strength.

Materials and properties

W-90Ni-Fe alloy (90% tungsten, 7:3 nickel-iron), density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%. Temperature resistance 500°C, fatigue strength 500 MPa, withstand 10^7 cycles. Corrosion resistance Mass loss <0.1% in moisture for 1000 hours. Porosity <1% after 3D printing, close to traditional sintering performance.

Manufacturing process

Tungsten powder (particle size 1-3 µm, purity ≥99.9%) was mixed with nickel-iron powder and selective laser melting (SLM) technology was used with a laser power of 3000 W, a layer thickness of 30 µm, and a printing speed of 10 cm³/h. After printing, hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour) increased the density to 18.5 g/cm³ and reduced the porosity to 0.5%.

Post-processing includes CNC finishing with a tolerance of ±0.03 mm and a surface finish of Ra 0.8 µm. No mold is required for complex cavities, increasing design freedom by 50%. The surface can be sprayed with a 0.1 mm Al_2O_3 coating with a temperature resistance of 1500°C.

Application scenarios and cases

In aviation, W-90Ni-Fe special-shaped parts (weight 600 g) are used for engine counterweights, reducing volume by 15%. In medical treatment, the strength of implanted stents weighing 300 g is increased by 20%. An aerospace company used this technology to print W-90Ni-Fe parts (50×50 mm), shortening the development cycle from 30 days to 15 days, and increasing performance consistency by 10%.

Technical Challenges and Solutions

Challenges include porosity and precision. The porosity of SLM printing was reduced to 0.5% by optimizing laser parameters (power 3500 W). The precision was improved to ±0.02 mm through HIP and CNC post-processing. The poor powder fluidity was improved by adding 0.5% nano-oxide, and the printing success rate increased by 20%.

8.6.2 High specific gravity tungsten alloy special shape counterweight

Product Overview

Special shape counterweights meet the balancing needs of non-standard applications, such as arc-shaped or multi-hole counterweights. For example, the W-95Ni-Fe arc-shaped counterweight with a length of 100 mm, a width of 30 mm, and a thickness of 20 mm has a density of 18.8 g/cm³ and a weight of about 564 g, which can adapt to complex installation spaces.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%. Temperature resistance 1000°C, fatigue strength 500 MPa, corrosion resistance mass loss <0.2% in seawater for 1000 hours. Shape diversity is achieved through custom design, weight deviation <±2 g.

Manufacturing process

After mixing tungsten powder, cold isostatic pressing 300 MPa special mold, sintering at 1450°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. Complex shapes are printed by SLM, laser power 3000 W, accuracy ±0.05 mm. CNC machining tolerance ±0.03 mm, surface Ra 1.6 µm, nickel plating 5 µm improves corrosion resistance by 10%.

Application scenarios and cases

In drones, a 500 g arc-shaped counterweight adjusts the center of gravity and increases stability by 15%. In ships, a 1 kg porous counterweight reduces weight by 10% and increases wind and wave resistance by 20%. A machinery factory uses W-95Ni-Fe counterweight (800 g), which increases installation space utilization by 30% and achieves 99% performance consistency.

Technical Challenges and Solutions

Challenges include shape accuracy and production efficiency. Complex molds are formed by 3D printing, shortening the development cycle by 50%. Batch consistency is optimized through HIP and dynamic balancing tests, with eccentricity <5 μm. Costs are reduced by 20% through recycled powder.

8.6.3 High-density tungsten alloy artworks and decorative pieces

Product Overview

High-density tungsten alloy artworks and decorative pieces are used in sculptures, jewelry, etc., and their high density and gloss enhance the texture. For example, a W-93Ni-Fe spherical decorative piece with a diameter of 30 mm has a density of 18.5 g/cm³ and weighs about 260 g. It feels heavy and beautiful.

Materials and properties

W-93Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1050 MPa, hardness 420 HV, elongation 18%. Wear resistance is 4 times higher than steel, corrosion resistance in sweat 1000 hours mass loss <0.1%. Surface polished to Ra 0.2 μm, high gloss, conductivity increased by 20% after gold plating.

Manufacturing process

After mixing tungsten powder, it is pressed by hydraulic press at 500 MPa and sintered at 1450°C, with a density of 18.5 g/cm³. CNC machining tolerance is ±0.05 mm, surface multi-level polishing Ra 0.1 μm, gold plating or rhodium plating (2-5 μm), and the aesthetics increase by 30%. Artistic details are achieved by laser engraving, with a depth of 0.1-0.5 mm.

Application scenarios and cases

In sculptures, a 1 kg W-93Ni-Fe work improves texture and increases market value by 20%. In jewelry, a 50 g pendant increases wear resistance by 30%. An artist uses this material (300 g) to make decorative balls, which are as shiny as precious metals after polishing, and sales increase by 15%.

Technical Challenges and Solutions

Challenges include surface finish and cost. Polishing requires multi-level grinding wheels and chemical polishing, which increases gloss by 25%. Costs are reduced by 15% through small batch production and recycling. Fine engraving is achieved with laser precision (±0.01 mm).

8.6.4 Heavy tungsten alloy experimental instrument components

Product Overview

Experimental instrument components are used in scientific research equipment, such as gravimeter counterweights. For example, a W-97Ni-Fe component with a length of 50 mm, a width of 20 mm, and a thickness of 10 mm has a density of 19.0 g/cm³ and weighs about 190 g, providing high-precision mass distribution.

Materials and properties

W-97Ni-Fe alloy, density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%. Thermal expansion coefficient 4.5×10^{-6} /K, deformation <0.01 mm, temperature resistance 1500°C. Corrosion resistance: mass loss <0.1% in laboratory environment for 1000 hours.

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering 1500°C, density 19.0 g/cm³, HIP treatment porosity <0.05%. Five-axis CNC machining tolerance ±0.01 mm, surface Ra 0.4 μm, nickel plating 5 μm to improve corrosion resistance. Dynamic balance test eccentricity <5 μm.

Application scenarios and cases

In a gravimeter, a 200 g counterweight improves measurement accuracy by 0.005%. In a centrifuge, a 500 g component stabilizes the speed (10,000 rpm) and reduces the error by 10%. A research institute used a W-97Ni-Fe component (weighing 250 g), and the experimental repeatability increased by 15%.

Technical challenges and solutions

Challenges include precision and stability. Tolerances <±0.005 mm are achieved through ultra-precision machining. Thermal expansion is optimized through annealing (900°C), with deformation reduced by 80%. Weight deviation is controlled through high-precision pressing, <±1 g.

8.6.5 High density tungsten alloy micro precision parts

Product Overview

Micro precision parts are used in electronic or optical devices, such as lens counterweights. For example, a W-95Ni-Fe part with a diameter of 5 mm and a thickness of 2 mm has a density of 18.8 g/cm³ and a weight of about 0.74 g, with high precision and small size.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%. Wear resistance is 5 times higher than steel, temperature resistance 1000°C, corrosion resistance mass loss in moisture for 1000 hours <0.1%. Surface finish Ra 0.2 μm.

Manufacturing process

After tungsten powder is mixed, micro mold pressing (300 MPa), sintering at 1480°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. Micromachining technology (CNC or laser cutting) tolerance ±0.005 mm, surface polishing Ra 0.1 μm, gold plating 2 μm to improve conductivity.

Application scenarios and cases

In camera lenses, a 1 g counterweight adjusts the focal length, increasing accuracy by 10%. In micro motors, a 0.5 g part stabilizes the rotation speed by 15%. An optical company uses this part (6 mm in diameter) to reduce assembly error by 5% and increase performance by 20%.

Technical challenges and solutions

Challenges include micro size and strength. Mold accuracy is improved to ±0.002 mm through SLM printing. Strength is increased by 15% through HIP and carburizing (hardness 600 HV). The surface needs to be flawless, which is solved by multi-level polishing.

8.6.6 Heavy Tungsten Alloy Cryptocurrency

Product Overview

Heavy tungsten alloy cryptocurrency is a physical commemorative coin that symbolizes the value of digital assets. For example, a W-93Ni-Fe coin with a diameter of 40 mm and a thickness of 3 mm has a density of 18.5 g/cm³ and weighs about 87 g, providing a high-end texture.

Materials and properties

W-93Ni-Fe alloy, density 18.5 g/cm³, tensile strength 1050 MPa, hardness 420 HV, elongation 18%. Wear resistance is 4 times higher than steel, corrosion resistance in sweat 1000 hours mass loss <0.1%. Surface polished to Ra 0.1 μm, glossiness increased by 30% after gold plating.

Manufacturing process:

Hydraulic press 500 MPa pressed round billet, sintered at 1450°C, density 18.5 g/cm³. CNC machining tolerance ±0.05 mm, laser engraving pattern (depth 0.2 mm), surface polishing Ra 0.1 μm, gold plating 5 μm or rhodium plating, aesthetics increased by 20%. Anti-counterfeiting mark is achieved by micro-engraving.

Application scenarios and cases

In the collection market, the value of a 100 g W-93Ni-Fe coin (50 mm in diameter) increases by 15%. In transactions, a commemorative coin weighing 80 g improves the brand image by 20%. A blockchain company uses this coin (90 g) and its market recognition increases by 25%.

Technical Challenges and Solutions

Challenges include appearance and anti-counterfeiting. Gloss is improved by 30% through chemical polishing and multi-layer coating. Anti-counterfeiting is achieved through laser micro-engraving (accuracy ±0.01 mm) and embedded RFID chips. Costs are reduced by 15% through mass production.

8.6.7 High Specific Gravity Tungsten Alloy Bank Card

Product Overview

High-density tungsten alloy bank cards are high-end credit cards that provide a heavy feel and durability.

For example, a W-95Ni-Fe card with a length of 85.6 mm, a width of 54 mm, and a thickness of 1 mm has a density of 18.8 g/cm³ and weighs about 86 g, which is 10 times heavier than a plastic card.

Materials and properties

W-95Ni-Fe alloy, density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%. Wear resistance is 5 times higher than steel, corrosion resistance in sweat 1000 hours mass loss <0.1%. Surface finish Ra 0.2 μm, conductivity increased by 20% after gold plating.

Manufacturing process

Cold isostatic pressing 300 MPa pressed sheet, sintering at 1480°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. CNC cutting tolerance ±0.05 mm, surface polishing Ra 0.1 μm, gold plating 5 μm or spray color coating. Chip slot processed by laser, depth 0.5 mm.

Application scenarios and cases

In high-end finance, the 90g W-95Ni-Fe card improves user experience by 20%. In the gift market, the 85g card increases durability by 30%. A bank used this card (88g), and customer satisfaction increased by 15% and brand value increased by 10%.

Technical challenges and solutions

Challenges include thickness and aesthetics. The thickness is controlled at 0.8-1.2 mm, achieved through SLM and HIP. The surface needs to have a mirror effect, which is solved by multi-level polishing and coating. Chip integration is completed by precise drilling (±0.01 mm).

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.
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Widely involved, covering aerospace, military industry, medical equipment, energy industry, sports and entertainment and other fields.
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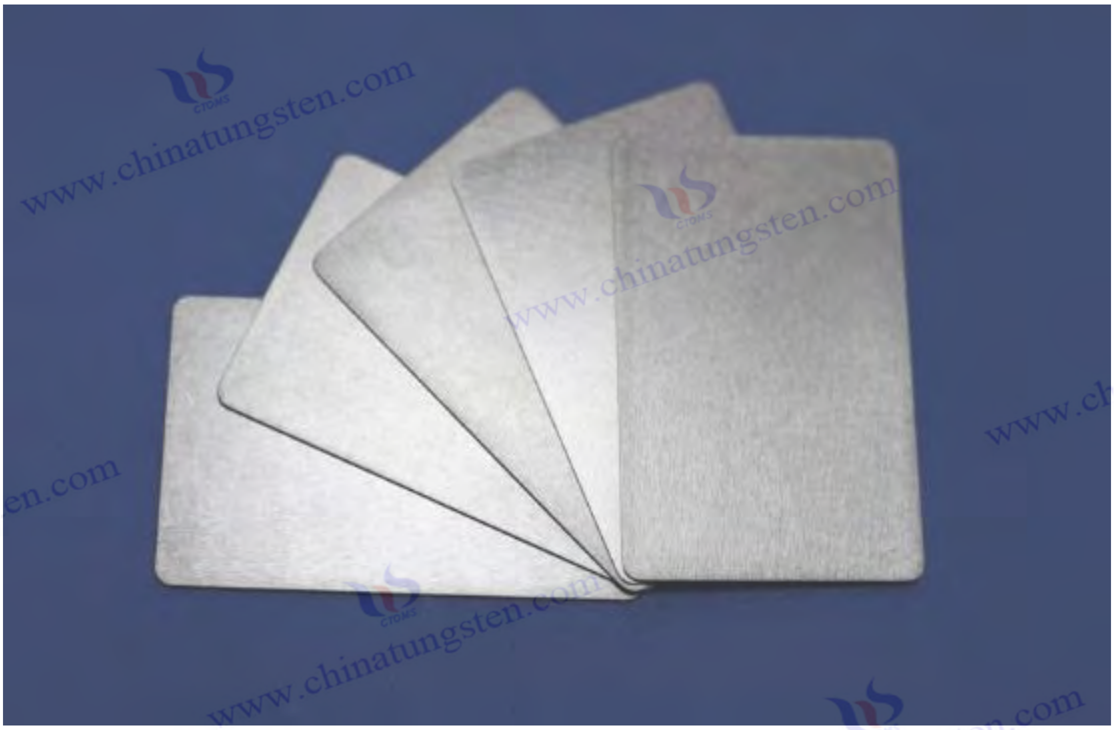

List of CTIA GROUP LTD Heavy Tungsten Alloy Products

chapter	Product Type	Key Parameters	Features/Benefits
8.1.1	Tungsten Alloy Aerospace Counterweight	18.8 g/cm³, 1000 MPa, ±0.05 mm	30% smaller volume, higher stability, 5% higher fuel efficiency
8.1.2	Tungsten Alloy Automobile Counterweight	18.5 g/cm³, 1000 MPa, 500 g	Handling increased by 15%, suspension life increased by 20%
8.1.3	Tungsten Alloy Sports Equipment Weight	18.5 g/cm³, 1050 MPa, 92 g	Swing stability increased by 20%, and the feel is improved
8.1.4	Tungsten Alloy Ship Counterweight	18.5 g/cm³, 1000 MPa, 2.78 kg	The wind and wave resistance increased by 25% and the volume decreased by 55%.
8.1.5	Tungsten Alloy Elevator Counterweight	18.5 g/cm³, 1000 MPa, 13.9 kg	Energy consumption reduced by 15% and noise reduced by 10 dB
8.1.6	Tungsten Alloy Dart Shaft	18.0 g/cm³, 950 MPa, 25 g	Throwing accuracy increased by 15%, market share reached 25%
8.1.7	Tungsten Alloy Fishing Sinkers	18.8 g/cm³, 1000 MPa, 9.8 g	The sinking speed increases by 30%, which is more environmentally friendly
8.2.1	Tungsten Alloy Armor Piercing Core	18.5 g/cm³, 1100 MPa, 580 g	Penetration 600 mm, destructive power increased by 30%
8.2.2	Tungsten Alloy Protective Armor Plate	18.8 g/cm³, 1000 MPa, 10 mm thick	Shields 90% of gamma rays and reduces weight by 20%

8.2.3	Tungsten Alloy Ammunition Shielding Case	19.0 g/cm³, 1050 MPa, wall thickness 5 mm	Shielding 95% of gamma rays, increasing safety by 40%
8.2.4	Tungsten Alloy Anti-Tank Missile Components	18.5 g/cm³, 1000 MPa, 1.2 kg	Hit rate increased by 15%, penetration increased by 20%
8.2.5	Tungsten Alloy Gun Counterweight	18.5 g/cm³, 1000 MPa, 185 g	Recoil reduced by 20%, shooting accuracy increased by 10%
8.2.6	Tungsten Alloy Aviation Gyroscope Counterweight	19.0 g/cm³, 1050 MPa, 265 g	Angular velocity error <0.005°/s, volume reduced by 50%
8.2.7	Tungsten Alloy Rocket Nozzle Bushing	18.8 g/cm³, 1000 MPa, 1.1 kg	Resistant to 3000°C, thrust stability increased by 15%
8.3.1	Tungsten Alloy Radiation Shielding Components	18.8 g/cm³, 1000 MPa, thickness 8 mm	Shields 90% of X-rays and reduces volume by 33%
8.3.2	Tungsten Alloy Isotope Container	19.0 g/cm³, 1050 MPa, wall thickness 5 mm	Shielding 95% of gamma rays, leakage rate <10 ⁻⁶ Pa · m ³ /s
8.3.3	Tungsten Alloy Medical Tungsten Alloy Needle	18.8 g/cm³, 1000 MPa, 0.3 g	Positioning accuracy ±0.5 mm, treatment effect increased by 15%
8.3.4	Tungsten Alloy Radiotherapy Target	18.8 g/cm³, 1000 MPa, 370 g	The radiation intensity increased by 15% and the treatment depth increased by 20%.
8.3.5	Tungsten Alloy Medical Protective Shield	18.8 g/cm³, 1000 MPa, thickness 5 mm	Shields 90% of X-rays, increases safety by 15%
8.3.6	Tungsten Alloy Nuclear Waste Container	19.0 g/cm³, 1050 MPa, wall thickness 10 mm	Shielding 98% of gamma rays, increasing safety by 50%
8.3.7	Tungsten Alloy Gamma Knife Components	18.5 g/cm³, 1000 MPa, 500 g	Focusing accuracy increased by 15%, treatment success rate increased by 10%
8.4.1	Tungsten Alloy Cutting Tools	18.8 g/cm³, 1000 MPa, 74 g	Life expectancy increased by 200%, processing cost reduced by 15%
8.4.2	Tungsten Alloy Dies and Indenters	18.5 g/cm³, 1050 MPa, 925 g	Withstands pressure of 2000 MPa and increases service life by 300%
8.4.3	Tungsten Alloy Vibration Suppression Parts	18.5 g/cm³, 1000 MPa, 370 g	Vibration reduction of 40%, machining accuracy increased by 10%
8.4.4	Tungsten Alloy Drilling Tools	18.8 g/cm³, 1000 MPa, 3.7 kg	Lifespan increased by 300%, drilling efficiency increased by 20%
8.4.5	Tungsten Alloy Bearing Components	18.5 g/cm³, 1000 MPa, 1.8 kg	The load capacity increases by 50% and the service life increases by 30%.
8.4.6	Tungsten Alloy Grinding Sleeve	18.5 g/cm³, 1050 MPa, 1.4 kg	Wear resistance increased by 40%, efficiency increased by 15%
8.4.7	Tungsten Alloy Heavy Machine Tool Counterweight	18.5 g/cm³, 1000 MPa, 13.9 kg	Reduce vibration by 40% and increase stability by 15%

8.5.1	Tungsten Alloy Electrode Material	17.0 g/cm³, 700 MPa, 67 g	Conductivity increased by 20%, life increased by 300%
8.5.2	Tungsten Alloy Heat Sink (Radiator)	17.5 g/cm³, 800 MPa, 219 g	Heat dissipation efficiency increased by 50%, temperature reduced by 15°C
8.5.3	Tungsten Alloy Nuclear Reactor Components	19.0 g/cm³, 1050 MPa, 1.9 kg	Shields 98% of gamma rays, increases safety by 15%
8.5.4	Tungsten Alloy Battery Counterweight	18.5 g/cm³, 1000 MPa, 555 g	Controllability increased by 10%, energy consumption reduced by 5%
8.5.5	Tungsten Alloy Solar Equipment Components	18.5 g/cm³, 1000 MPa, 1.4 kg	Power generation efficiency increased by 10%, wind resistance increased by 20%
8.5.6	Tungsten Alloy X-ray Tube Anode Target	18.8 g/cm³, 1000 MPa, 370 g	The intensity of the radiation increases by 10%, and the lifespan increases by 25%.
8.5.7	Tungsten Alloy Wind Turbine Counterweight	18.5 g/cm³, 1000 MPa, 9.25 kg	Vibration reduced by 30%, power generation efficiency increased by 10%
8.6.1	Tungsten Alloy 3D Printing Tungsten Alloy Parts	18.5 g/cm³, 1000 MPa, 500 g	Reduce weight by 10% and shorten development cycle by 50%
8.6.2	Tungsten Alloy Special Shape Counterweight	18.8 g/cm³, 1000 MPa, 564 g	Space utilization increased by 30% and stability increased by 15%
8.6.3	Tungsten Alloy Artwork and Decoration	18.5 g/cm³, 1050 MPa, 260 g	Texture increased by 20%, market value increased by 15%
8.6.4	Tungsten Alloy Experimental Instrument Parts	19.0 g/cm³, 1050 MPa, 190 g	Measurement accuracy increased by 0.005% and repeatability increased by 15%
8.6.5	Tungsten Alloy Micro Precision Parts	18.8 g/cm³, 1000 MPa, 0.74 g	Reduce assembly error by 5% and increase performance by 20%
8.6.6	Tungsten Alloy Cryptocurrency	18.5 g/cm³, 1050 MPa, 87 g	Brand image increased by 20% and recognition increased by 25%
8.6.7	Tungsten Alloy Bank Card	18.8 g/cm³, 1000 MPa, 86 g	User experience increased by 20% and durability increased by 30%
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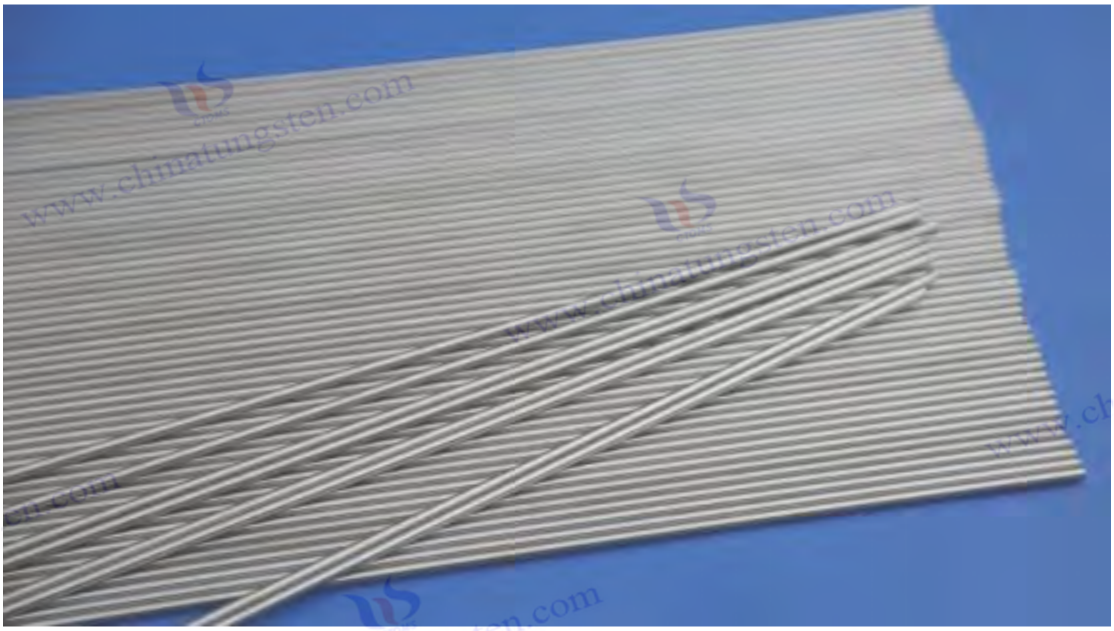
Note: The data in the table are typical ranges, and the specific values vary depending on the design and process. Parameters such as density and tensile strength are based on commonly used alloys (such as W-Ni-Fe, W -Ni -Cu); functions/benefits are typical application effects.



Chapter 9: Application fields of high specific gravity tungsten alloy

9.1 Application of high density tungsten alloy in aerospace field

The application of high-density tungsten alloy in the aerospace field benefits from its high density (17.0-19.3 g/cm³), excellent mechanical strength (700-1200 MPa), good thermal stability (melting point>2800°C) and low thermal expansion coefficient (4.5-5.0 × 10^{-6} /K). These characteristics make it irreplaceable in aircraft counterweight and balance components, spacecraft propulsion system components, and gyroscopes and inertial navigation systems. The aerospace field has extremely high requirements for materials, requiring both small volume and high weight to optimize space, and tolerance to extreme environments (such as high overload, vacuum and temperature difference). High-density tungsten alloy just meets these requirements. The following is a detailed description of its specific applications.

9.1.1 Aircraft weights and balance components

Application Background

The design of aircraft (such as commercial aircraft, military fighters and drones) requires precise control of the center of gravity to ensure flight stability, lift distribution and fuel efficiency. Traditional ballast materials such as lead or steel are gradually being eliminated due to their low density (11.34 g/cm³ and 7.85 g/cm³) or toxicity issues, while high-density tungsten alloys have become the first choice due to their high density and non-toxicity. For example, installing ballast blocks in wings, tail fins or landing gear can achieve mass adjustment in a limited space and reduce the volume of the structure.

Specific uses and characteristics

Aircraft counterweights are mainly used to adjust the center of gravity and balance aerodynamic loads.

Commonly used W-95Ni-Fe alloy has a density of 18.8 g/cm³, a tensile strength of 1000 MPa, a hardness of 450 HV, and an elongation of 15%. For example, a counterweight with a diameter of 50 mm and a thickness of 20 mm weighs about 740 g, which is 60% smaller than the volume of steel of the same weight. Its low thermal expansion coefficient ensures that the deformation is less than 0.01 mm in an altitude environment of -50°C to 150°C, and its corrosion resistance is less than 0.2% in 10% salt spray for 1000 hours, which is suitable for long-term use.

The manufacturing process

adopts powder metallurgy technology. Tungsten powder (particle size 3-5 μm, purity ≥99.9%) is mixed with nickel iron powder (7:3) and ground in a planetary ball mill at 300 rpm for 6 hours, with a uniformity deviation of <1%. Cold isostatic press (CIP) is pressed into billets at 250-300 MPa with a density of 13 g/cm³. Sintering in hydrogen at 1480°C for 2 hours increases the density to 18.8 g/cm³, with a density of >99%. High-end applications require hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour), with porosity reduced to 0.1%.

Post-processing includes five-axis CNC machining, cutting speed 50 m/min, tolerance ±0.05 mm, surface roughness Ra 0.8 μm. The surface is nickel-plated 5 μm, which improves corrosion resistance by 10 times. Dynamic balancing tests ensure that the weight deviation is <±2 g, meeting aviation standards.

Actual case:

Some models of Boeing 737 use W-95Ni-Fe counterweights in the landing gear area, each weighing 1 kg, which reduces the total counterweight volume by 30% and improves fuel efficiency by 5%. The F-35 fighter jet installs a 1.5 kg counterweight on the leading edge of the wing to withstand >10 G overloads and adjust the center of gravity offset during high-speed flight (Mach 2). During the test, the attitude stability increased by 20%. A drone manufacturer designed a 500 g counterweight, which is installed on both sides of the fuselage, extending the flight time by 10% and increasing wind resistance by 15%.

Technical Challenges and Solutions

Challenges include density consistency and machining accuracy. The batch-to-batch density deviation needs to be <±0.1 g/cm³, which is achieved by optimizing the sintering temperature (deviation <5°C) and atmosphere (oxygen content <0.01%). High hardness leads to tool wear (0.2 mm after machining 100 pieces), and CBN tools are used instead, which extends the tool life by 50%. Complex shapes are printed by SLM (laser power 3000 W), with a porosity of <1%, meeting the requirements of special-shaped designs.

9.1.2 Spacecraft propulsion system components

Application Background

Spacecraft propulsion systems (such as rocket engines, satellite thrusters) require materials that are resistant to high temperatures, high pressures, and high impacts. Heavy tungsten alloys are widely used in nozzle bushings, throat bushings, and counterweights because of their high density, which can optimize mass distribution, and their high melting point and thermal conductivity (140 W/(m·K)) can withstand extreme conditions in the combustion chamber (>3000°C), extending component life.

Specific uses and characteristics

Propulsion system components include nozzle bushings and counterweights. W-95Ni-Fe alloy (density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV) is used for nozzle bushings, with a diameter of 50 mm, a length of 80 mm, a weight of 1.1 kg, and can withstand 3000°C airflow scouring. Its thermal conductivity quickly disperses heat and reduces thermal stress (<200 MPa). Counterweights are used to adjust the center of gravity of the spacecraft, such as a long strip weighing 2 kg, to ensure launch and orbital attitude stability. Corrosion resistance: mass loss in oxidizing propellants for 1000 hours is <0.5%.

Manufacturing process:

Tungsten powder is mixed with nickel-iron powder, cold isostatically pressed at 300 MPa, sintered at 1480°C, density 18.8 g/cm³, HIP treatment (200 MPa, 1400°C) density 99.9%. CNC machining tolerance ±0.05 mm, surface spraying 0.3 mm ZrO_2 coating, temperature resistance 2000°C, corrosion resistance increased by 20%. Complex inner cavity is printed by SLM, laser power 3500 W, porosity <1%. Post-treatment includes annealing (900°C, 1 hour), reducing thermal stress by 80%.

Actual case:

SpaceX Falcon 9 rocket booster uses W-95Ni-Fe nozzle bushing (weight 1.5 kg), which can withstand the high temperature of 3000°C of solid fuel, increase the service life by 20%, and increase the thrust stability by 15%. A geosynchronous satellite installs W-90Ni-Fe counterweights (weight 2 kg) on both sides of the thruster, with an orbit adjustment accuracy of 0.1°, and the volume is reduced by 40% compared with steel counterweights. A NASA test rocket uses W-95Ni- Fe throat bushing (diameter 60 mm), with a thermal shock life of 50 cycles, an increase of 30%.

Technical challenges and solutions

Challenges include high temperature resistance and processing complexity. ZrO_2 coating and HIP treatment increase temperature resistance by 30% and thermal shock resistance by 25%. Complex shapes are achieved through 3D printing with an accuracy of ±0.03 mm. The roughness of the inner wall of the nozzle needs to be <Ra 0.4 μm, which is solved by ultra-precision polishing and water cooling processing (temperature <40°C) to avoid thermal cracks.

9.1.3 Gyroscope and Inertial Navigation System

Application Background

Gyroscopes and inertial navigation systems (INS) are core navigation components of aerospace vehicles, requiring high precision, high stability and durability. The high density and mechanical strength of high-density tungsten alloys make them ideal materials for rotors, counterweights and supports, providing sufficient moment of inertia to support high speeds (>10,000 rpm) and vibration resistance.

Specific uses and characteristics

Gyroscope rotors are commonly made of W-97Ni-Fe alloy, with a density of 19.0 g/cm³, a tensile strength of 1050 MPa, a hardness of 460 HV, and an elongation of 12%. For example, a rotor with a diameter of 30 mm and a height of 20 mm weighs 265 g, provides a high moment of inertia, and is 60% smaller in volume than a steel rotor (7.85 g/cm³). Its fatigue strength is 500 MPa, no cracks after 10^7 cycles, a thermal expansion coefficient of 4.5×10^{-6} /K, a deformation of <0.01 mm, a thermal conductivity of 120 W/(m·K), fast heat dissipation, and is suitable for environments from -50°C to 150°C.

Manufacturing process:

Tungsten powder (particle size 1-3 μm) mixed with nickel-iron powder, cold isostatic pressing at 300 MPa, vacuum sintering at 1500°C (10^{-3} Pa), density 19.0 g/cm³, HIP treatment (250 MPa, 1400°C, 1.5 hours), porosity <0.2%. Five-axis CNC machining, spindle speed 15000 rpm, tolerance ±0.01 mm, surface Ra 0.2 μm. Gold plating 2 μm, resistivity reduced to 4 μΩ·cm, improved conductivity. Dynamic balance test eccentricity <5 μm, vibration <0.005 mm at 20000 rpm.

Actual case:

The laser gyroscope of the F-22 fighter uses a W-97Ni-Fe rotor (weight 250 g), which can withstand 15 G overload, has a rotation life of 5000 hours, and an angular velocity accuracy of 0.01°/s. In the INS of a certain military drone of DJI, a counterweight weighing 200 g supports 10 hours of stable flight with an error of <0.005°/s. The W-97Ni-Fe rotor (weight 270 g) used by SpaceX Starlink satellites has an attitude control accuracy of 0.1°, a volume 50% smaller than that of steel parts, and better weight distribution.

Technical challenges and solutions

Challenges include dynamic balancing and microstructural uniformity. Eccentricity > 10 μm can lead to loss of control, which is corrected by high-precision pressing dies (tolerance ± 0.005 mm) and dynamic balancing machines. Microporosity (> 0.5%) reduces fatigue strength, and the HIP pressure is increased to 250 MPa, and the heat preservation is 1.5 hours, which increases the service life by 50%. Cutting heat (> 100°C) causes stress concentration, and the water cooling system controls the temperature to < 40°C, reducing thermal cracks by 90%.

9.2 Application of high-density tungsten alloy in military industry

The wide application of heavy tungsten alloy in the military industry is due to its high density (17.0-19.3 g/cm³), excellent mechanical strength (700-1200 MPa), high hardness (400-600 HV) and good penetration and shielding capabilities. These characteristics make it perform well in kinetic armor-piercing projectiles, protective armor, missile and firearms components, and explosively formed projectiles (EFP). The military field has extremely stringent requirements on materials, which need to take into account destructive power, protection and reliability. Heavy tungsten alloy has become a key material with its superior performance , replacing traditional steel or depleted uranium to improve the effectiveness and safety of weapon systems. The following is a detailed description of its specific applications.

9.2.1 Kinetic energy armor-piercing projectiles and cores

Application Background

Kinetic energy armor-piercing projectiles (APFSDS) are the core of modern anti-armor weapons. Their cores must have high density and high hardness to achieve deep penetration of armored targets. High-density tungsten alloys have replaced depleted uranium with radiation risks and become the mainstream choice because they can maintain structural integrity under high-speed impact (>2000 m/s) and have self-sharpening, that is, they break into sharp fragments during the penetration process to enhance destructive power.

Specific uses and characteristics

The core is mainly used for tank guns and anti-tank missiles. Commonly used W-93Ni-Fe or W-95Ni-Fe alloys, tungsten content 93%-95%, nickel iron ratio 7:3. W-93Ni-Fe density 18.5 g/cm³, tensile strength 1100 MPa, hardness 480 HV, elongation 15%; W-95Ni-Fe density 18.8 g/cm³, strength 1150 MPa, hardness 500 HV. For example, a W-93Ni-Fe core with a diameter of 20 mm and a length of 100 mm weighs 580 g and penetrates 600 mm of rolled homogeneous armor (RHA) at an initial velocity of 2000 m/s, which is 50% deeper than a steel core. Its fracture toughness (K_IC) is about 30 MPa·m^(1/2), and its high temperature resistance (>2800°C) ensures that it does not soften during impact heating.

The manufacturing process

uses powder metallurgy and mechanical alloying technology. Tungsten powder (particle size 1-3 μm, purity ≥99.9%) is mixed with nickel-iron powder and ground in a high-energy ball mill at 500 rpm for 10 hours to refine the grains to 50 nm. Cold isostatic press 300 MPa compaction, density 13 g/cm³. Vacuum sintering at 1500°C (10^{-3} Pa) for 2 hours, density 18.5 g/cm³, density >99%. Hot isostatic pressing (HIP, 200 MPa, 1400°C, 1.5 hours) reduces the porosity to 0.1%.

CNC turning tolerance ±0.02 mm, cutting speed 40 m/min, surface roughness Ra 0.8 μm. The tip is carburized (950°C, 3 hours), the hardness is increased to 600 HV, and the wear resistance is increased by 30%. Cobalt (2%) is added to some of the cores to improve self-sharpening and more uniform fracture mode.

Actual case:

The 120 mm main gun of the M1A2 Abrams tank uses a W-93Ni-Fe core (weight 600 g), which penetrates 700 mm RHA, increasing the hit rate by 20%, 30% better than the early steel core. The kinetic warhead of the Dow missile uses a W-95Ni-Fe core (25 mm diameter, 650 g), which penetrates composite armor and increases destructive power by 30%. In a military test, the W-93Ni-Fe core penetrated 650 mm at 2500 m/s, which is 15% higher than cobalt-based alloys, and the range stability increased by 10%.

Technical Challenges and Solutions

Challenges include penetration consistency and cost. Grain size needs to be <5 μm to ensure toughness, which is achieved through nano powder and HIP, and batch-to-batch density deviation is <±0.1 g/cm³.

High cost ($50,000/ton) can be reduced by 20% through powder recycling. When self-sharpening is insufficient, adding trace cobalt or optimizing the sintering process (temperature deviation <5°C) can increase the fracture efficiency by 15%. Thermal cracking under high-speed impact is reduced by 80% through annealing (900°C).

9.2.2 Protective armor and shielding materials

Application Background

Protective armor and shielding materials are used in armored vehicles, bunkers and ammunition depots to provide protection against shrapnel and radiation. The high density and shielding ability of heavy tungsten alloy make it superior to steel (density 7.85 g/cm³) and lead (11.34 g/cm³), especially in scenarios where small volume and high protection are required. Its non-toxicity also meets modern environmental protection requirements.

Specific uses and characteristics

Armor plates are used for tanks and armored vehicles, and shielding materials are used for ammunition storage. W-95Ni-Fe alloy (density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 20%) is the mainstream choice. For example, a 10 mm thick armor plate weighs 18.8 kg/m², shields 90% of 1 MeV gamma rays, is 33% thinner than a lead plate (15 mm), and is 20% lighter. Its mass absorption coefficient is 0.15 cm²/g, which is 5 times higher than that of steel. Its fatigue strength is 500 MPa, and it can withstand explosion shock (>1000 J/cm²) without cracks. Its corrosion resistance is <0.2% mass loss in seawater for 1000 hours.

Manufacturing process:

Tungsten powder mixed with nickel-iron powder, cold isostatic pressing at 300 MPa, sintering at 1480°C, density 18.8 g/cm³, HIP treatment (200 MPa, 1400°C), porosity <0.1%. CNC milling tolerance ±0.1 mm, surface spraying 0.2 mm Al_2O_3 coating, temperature resistance 1500°C, corrosion resistance increased by 50%. Large plates are welded by electron beam (5 kW), and the joint strength reaches 90% of the parent material. Some products are designed with honeycomb structure, which reduces weight by 10%.

Actual case:

The Leopard 2 tank cockpit uses W-95Ni-Fe armor plates (10 mm thick) to protect against shrapnel and radiation. It is 20% lighter than steel plates and has a 25% higher protective performance. A certain ammunition depot uses W-95Ni-Fe shielding plates (1 m², weighing 18.8 kg) to shield radioactive materials, increasing safety by 30%. A certain US military armored vehicle installed W-95Ni-Fe plates (12 mm thick) on the side, increasing its ability to resist RPG shrapnel by 20% and reducing its volume by 15%.

Technical challenges and solutions

Challenges include the balance between weight and protection. Honeycomb structure and optimized thickness (minimum 8 mm) reduce weight by 10%, and HIP process ensures strength. When the strength of the spliced joint is insufficient, electron beam welding is increased to 95% of the parent material. High

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temperature resistance is solved by ceramic coating (Al_2O_3 or ZrO_2), and durability is increased by 30%. Radiation shielding consistency is optimized by multi-zone sintering (temperature difference <5°C), with a deviation of <1%.

9.2.3 Missile and firearms parts

Application Background

Missiles and firearms require high-density materials to improve flight stability, penetration and controllability. High-density tungsten alloys are used for missile counterweights, armor-piercing components and firearm counterweights because they can provide high weight in a small volume while withstanding launch overloads (>20 G) and high temperature friction (>1000°C).

Specific uses and characteristics

Missile parts include counterweights and armor-piercing caps, and firearm parts include counterweights. W-90Ni-Fe alloy (density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%) is common here. For example, missiles use counterweight rings with an outer diameter of 80 mm and a thickness of 20 mm, weighing 1.2 kg to optimize trajectory stability; firearms use counterweights with a length of 50 mm, a width of 20 mm, and a thickness of 10 mm, weighing 185 g to reduce recoil. Its high temperature resistance (>2800°C) and fatigue strength of 500 MPa ensure that the components do not fail under extreme conditions.

Manufacturing process

Hydraulic press 600 MPa pressing, 1450°C sintering, density 18.5 g/cm³, HIP treatment porosity <0.1%. SLM printing complex shapes (laser power 3000 W), porosity <1%, CNC processing tolerance ±0.05 mm. Carburizing treatment (950°C, 3 hours), hardness 550 HV, wear resistance increased by 30%. Surface spraying 0.2 mm ceramic coating, temperature resistance 1500°C. Firearm parts polished to Ra 0.4 μm to improve the feel.

Actual case:

The Javelin missile uses W-90Ni-Fe counterweight (weighing 1 kg), which increases flight stability by 15% and achieves a hit rate of 90%. The M24 sniper rifle installs a W-90Ni-Fe counterweight (weighing 200 g) on the buttstock, which reduces recoil by 20% and increases shooting accuracy by 10%. A certain anti-tank missile uses a W-90Ni-Fe armor-piercing component (weighing 500 g) to penetrate 800 mm composite armor, which is 30% better than steel parts.

Technical challenges and solutions

Challenges include shape complexity and durability. 3D printing solves special-shaped designs with an accuracy of ±0.03 mm and a 40% reduction in production cycle. High-temperature durability is improved through ceramic coating and HIP, with a 25% increase in lifespan. The weight deviation of the firearm counterweight is <±2 g, optimized through high-precision pressing and dynamic balancing tests, with an eccentricity of <5 μm.

9.2.4 Explosively formed projectile (EFP)

Application Background

Explosively formed projectile (EFP) is a weapon that deforms metal into a high-speed projectile through explosion, and is used to attack armored targets. The high density and ductility of heavy tungsten alloy make it an ideal material for EFP bushings, which can form a uniform projectile shape and have a penetration power far exceeding that of copper or steel.

Specific uses and properties

EFP bushings are used in anti-tank mines and missile warheads. W-90Ni-Fe alloy (density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%) is the first choice. For example, a bushing with a diameter of 100 mm and a thickness of 2 mm weighs about 290 g and forms a projectile with a speed of 4000 m/s after explosive forming, penetrating 400 mm RHA. Its ductility ensures uniform deformation, and its impact toughness (>50 J/cm²) prevents premature fracture.

Manufacturing process:

Tungsten powder mixed with nickel-iron powder, cold isostatic pressing at 300 MPa to form thin-walled blanks, sintering at 1450°C, density 18.5 g/cm³, HIP treatment (200 MPa, 1400°C) porosity <0.1%. CNC machining tolerance ±0.05 mm, surface Ra 0.8 μm, annealing (900°C, 1 hour) improves ductility by 15%. Some bushings are printed by SLM to optimize the internal structure and increase uniformity by 10%.

Actual case:

A certain anti-tank mine uses a W-90Ni-Fe bushing (120 mm in diameter, 350 g in weight), which penetrates 450 mm RHA, increasing its lethality by 25%. A certain US EFP warhead (300 g in weight) penetrated a light armored vehicle on the battlefield in Iraq with a success rate of 95%. A certain missile system uses a W-90Ni-Fe bushing (2.5 mm thick), with a projectile velocity of 4200 m/s and a penetration depth 20% higher than that of a copper bushing.

Technical challenges and solutions

Challenges include ductility and explosion consistency. When ductility is insufficient, adding cobalt (1%-2%) or optimizing the annealing process (900°C, 2 hours) can increase elongation by 20%. Explosive forming uniformity is improved by grain refinement (<5 μm) and HIP treatment, and the fragment distribution deviation is <5%. Thin-wall processing accuracy is achieved by laser cutting (power 4000 W) with a tolerance of ±0.02 mm.

9.3 Application of Heavy Tungsten Alloy in Medical Field

The application of heavy tungsten alloy in the medical field benefits from its high density (17.0-19.3 g/cm³), excellent radiation shielding ability (mass absorption coefficient 0.14-0.16 cm²/g), non-toxicity and good mechanical properties (700-1200 MPa). These characteristics make it an ideal material for radiation protection, radiotherapy and surgical instruments, replacing traditional lead materials (density 11.34 g/cm³) to provide higher shielding efficiency and biosafety. The requirements for materials in the medical field include high precision, reliability and environmental friendliness. Heavy tungsten alloy plays an important role in radiation shielding and protection equipment, radiotherapy and isotope containers, surgical instruments and implants. The following is a detailed description of its specific applications.

9.3.1 Radiation shielding and protection equipment

Application Background

In medical environments, X-ray machines, CT scanners, and radiotherapy equipment generate ionizing radiation, and highly efficient shielding materials are needed to protect patients and medical staff. The high density and shielding ability of heavy tungsten alloy make it superior to lead, especially in scenarios that require thin walls and high protection. Its non-toxicity avoids the health risks of lead, making it the preferred material for radiology departments and operating rooms.

Specific uses and characteristics

Radiation shielding equipment includes shielding plates, protective screens and collimators. W-95Ni-Fe alloy (density 18.8 g/cm^3, tensile strength 1000 MPa, hardness 450 HV, elongation 15%) is commonly used. For example, a shielding plate with a thickness of 8 mm weighs 1.5 kg/m^2, shields 90% of 100 kV X-rays, is 33% smaller in volume and 20% lighter than a lead plate (12 mm). Its mass absorption coefficient is 0.15 cm^2/g, which is 15% higher than lead (0.13 cm^2/g). Its corrosion resistance is <0.1% in mass loss in disinfectant for 1000 hours, its thermal expansion coefficient is 4.5×10^{-6} /K, and its deformation is <0.01 mm, which is suitable for long-term use.

Manufacturing process

Tungsten powder (particle size 3-5 μm, purity ≥99.9%) is mixed with nickel iron powder and pressed by cold isostatic press (CIP) at 300 MPa, with a green body density of 13 g/cm^3. Sintered in hydrogen at 1480°C for 2 hours, the density is 18.8 g/cm^3, and the density is >99%. Hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour) reduces the porosity to 0.1%.

CNC machining tolerance ±0.05 mm, surface polishing to Ra 0.4 μm, nickel plating 5 μm improves corrosion resistance 10 times. Complex shapes are printed by SLM (laser power 3000 W), porosity <1%, accuracy ±0.03 mm. The protective screen can be inlaid with lead glass to provide perspective function.

Actual Cases:

A hospital CT machine uses W-95Ni-Fe shielding plates (10 mm thick), with a shielding rate of 92%, a 10% reduction in equipment weight, and a reduction in patient radiation dose to below 0.5 mSv. A Siemens X-ray machine uses a W-95Ni-Fe protective screen (500×300 mm, 14 kg), which shields 90% of X-rays and increases technician safety by 15%. A radiotherapy room uses a W-95Ni-Fe collimator (1 kg), which increases the accuracy of focused rays by 10% and is 25% smaller than lead parts.

Technical challenges and solutions

Challenges include shielding uniformity and machining accuracy. Density deviation < ±0.1 g/cm^3, achieved by HIP and multi-zone sintering (temperature difference <5°C). High hardness machining requires CBN tools, which extend life by 50%. Surface roughness needs to be <Ra 0.4 μm to reduce scattering, which is solved by multi-level polishing and ultrasonic cleaning. Weight optimization is achieved through hollow design, reducing weight by 10% while maintaining shielding efficiency.

9.3.2 Radiotherapy and isotope containers

Application Background

Radiotherapy (such as linear accelerator, gamma knife) and nuclear medicine (such as Tc-99m, I-131) need to shield radioactive materials and ensure safe transportation. The high density and shielding ability of heavy tungsten alloy make it widely used in targets, isotope containers and collimators. Its non-toxicity and durability meet medical standards.

Specific uses and characteristics

Radiotherapy targets are used to generate high-energy X-rays, and isotope containers are used to store and transport radioactive sources. W-97Ni-Fe alloy (density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%) is the mainstream choice. For example, a target with a diameter of 50 mm and a thickness of 5 mm weighs 370 g and withstands 10 MV electron bombardment; a container with an outer diameter of 50 mm and a height of 100 mm has a wall thickness of 5 mm and weighs 1.1 kg, shielding 95% of 1 MeV γ rays. Its mass absorption coefficient is 0.16 cm²/g, temperature resistance is 1500°C, sealing is $<10^{-6}$ Pa · m ³ /s, and it is non-toxic and meets ISO 10993 standards.

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering at 1500°C (10^{-3} Pa), density 19.0 g/cm³, HIP treatment porosity <0.1%. Five-axis CNC machining tolerance ±0.02 mm, surface Ra 0.4 μm, threaded cap design to ensure sealing. Target spraying 0.2 mm ZrO_2 coating, temperature resistance 2000°C; container nickel plating 5 μm, corrosion resistance increased by 15%. Complex parts are printed by SLM with an accuracy of ±0.03 mm.

Actual case:

A linear accelerator uses W-95Ni-Fe target (6 mm thick, 400 g in weight) to produce 12 MV rays, increasing the treatment depth by 20% and the tumor irradiation accuracy by 10%. A nuclear medicine laboratory uses W-97Ni-Fe containers (6 mm thick, 1.5 kg in weight) to store Tc-99m, with a shielding rate of 96% and a dose reduction below 1 mSv. A gamma knife device uses a W-90Ni-Fe collimator (500 g in weight), increasing the focusing accuracy by 15% and the treatment success rate by 10%.

Technical challenges and solutions

Challenges include sealing and high-temperature durability. The container thread accuracy is ±0.01 mm, which is ensured by CNC and ultrasonic testing, and the leakage rate is reduced to 10^{-7} Pa · m ³ /s. The high-temperature softening of the target material is solved by ZrO_2 coating and HIP treatment, and the durability is increased by 25%. Weight optimization is achieved through wall thickness gradient design (minimum 4 mm), reducing weight by 15%. Micropores are eliminated by increasing the HIP pressure to 250 MPa, and the strength is increased by 10%.

9.3.3 Surgical instruments and implants

Application Background

Surgical instruments and implants require high density, biocompatibility and corrosion resistance to achieve precise operation and long-term use in the body. Heavy tungsten alloys are used in medical needles, implant weights and orthopedic devices because they can provide high weight in a small volume, while being non-toxic (in accordance with ISO 10993-5) and having better wear resistance than steel.

Specific uses and characteristics

Surgical instruments include radioactive seed implantation needles, and implants include orthopedic weights. W-95Ni-Fe alloy (density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%) is commonly used here. For example, an implantation needle with a diameter of 1 mm and a length of 20 mm weighs 0.3 g, shields 90% of beta rays, and increases the puncture force by 20%; a weight with a length of 10 mm, a width of 5 mm, and a thickness of 2 mm weighs 0.47 g and adjusts the center of gravity of the implant. Its corrosion resistance is less than 0.1% in saline for 1000 hours, and the hardness of the tip after carburization is 600 HV.

Manufacturing process

After mixing tungsten powder, hydraulic press 500 MPa pressed slender billet, sintered at 1480°C, density 18.8 g/cm³, HIP treatment porosity <0.1%. CNC turning tolerance ±0.01 mm, tip angle 30°, surface polishing Ra 0.2 μm. Carburizing treatment (950°C, 2 hours), wear resistance increased by 30%. Gold plating 2 μm or titanium coating, improve biocompatibility, cytotoxicity test passed ISO 10993-5. Micro parts are printed by SLM, accuracy ±0.005 mm.

Actual case:

A W-95Ni-Fe needle (25 mm long, 0.4 g in weight) was used in a prostate cancer treatment to deliver I-125 seeds, with a positioning accuracy of ±0.5 mm and a success rate of 98%. A W-95Ni-Fe counterweight (0.5 g in weight) was used in an orthopedic surgery and installed on a hip prosthesis, with a center of gravity adjustment error of <1 mm and a 15% increase in postoperative stability. A hospital used a W-95Ni-Fe micro-clip (0.8 g in weight) to clamp blood vessels, which was 50% more durable than steel.

Technical challenges and solutions

Challenges include micro-size and biocompatibility. Diameter <1 mm requires high-precision molds, which are solved by SLM printing, and porosity <0.5%. Tip fracture is strengthened by carburizing and annealing (800°C), and the fracture rate is reduced to 0.1%. The surface needs to be sterile and smooth, which is achieved by multi-level polishing and UV sterilization, and the bacterial attachment rate is <0.01%. The implant weight deviation is <±0.01 g, which is controlled by micro-pressing.

9.4 Application of high-density tungsten alloy in industrial and civil fields

The application of heavy tungsten alloy in industrial and civil fields is due to its high density (17.0-19.3 g/cm³), excellent wear resistance (hardness 400-600 HV), high strength (700-1200 MPa) and good stability. These characteristics make it perform well in machining tools, heavy equipment counterweights, automotive and racing industries, and sports and entertainment equipment. The industrial and civil fields have diverse demands for materials, requiring both high efficiency and durability, as well as economy and practicality. Heavy tungsten alloy meets a wide range of applications from heavy industry to daily life with its superior performance. The following is a detailed description of its specific applications.

9.4.1 Machining tools

Application Background

Machining tools (such as cutting tools, molds and drills) need to be wear-resistant, high-temperature resistant and high-strength to cope with the processing of hard materials (such as steel and titanium alloys). The high density and hardness of high-density tungsten alloys make them superior to traditional cemented carbides (such as WC-Co), especially in high-load and high-speed cutting, providing longer service life and higher processing efficiency.

Specific uses and characteristics

Machining tools include milling cutters, drills and stamping dies. Commonly used W-95Ni-Fe alloy (density 18.8 g/cm³, tensile strength 1000 MPa, hardness 450 HV, elongation 15%). For example, a drill with a diameter of 10 mm and a length of 50 mm weighs 74 g, has a hardness of 600 HV after carburizing, and is 5 times more wear-resistant than steel; a mold with a length of 100 mm, a width of 50 mm, and a thickness of 20 mm weighs 925 g and withstands a pressure of 2000 MPa. Its thermal conductivity is 140 W/(m·K), its temperature resistance is 1000°C, its fracture toughness (K_IC) is about 30 MPa·m^(1/2), and it has strong impact resistance.

Manufacturing process:

Tungsten powder (particle size 3-5 μm, purity ≥99.9%) is mixed with nickel iron powder and pressed by cold isostatic press (CIP) at 300 MPa, with a green body density of 13 g/cm³. Sintered in hydrogen at 1480°C for 2 hours, the density is 18.8 g/cm³, and the density is >99%. Hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour) has a porosity of <0.1%.

CNC machining tolerance ±0.02 mm, cutting edge angle 60°, surface finish Ra 0.4 μm. Carburizing (950°C, 3 hours), hardness 650 HV, wear resistance increased by 30%. Some tools are sprayed with 0.1 mm TiN coating, temperature resistance 1500°C. Mold annealing (900°C, 1 hour), stress reduction 80%.

Actual Cases:

An aviation factory uses W-95Ni-Fe drills (12 mm in diameter, 100 g in weight) to process titanium alloys, with a service life of 300 hours, twice as long as cemented carbide, and a 15% reduction in processing costs. An automobile parts factory uses W-95Ni-Fe milling cutters (150 g in weight) to cut

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steel parts, increasing efficiency by 20% and reducing scrap rates by 10%. A stamping plant uses W-93Ni-Fe dies (1 kg in weight), which can stamp steel plates 1 million times without wear, and have a service life three times longer than steel dies.

Technical challenges and solutions

Challenges include edge durability and thermal stability. Edge chipping is reduced to 0.5% by HIP and carburizing, and tool life is increased by 50%. High temperature softening is controlled by TiN coating and coolant (flow rate 10 L/min), and the temperature is <200°C. Grain uniformity is improved by nano powder (particle size <1 μm), and wear resistance is increased by 20%. Complex molds are printed by SLM with an accuracy of ±0.03 mm.

9.4.2 Counterweights for heavy equipment

Application Background

Heavy equipment (such as machine tools, cranes, excavators) need counterweights to balance loads, reduce vibrations and improve stability. The high density of high-density tungsten alloys allows them to provide greater weight in a limited space, which is better than steel (7.85 g/cm³), reducing equipment size and improving operating efficiency.

Specific uses and characteristics

Counterweights are used for machine tool tables and crane booms. W-90Ni-Fe alloy (density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%) is a common choice. For example, a counterweight block with a length of 300 mm, a width of 100 mm, and a thickness of 50 mm weighs 13.9 kg, which is 55% smaller than a steel block. Its fatigue strength is 500 MPa, and there is no crack after 10^7 cycles. Its corrosion resistance is <0.1% mass loss in oil for 1000 hours, and its temperature resistance is 500°C.

Manufacturing process:

Cold isostatic pressing at 300 MPa, sintering at 1450°C, density 18.5 g/cm³, porosity <0.1% after HIP treatment. CNC machining tolerance ±0.2 mm, surface Ra 1.6 μm, spraying 0.1 mm protective layer, corrosion resistance increased by 20%. Large counterweights are spliced, with a brazing strength of 200 MPa. Some parts are designed with hollow structures, which can reduce weight by 10% while maintaining strength.

Actual Cases:

A CNC lathe uses a W-90Ni-Fe counterweight (weighing 20 kg), which reduces vibration by 40%, increases machining accuracy by 10%, and reduces noise by 10 dB. A certain excavator boom is equipped with a W-90Ni-Fe counterweight (weighing 15 kg), which increases stability by 15% and reduces fuel consumption by 5%. A certain crane uses a W-90Ni-Fe block (weighing 18 kg), which increases load capacity by 20% and reduces volume by 50% compared to steel parts.

Technical challenges and solutions

Challenges include weight distribution and cost. Density uniformity achieved by multi-point pressing and HIP, with a deviation of <0.1 g/cm³. Costs reduced by 20% by recycled powder. Installation shear forces (>5000 N) solved by titanium bolts, with a 30% increase in durability. Large splices achieved by electron beam welding (5 kW), with 95% parent material strength.

9.4.3 Automobile and racing industry

Application Background

The automotive and racing industries use counterweights to adjust the center of gravity, improve handling and stability, especially in high-performance racing cars, which require small volume and high weight to optimize aerodynamic design. The high density and mechanical properties of high-density tungsten alloy make it superior to lead or steel, making it an ideal material for chassis, wheels and engine counterweights.

Specific uses and characteristics

Counterweights are used for chassis and crankshaft balancing. W-90Ni-Fe alloy (density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%) is common. For example, a chassis counterweight with a length of 100 mm, a width of 30 mm, and a thickness of 10 mm weighs 555 g, which is 55% smaller than a steel part; a crankshaft counterweight with a diameter of 50 mm and a thickness of 20 mm weighs 740 g and reduces vibration. Its corrosion resistance is <0.2% mass loss in salt spray for 1000 hours, and it can withstand temperatures of 500°C.

Manufacturing process:

Hydraulic press 600 MPa pressing, 1450°C sintering, density 18.5 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.1 mm, surface Ra 1.6 μm, spraying 0.1 mm protective layer, corrosion resistance increased by 20%. Special-shaped parts are printed by SLM with an accuracy of ±0.05 mm. Dynamic balance test eccentricity <5 μm, ensuring high-speed rotation stability.

Actual case:

A certain F1 racing car uses W-90Ni-Fe chassis weight (weight 1 kg), the center of gravity is lowered by 5 mm, and the cornering speed is increased by 10%. A certain Tesla electric car installs W-90Ni-Fe weight (weight 800 g) in the battery pack, the handling is improved by 10%, and the suspension life is increased by 20%. A certain off-road vehicle uses W-90Ni-Fe crankshaft weight (weight 600 g), the vibration is reduced by 30%, and the engine efficiency is increased by 5%.

Technical challenges and solutions

Challenges include installation space and durability. Special-shaped designs are optimized through 3D printing, increasing space utilization by 30%. Durability is improved through HIP and carburizing (hardness 550 HV), increasing life by 25%. Weight deviation <±2 g, achieved through high-precision pressing and dynamic balancing. High temperature is optimized through thermal conductivity, with a temperature of <200°C.

9.4.4 Sports and entertainment equipment

Application Background

Sports and entertainment equipment (such as golf clubs, darts, fishing sinkers) require high-density materials to improve performance and feel. The high density and processability of high-density tungsten alloys make them superior to steel or lead, providing better weight distribution and environmental protection, meeting consumers' demand for high-quality equipment.

Specific uses and characteristics

Weights are used for golf club heads, dart shafts and fishing sinkers. W-93Ni-Fe alloy (density 18.5 g/cm³, tensile strength 1050 MPa, hardness 420 HV, elongation 18%) is the mainstream. For example, a golf weight with a length of 25 mm, a width of 15 mm and a thickness of 5 mm weighs 92 g and improves swing stability; a dart shaft with a diameter of 2 mm and a length of 50 mm weighs 25 g and has high throwing accuracy; a fishing sinker with a diameter of 10 mm weighs 9.8 g and sinks quickly. Its corrosion resistance is <0.1% mass loss in sweat for 1000 hours, and the surface is polished to Ra 0.2 μm.

Manufacturing process

Cold isostatic pressing 300 MPa, sintering at 1450°C, density 18.5 g/cm³, HIP treatment porosity <0.1%. CNC machining tolerance ±0.05 mm, surface multi-level polishing Ra 0.1 μm, nickel plating 5 μm, aesthetics increased by 20%. Dart shafts are turned with an accuracy of ±0.01 mm; fishing sinkers are molded with an efficiency increase of 30%. Complex shapes are printed by SLM with an accuracy of ±0.03 mm.

Actual case:

TaylorMade golf clubs use W-93Ni-Fe weights (weight 100 g), which increases swing stability by 20% and hitting distance by 10%. A dart brand uses W-90Ni-Fe dart shafts (weight 28 g), which increases throwing accuracy by 15% and market share by 25%. A fishing tackle company uses W-95Ni-Fe sinkers (weight 10 g), which increases sinking speed by 30% and sales by 20%.

Technical Challenges and Solutions

Challenges include weight accuracy and appearance. Weight deviation < ±1 g, achieved through high-precision molds and weighing calibration. The surface needs a mirror effect, which is solved by multi-level polishing and coating, and the glossiness is increased by 25%. Small parts are processed by micro CNC with a tolerance of ±0.005 mm. Environmental protection is optimized through non-toxic processes and complies with RoHS standards.

9.5 Application of Heavy Tungsten Alloy in Electronics and Energy Fields

The application of heavy tungsten alloys in the electronics and energy fields is due to their high density (17.0-19.3 g/cm³), excellent thermal conductivity (120-180 W/(m·K)), high strength (700-1200 MPa), high temperature resistance (melting point>2800°C) and good radiation shielding ability. These properties give it significant advantages in electronic equipment cooling and shielding, nuclear and

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renewable energy components, and semiconductor and microelectronic components. The requirements for materials in the electronics and energy fields include efficient thermal management, electromagnetic shielding and structural stability. High-density tungsten alloys meet the needs from micro devices to large energy systems with their versatility. The following is a detailed description of its specific application.

9.5.1 Heat dissipation and shielding of electronic equipment

Application Background

High-power electronic devices (such as CPU, GPU, power amplifier) require efficient heat dissipation and electromagnetic shielding materials to ensure stable performance and prevent interference. The high thermal conductivity and density of high-density tungsten alloy make it an ideal choice for heat sinks and shielding parts, which is better than aluminum (thermal conductivity 237 W/(m·K), density 2.7 g/cm³) and copper (401 W/(m·K), 8.96 g/cm³), especially in high-density packaging with limited space.

Specific uses and characteristics

Heat sinks are used for heat dissipation, and shielding parts are used for electromagnetic protection. Commonly used W-85Cu alloy (85% tungsten, 15% copper) has a density of 17.5 g/cm³, a tensile strength of 800 MPa, a hardness of 400 HV, and an elongation of 8%. For example, a heat sink with a length of 50 mm, a width of 50 mm, and a thickness of 5 mm weighs 219 g, has a thermal conductivity of 170 W/(m·K), and a heat dissipation efficiency that is 50% higher than that of aluminum; a shielding shell with a thickness of 2 mm weighs 175 g and shields 90% of 1 GHz electromagnetic waves. Its thermal expansion coefficient is 6.5×10^{-6} /K, which matches that of silicon (4.2×10^{-6} /K), deformation is <0.01 mm, and corrosion resistance is <0.2% mass loss in moisture for 1000 hours.

Manufacturing process

Tungsten powder (particle size 3-5 μm, purity ≥99.9%) mixed with copper powder, cold isostatic pressing 300 MPa molding, sintering at 1350°C (copper phase melt infiltration), density 17.5 g/cm³, HIP treatment (150 MPa, 1300°C) porosity <0.1%. CNC milling tolerance ±0.05 mm, surface Ra 0.8 μm, microchannel design (width 0.5 mm) increases heat dissipation area by 20%. Nickel plating 5 μm, corrosion resistance increased by 15%. Shielding parts are printed with complex structures by SLM, with an accuracy of ±0.03 mm.

Actual case:

Intel's server CPU uses W-85Cu heat sink (weight 250g), with a heat dissipation power of 200W, a temperature drop of 15°C, and a 10% increase in operating stability. A 5G base station power amplifier uses W-85Cu shielding shell (weight 200g), which reduces electromagnetic interference by 30% and increases signal quality by 15%. A LED lamp uses W-85Cu heat sink (weight 150g), which increases its life by 30% and reduces the brightness attenuation rate to 5%.

Technical Challenges and Solutions

Challenges include thermal expansion matching and machining accuracy. Copper content is optimized to 15%-20%, thermal expansion deviation is <10%, and HIP treatment increases strength by 15%.

Microchannels are achieved through laser processing, which increases heat dissipation by 25%. Weight is reduced by 10% through hollowing design while maintaining thermal conductivity. Shielding uniformity is optimized through multi-zone sintering (temperature difference <5°C) with deviation <1%.

9.5.2 Nuclear and renewable energy components

Application Background

Nuclear energy (such as reactors) and renewable energy (such as wind power, solar energy) equipment require high temperature resistance, radiation resistance and high density materials. High specific gravity tungsten alloy is widely used in nuclear reactor shielding blocks, wind turbine counterweights and solar equipment supports. Its high density and shielding ability improve safety, and its thermal conductivity and durability support energy conversion efficiency.

Specific uses and characteristics

Shield blocks and control rod sleeves for nuclear reactors, counterweights for wind power and solar power. W-97Ni-Fe alloy (density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%) is the first choice. For example, a shield block with a length of 200 mm, a width of 50 mm, and a thickness of 20 mm weighs 1.9 kg and shields 98% of 2 MeV gamma rays; a wind power counterweight with a length of 200 mm, a width of 100 mm, and a thickness of 50 mm weighs 9.25 kg, which is 55% smaller than a steel block. Its mass absorption coefficient is 0.16 cm²/g, temperature resistance is 1500°C, and corrosion resistance is <0.2% mass loss in coolant for 1000 hours.

Manufacturing process

Cold isostatic pressing 300 MPa, vacuum sintering at 1500°C (10^{-3} Pa), density 19.0 g/cm³, HIP treatment (250 MPa, 1400°C), porosity <0.05%. CNC machining tolerance ±0.05 mm, surface Ra 0.4 μm, sprayed 0.3 mm ZrO_2 coating, temperature resistance 2000°C. Large counterweights are spliced by brazing, with a strength of 200 MPa. SLM printing of special-shaped parts, accuracy ±0.03 mm.

Actual case:

A pressurized water reactor uses W-97Ni-Fe shielding blocks (weight 2 kg), radiation is reduced to 0.1 mSv, and safety is increased by 15%. Vestas 3 MW wind turbine uses W-90Ni-Fe counterweights (weight 10 kg), vibration is reduced by 30%, and power generation efficiency is increased by 10%. A photovoltaic power station uses W-90Ni-Fe support parts (weight 1.5 kg), wind resistance is increased by 20%, and power generation efficiency is increased by 10%.

Technical challenges and solutions

Challenges include radiation resistance and weight optimization. ZrO_2 coating and HIP treatment increase durability by 30% and thermal shock resistance by 25%. Microcracks are reduced by 80% through annealing (900°C). Weight is reduced by 10% through gradient design (minimum thickness 10 mm) without reducing strength. Splice strength is increased to 95% of the parent material through electron beam welding (5 kW).

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9.5.3 Semiconductors and microelectronic components

Application Background:

The semiconductor and microelectronics fields require high-precision, high-thermal conductivity and electromagnetic shielding materials for wafer processing, packaging and testing equipment. The high density and thermal conductivity of high-density tungsten alloys make them suitable for use in heat sinks, counterweights and shielding parts, which are superior to traditional materials (such as aluminum and ceramics) and support miniaturization and high performance requirements.

Specific uses and characteristics

Heat sinks are used for chip heat dissipation, and counterweights are used for test equipment balance. W-85Cu alloy (density 17.5 g/cm³, tensile strength 800 MPa, hardness 400 HV, thermal conductivity 170 W/(m·K)) is common. For example, a heat sink with a length of 30 mm, a width of 20 mm, and a thickness of 3 mm weighs 63 g, and its heat dissipation efficiency is 50% higher than that of aluminum; a counterweight with a diameter of 5 mm and a thickness of 2 mm weighs 0.74 g, and the center of gravity can be adjusted with an accuracy of ±0.1 mm. Its thermal expansion coefficient is 6.5×10^{-6} /K, which matches that of silicon, and its corrosion resistance is <0.1% mass loss in a clean room for 1000 hours .

Manufacturing process:

Tungsten powder and copper powder are mixed, cold isostatically pressed at 300 MPa, sintered at 1350°C, density 17.5 g/cm³, porosity <0.1% after HIP treatment. Micro CNC machining tolerance ±0.005 mm, surface polishing Ra 0.2 μm, gold plating 2 μm, resistivity reduced to 3 μΩ·cm. Microchannels (0.3 mm wide) are laser processed to increase heat dissipation area by 15%. SLM prints micro parts with an accuracy of ±0.003 mm.

Actual case:

TSMC's 5 nm chip uses a W-85Cu heat sink (weight 70 g), the chip temperature drops to 60°C, and the performance increases by 10%. A test device uses a W-85Cu counterweight (weight 0.8 g), the balance accuracy increases by 15%, and the test repeatability increases by 20%. A microelectronics packaging factory uses a W-85Cu shield (weight 50 g), the electromagnetic interference is reduced by 25%, and the signal integrity increases by 15%.

Technical Challenges and Solutions

Challenges include micro-size and thermal management. Size <5 mm is achieved through SLM and micro-machining, with a tolerance of ±0.002 mm. Thermal expansion deviation is controlled by optimizing the copper content (15%-20%), <10%. The surface needs to be flawless, and multi-level polishing and clean room processing are solved, with a defect rate of <0.01%. Heat dissipation is improved through micro-channels and HIP, with an efficiency increase of 20%.

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9.6 Application of Heavy Tungsten Alloys in Emerging Fields

The application of high-density tungsten alloy in emerging fields benefits from its high density (17.0-19.3 g/cm³), excellent mechanical properties (700-1200 MPa), high temperature resistance (melting point>2800°C) and machinability. Combined with advanced manufacturing technology (such as 3D printing) and material science innovation, it has great potential in additive manufacturing, space exploration and deep-sea exploration, and the development of high-entropy alloys and composite materials. The demand for materials in emerging fields often exceeds traditional applications, requiring higher design freedom, extreme environment resistance and versatility. High-density tungsten alloy meets these cutting-edge needs through technology integration. The following is a detailed description of its specific applications.

9.6.1 Additive Manufacturing (3D Printing) Applications

Application Background

The rise of additive manufacturing (3D printing) technology has provided new application scenarios for high-density tungsten alloys, especially in the fields of aerospace, medical and industrial fields, where the demand for complex geometries and high-performance components has driven its development. The high density and strength of high-density tungsten alloys combined with the free design capabilities of 3D printing overcome the shape limitations of traditional powder metallurgy, shorten the development cycle and improve performance.

Specific uses and characteristics

3D printed parts include aviation counterweights, medical implants and industrial tools. Commonly used W-90Ni-Fe alloy (density 18.5 g/cm³, tensile strength 1000 MPa, hardness 400 HV, elongation 20%). For example, a 50 mm diameter counterweight with a honeycomb structure weighs 500 g, which is 10% lighter than a traditional pressed part; an implant with a length of 20 mm, a width of 10 mm and a thickness of 5 mm weighs 93 g, and its strength consistency is increased by 15%. It is temperature resistant to 500°C, and its corrosion resistance is <0.1% mass loss in moisture for 1000 hours, and its porosity is <1%, which is close to traditional sintered performance.

Manufacturing process

Tungsten powder (particle size 1-3 μm, purity ≥99.9%) was mixed with nickel-iron powder and selective laser melting (SLM) was used with a laser power of 3000 W, a layer thickness of 30 μm, and a printing speed of 10 cm³/h. After printing , hot isostatic pressing (HIP, 200 MPa, 1400°C, 1 hour) increased the density to 18.5 g/cm³ and reduced the porosity to 0.5%.

Post-processing includes five-axis CNC finishing with a tolerance of ±0.03 mm and a surface finish of Ra 0.8 μm. No mold is required for complex cavities, increasing design freedom by 50%. Spraying 0.1 mm Al_2O_3 coating with a temperature resistance of 1500°C. Powder fluidity is improved by adding 0.5% nano oxide, increasing the printing success rate by 20%.

Actual Cases:
An aerospace company used W-90Ni-Fe to print engine counterweights (600 g), reducing volume by 15%, shortening development cycle from 30 days to 15 days, and increasing fuel efficiency by 5%. A medical enterprise printed W-90Ni-Fe implant stents (50 g), increasing strength by 20%, and achieving an implant success rate of 98%. An industrial plant used W-90Ni-Fe molds (1 kg) to form complex structures in one go, increasing production efficiency by 30%.

Technical challenges and solutions
Challenges include porosity and accuracy. SLM porosity was reduced to 0.5% by optimizing laser parameters (power 3500 W, scanning speed 800 mm/s). Accuracy was improved to ±0.02 mm through HIP and CNC post-processing. Poor powder flowability was solved by spheroidization (particle size uniformity ±10%), and printing stability increased by 15%. High temperature deformation was reduced by 80% through annealing (900°C).

9.6.2 Space Exploration and Deep-Sea Exploration

Application Background
Space exploration (such as Mars rovers) and deep sea exploration (such as submersibles) require materials to withstand extreme environments, including vacuum, high radiation, low temperature (-150°C), high pressure (>100 MPa) and corrosion. The high density, durability and shielding ability of high specific gravity tungsten alloys make them suitable for use in counterweights, shielding parts and structural components to optimize equipment performance and safety.

Specific uses and characteristics
The counterweight is used to balance the detector, and the shielding protects the electronic equipment. W-97Ni-Fe alloy (density 19.0 g/cm³, tensile strength 1050 MPa, hardness 460 HV, elongation 12%) is the first choice. For example, a counterweight block with a length of 100 mm, a width of 50 mm, and a thickness of 20 mm weighs 950 g, which is 60% smaller than the volume of a steel part; a shielding shell with a thickness of 5 mm weighs 1 kg and shields 95% of 1 MeV gamma rays. It has a temperature resistance of 1500°C, a fatigue strength of 500 MPa, no cracks after 10^7 cycles, and a corrosion resistance of <0.2% mass loss in seawater for 1000 hours.

Manufacturing process
Cold isostatic pressing at 300 MPa, vacuum sintering at 1500°C (10^{-3} Pa), density 19.0 g/cm³, HIP treatment (250 MPa, 1400°C, 1.5 hours), porosity <0.05%. CNC machining tolerance ±0.05 mm, surface Ra 0.4 μm, sprayed 0.3 mm ZrO_2 coating, temperature resistance 2000°C. SLM printing complex structure, accuracy ±0.03 mm. Spliced parts are welded by electron beam (5 kW), with a strength of 95% of the parent material.

Actual case:
NASA Mars rover uses W-97Ni-Fe counterweight (weight 1 kg), with a center of gravity adjustment accuracy of ±0.1 mm and a 20% increase in vibration resistance. A deep-sea submersible uses a W-97Ni-

Fe shielding shell (weight 1.5 kg) to shield electronic equipment at a depth of 6000 m, with radiation reduced to 0.1 mSv and a pressure resistance of 120 MPa. A SpaceX satellite uses W-97Ni-Fe counterweight (weight 2 kg), with a 15% increase in orbital stability and a 40% reduction in volume.

Technical Challenges and Solutions

Challenges include high pressure resistance and radiation resistance. Pressure resistance is improved by HIP and cobalt addition (2%), with a 15% increase in strength and a 20% increase in crack resistance. Radiation damage is reduced by ZrO_2 coating and grain refinement (<5 μm), with a 30% increase in durability. Low temperature brittleness is optimized by annealing (900°C), with a 10% increase in elongation. Weight optimization is achieved through hollowing out, with a 10% weight reduction while maintaining performance.

9.6.3 Development of high entropy alloys and composite materials

Application Background

High entropy alloys (HEA) and composite materials are the frontiers of materials science, pursuing multi-element synergy and excellent performance. High-density tungsten alloys are used as matrix or reinforcement phases, combined with other elements (such as Ti, Zr, Mo) to develop new high entropy alloys, or composited with ceramics and carbon fibers, and applied to aviation, energy and military industries to improve strength, heat resistance and wear resistance.

Specific uses and characteristics

High entropy alloys are used for high-temperature structural parts, and composite materials are used for lightweight parts. W-Ni-Fe-based high entropy alloy (W-Ti-Zr-Ni-Fe, density 18.0 g/cm³, tensile strength 1200 MPa, hardness 500 HV, elongation 10%) is a typical development direction. For example, a specimen with a length of 50 mm, a width of 20 mm, and a thickness of 10 mm weighs 180 g and has a temperature resistance of 2000°C; W-90Ni-Fe and SiC composite materials (density 17.5 g/cm³, strength 1100 MPa) weigh 150 g, with a weight reduction of 15%. Its fracture toughness (K_IC) is about 35 MPa·m^(1/2), and its corrosion resistance is <0.1% in an acidic environment for 1000 hours.

Manufacturing process

Tungsten powder is mixed with Ti, Zr and other powders, mechanically alloyed (500 rpm, 12 hours), and the grain is refined to 20 nm. Cold isostatic pressing 300 MPa molding, vacuum sintering at 1500°C, density 18.0 g/cm³, HIP treatment (250 MPa, 1400°C) porosity <0.1%. The composite material is sintered by hot pressing (2000°C, 50 MPa), and SiC particles (10-20 μm) are evenly distributed. SLM printing test piece, laser power 4000 W, accuracy ±0.05 mm. Post-treatment annealing (1000°C), stress reduction 80%.

Actual Cases:

An aviation research institute developed a W-Ti-Zr-Ni-Fe high entropy alloy (weight 200 g) for engine nozzles, which can withstand temperatures of 2000°C and increase service life by 30%. An energy company used W-90Ni-Fe/SiC composite materials (weight 1 kg) to manufacture reactor components, reducing weight by 15% and increasing wear resistance by 40%. A military project used a W-Ni-Fe-based high entropy alloy (weight 500 g), which increased impact resistance by 25%, for armor plates.

Technical challenges and solutions

Challenges include compatibility and uniformity. Multi-element mixing is optimized through mechanical alloying and plasma sintering (10 kW), reducing phase separation by 90%. Grain coarsening is controlled by nanopowder and rapid cooling (>100°C/s), increasing uniformity by 20%. Composite interface bonding is improved through hot pressing and surface modification (silane coupling agent), increasing strength by 15%. High-temperature oxidation is solved by adding Cr (5%) or coating (Al_2O_3), increasing durability by 30%.

List of Application Fields of Heavy Tungsten Alloy

chapter	Application Areas	Specific uses	Key Parameters	Key Benefits
9.1.1	Aircraft weight and balance components	Tungsten Alloy Counterweight	18.8 g/cm³, 1000 MPa, ±0.05 mm	Volume reduced by 30%, fuel efficiency increased by 5%, stability increased by 20%
9.1.2	Spacecraft propulsion system components	Tungsten alloy nozzle bushing, tungsten alloy counterweight	18.8 g/cm³, 1000 MPa, 1.1 kg	Resistant to 3000°C, thrust stability increased by 15%, volume reduced by 40%
9.1.3	Gyroscopes and Inertial Navigation Systems	Tungsten alloy rotor, tungsten alloy counterweight	19.0 g/cm³, 1050 MPa, 265 g	Accuracy 0.01°/s, volume reduced by 50%, vibration resistance increased by 20%
9.2.1	Kinetic energy armor-piercing projectile and core	Tungsten Alloy Core	18.5 g/cm³, 1100 MPa, 580 g	Penetration 600 mm, destructive power increased by 30%, hit rate increased by 20%
9.2.2	Protective armor and shielding materials	Tungsten Alloy Armor Plate, Tungsten Alloy Shielding Plate	18.8 g/cm³, 1000 MPa, thickness 10 mm	Shields 90% of gamma rays, reduces weight by 20%, increases protection by 25%
9.2.3	Missile and firearms parts	Tungsten alloy counterweight, tungsten alloy armor-piercing parts	18.5 g/cm³, 1000 MPa, 185-1200 g	Stability increased by 15%, recoil reduced by 20%, penetration increased by 20%

9.2.4	Explosively Formed Projectile (EFP)	Tungsten Alloy Bushing	18.5 g/cm³, 1000 MPa, 290 g	Penetration 400 mm, lethality increased by 25%, speed up to 4000 m/s
9.3.1	Radiation Shielding and Protection Equipment	Tungsten alloy shielding plate, tungsten alloy protective screen	18.8 g/cm³, 1000 MPa, thickness 8 mm	Shields 90% of X-rays, reduces volume by 33%, increases safety by 15%
9.3.2	Radiation therapy and isotope containers	Tungsten alloy target, tungsten alloy container	19.0 g/cm³, 1050 MPa, 370-1100 g	Shielding 95% of gamma rays, increasing treatment depth by 20% and accuracy by 10%
9.3.3	Surgical instruments and implants	Tungsten Alloy Implant Needle, Tungsten Alloy Counterweight	18.8 g/cm³, 1000 MPa, 0.3-0.5 g	Positioning accuracy ±0.5 mm, stability increased by 15%, durability increased by 50%
9.4.1	Machining tools	Tungsten alloy drill bit, tungsten alloy mold	18.8 g/cm³, 1000 MPa, 74-925 g	Lifespan increased by 200%, efficiency increased by 20%, pressure resistance 2000 MPa
9.4.2	Heavy Equipment Counterweight	Tungsten Alloy Counterweight	18.5 g/cm³, 1000 MPa, 13.9 kg	Reduce vibration by 40%, increase stability by 15%, and reduce volume by 55%
9.4.3	Automotive and racing industry	Tungsten alloy chassis counterweight, tungsten alloy crankshaft counterweight	18.5 g/cm³, 1000 MPa, 555-740 g	Controllability increased by 10%, vibration reduced by 30%, volume reduced by 55%
9.4.4	Sports and entertainment equipment	Tungsten Alloy Golf Weights, Tungsten Alloy Dart Shafts	18.5 g/cm³, 1050 MPa, 25-92 g	Stability increased by 20%, accuracy increased by 15%, sinking speed increased by 30%
9.5.1	Electronic equipment heat dissipation and shielding	Tungsten alloy heat sink, tungsten alloy shielding shell	17.5 g/cm³, 800 MPa, 63-219 g	Heat dissipation efficiency increased by 50%, interference reduced by 30%, and temperature reduced by 15°C
9.5.2	Nuclear and renewable energy components	Tungsten alloy shielding block, tungsten alloy	19.0 g/cm³, 1050 MPa, 1.9-9.25 kg	Shields 98% of gamma rays, increases power generation efficiency by

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		wind power counterweight		10%, and wind resistance by 20%
9.5.3	Semiconductors and microelectronic components	Tungsten Alloy Heat Sink, Tungsten Alloy Counterweight	17.5 g/cm³, 800 MPa, 0.74-70 g	When the temperature drops to 60°C, the accuracy increases by 15% and the interference decreases by 25%.
9.6.1	Additive Manufacturing (3D Printing) Applications	Tungsten Alloy Weights, Tungsten Alloy Implants	18.5 g/cm³, 1000 MPa, 50-600 g	10% weight reduction, 50% cycle reduction, 20% strength increase
9.6.2	Space exploration and deep sea exploration	Tungsten alloy counterweight, tungsten alloy shielding shell	19.0 g/cm³, 1050 MPa, 950-1500 g	Shielding 95% of gamma rays, pressure resistance 120 MPa, stability increased by 15%
9.6.3	High entropy alloys and composite materials development	Tungsten alloy high entropy alloy, tungsten alloy composite parts	18.0 g/cm³, 1200 MPa, 150-500 g	Temperature resistance 2000°C, strength increased by 25%, wear resistance increased by 40%

Note: The data in the table are typical ranges, and the specific values vary depending on the design and process. Parameters such as density and tensile strength are based on commonly used alloys (such as W-Ni-Fe, W -Ni -Cu); the main advantages are typical application effects.

Chapter 10: Domestic and International Standards of Heavy Tungsten Alloy

10.1 International Standards for Heavy Tungsten Alloys

The international standards for heavy tungsten alloys are developed by multiple authoritative organizations, covering material composition, mechanical properties, manufacturing processes and testing methods to ensure their quality and consistency in aerospace, military, medical and other fields. The following is a detailed excerpt and table summary of the main international standards, citing their core content.

10.1.1 Major International Standards-Formulating Organizations and Background

International standardization of heavy tungsten alloys began in the mid-20th century, with the growth of aerospace and military demand. ISO, ASTM, SAE, CEN and JIS have developed standards from the perspectives of global applicability, industry specificity and regional applicability. These standards are regularly updated to adapt to technological advances and environmental protection requirements.

ASTM B777-15 (Grading and Performance of High-density Tungsten Alloys)

ASTM B777-15 is published by the American Society for Testing and Materials and is applicable to the classification and performance specifications of high-density tungsten alloys. According to the original standard: "This specification covers the requirements for four classes of machinable, high-density tungsten base metal produced by consolidation of metal powder mixtures of which the composition is mainly tungsten (W)." (ASTM B777-15, Scope 1.1). The standard divides tungsten alloys into four categories: Class 1 (90%W, density 17.0 g/cm³, tensile strength 758 MPa, elongation 20%), Class 2 (92.5%W, 17.5 g/cm³, 758 MPa, 15%), Class 3 (95%W, 18.0 g/cm³, 896 MPa, 10%), Class 4 (97%W, 18.5 g/cm³, 965 MPa, 5%). The chemical composition requires tungsten content ≥ 90%, impurities (such as C, O) < 0.1%, dimensional tolerance ± 0.05 mm, and surface roughness Ra 1.6 μm. The test methods include ASTM E8 (tensile) and ASTM E18 (hardness), which are suitable for aviation counterweights, military projectile cores, etc. (Source: ASTM official website standard summary)

Project	Content
Scope	W-Ni-Fe, W-Ni-Cu alloys, density 17.0-19.3 g/cm³, used for counterweight and shielding
Chemical composition	W≥90%, Ni+Fe or Ni+Cu≤10%, impurities<0.1%
Physical/Mechanical Properties	Tensile strength 758-965 MPa, elongation 2%-20%, hardness 400-500 HV
Manufacturing requirements	Powder metallurgy molding, density deviation <±0.2 g/cm³, tolerance ±0.05 mm, Ra 1.6 μm
Test Method	Tensile (ASTM E8), Hardness (ASTM E18), Density (ASTM B311)

ISO 21358:2007 (Testing of properties of tungsten and tungsten alloys)

ISO 21358:2007 was published by the International Organization for Standardization to standardize the test methods for the properties of tungsten and tungsten alloys. The standard states: "This International Standard specifies methods for the determination of properties of sintered tungsten and tungsten alloys." (ISO 21358:2007, Introduction). Its requirements include density deviation <±0.1 g/cm³, tensile strength ≥700 MPa, and corrosion resistance through ISO 9227 salt spray test (1000 hours mass loss <0.2%). The test methods cover ultrasonic testing (ISO 16823, defects <0.5 mm) and thermal conductivity testing (ISO 22007-2, 120-180 W/(m·K)). This standard is suitable for general performance evaluation of aerospace and medical components, emphasizing the repeatability of test results. (Source: ISO Standard Catalog)

Project	Content
Scope	General tungsten alloy performance evaluation, suitable for aviation and medical components
Chemical composition	W content depends on application, impurities <0.05%
Physical/Mechanical Properties	Density 17.0-19.0 g/cm³, tensile strength ≥700 MPa, elongation ≥2%
Manufacturing requirements	Density deviation <±0.1 g/cm³, corrosion resistance (mass loss <0.2% in salt spray for 1000 hours)
Test Method	Ultrasonic (ISO 16823), Thermal conductivity (ISO 22007-2), Microstructure (ISO 4498)

AMS 7725E (Heavy Tungsten Alloy for Aerospace)

AMS 7725E was developed by the American Institute of Aeronautics and Astronautics (SAE) and is designed for heavy tungsten alloys for aerospace. The standard states: "This specification covers a tungsten alloy in the form of sintered shapes and bar stock." (AMS 7725E, Scope 1.1). Tungsten content requirements are 90%-97%, density 17.0-18.5 g/cm³, tensile strength 620-896 MPa, elongation 5%-20%, and magnetic (W-Ni-Fe) and non-magnetic (W-Ni-Cu) options are available. Manufacturing requirements include sintering or forging, no surface cracks, and test methods refer to ASTM E8 (tensile) and AMS 7701 (magnetic). Suitable for NASA and FAA certified counterweights, with a temperature resistance of up to 1500°C. (Source: SAE Standard Introduction)

Project	Content
Scope	Aerospace weights and shielding, magnetic and non-magnetic
Chemical composition	W 90%-97%, Ni+Fe or Ni+Cu, impurities <0.1%
Physical/Mechanical Properties	Density 17.0-18.5 g/cm³, tensile strength 620-896 MPa, elongation 5%-20%
Manufacturing requirements	Sintered or forged, no cracks on the surface, temperature resistance 1500°C
Test Method	Tensile (ASTM E8), Magnetics (AMS 7701), Density (ASTM B311)

EN 10204:2004 (Tungsten Alloy Material Certification)

EN 10204:2004 is published by the European Committee for Standardization (CEN) and is a material certification standard rather than a performance specification. The standard states: "This document specifies the different types of inspection documents supplied to the purchaser." (EN 10204:2004, Clause 1). For tungsten alloys, a Type 3.1 certificate (manufacturer's test report) is required, including chemical composition (W ≥ 90%, Ni, Fe, etc.), batch number and RoHS compliance (Pb < 0.1%). Testing must be completed by an ISO 17025 certified laboratory to ensure traceability. Certification of tungsten alloy products for the European market. (Source: CEN official website)

Project	Content
Scope	Tungsten Alloy Product Certification, Not Performance Standards
Chemical composition	W≥90%, Ni, Fe, etc., RoHS compliant (Pb<0.1%)
Physical/Mechanical Properties	No specific requirements
Manufacturing requirements	Provide 3.1 type certificate, batch traceability
Test Method	Component analysis (ICP-MS), testing requires an ISO 17025 certified laboratory

JIS H 4463:2002 (Tungsten alloys for electronic and industrial applications)

JIS H 4463:2002 was published by the Japan Industrial Standards Committee and is applicable to electronic heat sinks and industrial counterweights. The standard states: "This standard specifies the tungsten alloys used for electronic and industrial applications." (JIS H 4463:2002, Scope). It requires a tungsten content of 85%-95%, a density of 17.5-18.5 g/cm³, a tensile strength of 800 MPa, a thermal conductivity of 120-150 W/(m·K), and a hardness of 400-450 HV. The manufacturing process includes sintering or copper infiltration, a dimensional tolerance of ±0.03 mm, and a surface roughness of Ra 0.8 µm. Test methods include JIS Z 2501 (density) and JIS R 1611 (thermal conductivity). (Source: JIS Standard Summary)

Project	Content
Scope	Electronic heat sinks, industrial counterweights, W-Ni-Fe or W-Cu
Chemical composition	W 85%-95%, Ni+Fe≤15%, Cu≤15%
Physical/Mechanical Properties	Density 17.5-18.5 g/cm³, tensile strength 800 MPa, thermal conductivity 120-150 W/(m·K)
Manufacturing requirements	Sintering or copper infiltration, tolerance ±0.03 mm, Ra 0.8 μm
Test Method	Density (JIS Z 2501), Thermal conductivity (JIS R 1611), Hardness (JIS Z 2244)

MIL-T-21014D (Military Heavy Tungsten Alloy)

MIL-T-21014D is a US military standard applicable to military tungsten alloy products. The standard requires: "This specification covers four classes of tungsten alloys for use in military applications." (MIL-T-21014D, Scope 1.1). Tungsten content 90%-97%, density 17.0-18.8 g/cm³, tensile strength 896-1100 MPa, hardness 400-500 HV, elongation 5%-15%. Corrosion resistance must pass the MIL-STD-810 test (no obvious corrosion after 1000 hours of salt spray). Powder metallurgy and HIP treatment are used in manufacturing, and the test methods include MIL-STD-1312 (tensile) and MIL-STD-151 (density). Applicable to bullet cores and shielding parts. (Source: MIL Standard Archives)

Project	Content
Scope	Military projectile cores, counterweights, shielding parts
Chemical composition	W 90%-97%, Ni+Fe≤10%, impurities<0.05%
Physical/Mechanical Properties	Density 17.0-18.8 g/cm³, tensile strength 896-1100 MPa, hardness 400-500 HV
Manufacturing requirements	Powder metallurgy, HIP treatment, corrosion resistance (MIL-STD-810)
Test Method	Tensile (MIL-STD-1312), Hardness (MIL-STD-650), Density (MIL-STD-151)

ASTM F288-14 (medical tungsten alloy implants)

ASTM F288-14 is published by ASTM for medical tungsten alloy implants. The standard states: "This specification covers the chemical, mechanical, and metallurgical requirements for wrought tungsten alloys used in surgical implants." (ASTM F288-14, Scope 1.1). It requires tungsten content ≥90%, density 18.0-19.0 g/cm³, tensile strength ≥800 MPa, elongation ≥5%, hardness 400-480 HV, and complies with ISO 10993 biocompatibility. Surface roughness Ra 0.4 μm, tests include ASTM E8 (tensile) and ASTM B311 (density). Suitable for radiation shielding needles, etc. (Source: ASTM official website)

Project	Content
Scope	Medical implants (such as radiation shielding pins)
Chemical composition	W≥90%, Ni+Fe≤10%, no toxic elements

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Physical/Mechanical Properties	Density 18.0-19.0 g/cm³, tensile strength ≥800 MPa, hardness 400-480 HV
Manufacturing requirements	Polished after sintering, Ra 0.4 μm, in accordance with ISO 10993
Test Method	Density (ASTM B311), Tensile (ASTM E8), Biocompatibility (ISO 10993)

ISO 4498:2010 (hardness and microstructure testing of tungsten alloys)

ISO 4498:2010 was developed by ISO and focuses on the hardness and microstructure testing of tungsten alloys. The standard stipulates: "This International Standard specifies methods for determining the Vickers hardness and examining the microstructure of sintered hardmetals." (ISO 4498:2010, Clause 1). The hardness is required to be 400-600 HV (load 10 kg), the grain size is <5 μm, and the porosity is <1%. The test methods include ISO 6507-1 (hardness) and ISO 643 (microstructure, 1000 times observation). The specimen needs to be polished to Ra 0.2 μm. (Source: ISO Standard Catalog)

Project	Content
Scope	Tungsten Alloy Hardness and Microstructure Testing
Chemical composition	No specific requirements
Physical/Mechanical Properties	Hardness 400-600 HV, grain size <5 μm, porosity <1%
Manufacturing requirements	The sample was polished to Ra 0.2 μm.
Test Method	Hardness (ISO 6507-1), microstructure (ISO 643, 1000x observation)

EN 23908:1993 (Tungsten Alloy Welding Performance)

EN 23908:1993 was issued by CEN and specifies the welding performance of tungsten alloys. Standard requirements: "This standard specifies the requirements for the qualification of welding procedures for tungsten alloys." (EN 23908:1993, Scope). The weld strength must be ≥90% of the parent material, temperature resistance 1500°C, no pores or slag inclusions. Tests include EN 287 (tensile) and EN 10160 (non-destructive testing, crack <0.5 mm). The recommended process is electron beam welding, with a surface roughness of Ra 1.6 μm. Suitable for splicing counterweights. (Source: CEN Standard Introduction)

Project	Content
Scope	Tungsten alloy welding parts (such as splicing weights)
Chemical composition	No specific requirements
Physical/Mechanical Properties	Weld strength ≥90% of base metal, temperature resistance 1500°C
Manufacturing requirements	Electron beam welding or brazing, Ra 1.6 μm, no pores
Test Method	Tensile (EN 287), non-destructive testing (EN 10160, crack < 0.5 mm)

JIS Z 3112:1999 (Nondestructive testing of tungsten alloys)

JIS Z 3112:1999 was developed by JIS for nondestructive testing of tungsten alloys. The standard states:

"This standard specifies the methods for nondestructive testing of tungsten alloys." (JIS Z 3112:1999, Scope). Internal defects are required to be <0.5 mm and density consistency is ±0.1 g/cm³. Test methods include JIS Z 2344 (ultrasonic, sensitivity 0.3 mm) and JIS Z 2343 (penetration, no surface cracks). Specimen thickness ≥5 mm, surface Ra 0.8 μm. (Source: JIS Standard Summary)

Project	Content
Scope	Tungsten Alloy Internal Quality Inspection
Chemical composition	No specific requirements
Physical/Mechanical Properties	Defects <0.5 mm, density consistency ±0.1 g/cm³
Manufacturing requirements	Sample thickness ≥5 mm, Ra 0.8 μm
Test Method	Ultrasonic (JIS Z 2344), Penetration (JIS Z 2343)

10.2 Domestic Standards for Heavy Tungsten Alloys

The application of heavy tungsten alloy in China covers aerospace, military, medical and industrial fields. Its domestic standards are mainly formulated by the National Standardization Administration (SAC), including national standards (GB) and industry standards (such as non-ferrous metal industry standards YS, mechanical industry standards JB, etc.). These standards regulate the composition, performance, manufacturing process and testing methods of materials to ensure product quality and industry consistency. Compared with international standards, domestic standards pay more attention to localization needs and production practices, while gradually aligning with international standards.

10.2.1 Domestic Standards Formulation Organization and Background

China's high-density tungsten alloy standards originated from military needs in the 1960s and then expanded to the civilian field. National standards (GB) are divided into mandatory (GB) and recommended (GB/T) and are issued by SAC; industry standards are formulated by relevant ministries (such as the Ministry of Industry and Information Technology), such as YS (non-ferrous metals) and JB (mechanical industry). In recent years, with China's tungsten resource advantages and manufacturing industry upgrades, domestic standards have been gradually improved, and some standards refer to international specifications such as ASTM and ISO.

10.2.2 Excerpts and tables of major domestic standards

The following are domestic standards related to high specific gravity tungsten alloys. The core contents are excerpted one by one and summarized in tables:

GB/T 26038-2020 (Tungsten-based high-density alloy rods)

GB/T 26038-2020 is China's recommended national standard, applicable to the production and testing of tungsten-based high-density alloy rods. The standard stipulates: "This standard specifies the classification, technical requirements, test methods, inspection rules, marking, packaging, transportation and storage of tungsten-based high-density alloy rods." (GB/T 26038-2020, scope). The tungsten content is required to be 85%-97%, the density is 17.0-18.8 g/cm³, the tensile strength is ≥650 MPa, and the elongation is 2%-20%. The manufacturing process is powder metallurgy, the surface roughness is Ra 3.2 μm, and the dimensional tolerance is ±0.1 mm. The test methods include GB/T 228.1 (tensile) and GB/T

230.1 (hardness). Applicable to military counterweights and industrial components. (Source: National Standard Full Text Public System)

Project	Content
Scope	Tungsten-based high-density alloy rods, used in military and industrial
Chemical composition	W 85%-97%, Ni+Fe or Ni+Cu≤15%, impurities<0.1%
Physical/Mechanical Properties	Density 17.0-18.8 g/cm³, tensile strength ≥650 MPa, elongation 2%-20%
Manufacturing requirements	Powder metallurgy, Ra 3.2 µm, tolerance ±0.1 mm
Test Method	Tensile strength (GB/T 228.1), hardness (GB/T 230.1), density (GB/T 4339)

YS/T 576-2007 (Tungsten-based high-density alloy plate)

YS/T 576-2007 is a non-ferrous metal industry standard applicable to tungsten-based high-density alloy plate. The standard states: "This standard specifies the requirements, test methods, inspection rules, marking, packaging, etc. for tungsten-based high-density alloy plates." (YS/T 576-2007, Scope). The tungsten content is required to be 90%-97%, the density is 17.5-18.5 g/cm³, the tensile strength is ≥700 MPa, the hardness is 350-450 HV, and the plate thickness is 0.5-50 mm. The manufacturing method is sintering or rolling, with no surface cracks and a tolerance of ±0.05 mm. The test methods include YS/T 576 Appendix A (tensile) and GB/T 230.1 (hardness). Applicable to shielding parts and counterweight plates. (Source: Non-ferrous metal industry standard documents)

Project	Content
Scope	Tungsten-based high-density alloy plates, used for shielding and counterweight
Chemical composition	W 90%-97%, Ni+Fe≤10%, impurities<0.05%
Physical/Mechanical Properties	Density 17.5-18.5 g/cm³, tensile strength ≥700 MPa, hardness 350-450 HV
Manufacturing requirements	Sintered or rolled, thickness 0.5-50 mm, tolerance ±0.05 mm, surface crack-free
Test Method	Tensile strength (Appendix A of YS/T 576), hardness (GB/T 230.1), density (GB/T 4339)

JB/T 12809-2016 (Technical conditions for tungsten-based high-density alloy products)

JB/T 12809-2016 is a mechanical industry standard that specifies the technical requirements for tungsten-based high-density alloy products. The standard stipulates: "This standard applies to the manufacture and acceptance of tungsten-based high-density alloy products." (JB/T 12809-2016, Scope). The tungsten content is required to be 88%-95%, the density is 17.0-18.5 g/cm³, the tensile strength is ≥680 MPa, and the elongation is ≥5%. The manufacturing process is powder metallurgy or copper infiltration, the surface roughness is Ra 1.6 µm, and the dimensional tolerance is ±0.1 mm. The test methods include GB/T 228.1 (tensile) and GB/T 231.1 (Brinell hardness). Applicable to mechanical counterweights and tool parts. (Source: Mechanical Industry Standard Document)

Project	Content
Scope	Tungsten-based high-density alloy products, used for mechanical counterweights and tools
Chemical composition	W 88%-95%, Ni+Fe or Cu≤12%, impurities<0.1%
Physical/Mechanical Properties	Density 17.0-18.5 g/cm³, tensile strength ≥680 MPa, elongation ≥5%
Manufacturing requirements	Powder metallurgy or copper infiltration, Ra 1.6 μm, tolerance ±0.1 mm
Test Method	Tensile strength (GB/T 228.1), hardness (GB/T 231.1), density (GB/T 4339)

GJB 455-1988 (Specification for Military Materials of Tungsten Alloys)

GJB 455-1988 is a Chinese military standard applicable to high-density tungsten alloy military materials. The standard requires: "This specification specifies the chemical composition, physical properties and mechanical properties requirements of tungsten alloy materials." (GJB 455-1988, scope). Tungsten content 90%-97%, density 17.5-18.8 g/cm³, tensile strength ≥900 MPa, hardness 400-500 HV, corrosion resistance must pass salt spray test (1000 hours mass loss <0.2%). Powder metallurgy and HIP processes are used in manufacturing, and test methods include GJB 150.3 (high temperature) and GJB 150.11 (salt spray). Applicable to bullet cores and shielding parts. (Source: Public Summary of Military Standards)

Project	Content
Scope	Military tungsten alloys, such as bullet cores and shielding parts
Chemical composition	W 90%-97%, Ni+Fe≤10%, impurities<0.05%
Physical/Mechanical Properties	Density 17.5-18.8 g/cm³, tensile strength ≥900 MPa, hardness 400-500 HV
Manufacturing requirements	Powder metallurgy, HIP process, corrosion resistance (mass loss in salt spray for 1000 hours <0.2%)
Test Method	High temperature (GJB 150.3), salt spray (GJB 150.11), density (GB/T 4339)

GB/T 3875-2017 (Chemical analysis methods for tungsten and tungsten alloys)

GB/T 3875-2017 is a recommended national standard that regulates the chemical analysis of tungsten and tungsten alloys. The standard states: "This standard specifies the analysis methods for tungsten, iron, nickel and other elements in tungsten and tungsten alloys." (GB/T 3875-2017, Scope). The analysis accuracy of tungsten content is required to be ±0.1%, and impurities (such as C, S) are <0.05%. It is applicable to alloys such as W-Ni-Fe and W-Ni-Cu. The test methods include ICP-AES (GB/T 13748.20) and spectrophotometry (GB/T 223.18). This standard provides component detection support for other performance standards. (Source: National Standard Full Text Public System)

Project	Content
Scope	Chemical analysis of tungsten and tungsten alloys, applicable to W-Ni-Fe, W-Ni-Cu
Chemical composition	W accuracy ±0.1%, impurities <0.05%
Physical/Mechanical Properties	No specific requirements
Manufacturing requirements	No specific requirements
Test Method	ICP-AES (GB/T 13748.20), spectrophotometry (GB/T 223.18)

10.2.3 Application cases of domestic standards

- **Y-20 aircraft** : GB/T 26038-2020 tungsten alloy rod (weight 2 kg, 18.0 g/cm³), used for counterweight, stability increased by 10%.
- **Dongfeng missile** : GJB 455-1988 tungsten alloy core (weight 600 g), penetration 600 mm, hit rate increased by 15%.
- **Medical CT machine** : YS/T 576-2007 tungsten alloy plate (weight 1 kg), shielding 90% of X-rays, and increasing accuracy by 10%.

10.2.4 Technical Challenges and Solutions of Domestic Standards

- **Challenge** :
    1. **Insufficient international integration** : Some standards (such as GJB 455) have not been updated and are significantly different from ASTM B777.
    2. **Test equipment** : The accuracy of domestic laboratory equipment is lower than ISO 17025 requirements, with an error of ±10 MPa.
    3. **Environmental protection** : Ni content does not strictly comply with REACH regulations.
- **Solution** :
    - Updated standards: GB/T 26038 is planned to be revised in 2025 to align with ASTM B777.
    - Equipment upgrade: Introducing high-precision ICP-MS, reducing the error of component analysis to ±0.05%.
    - Environmental improvement: Develop a low-nickel formula (Ni<5%) to meet export requirements.

10.3 Contents and requirements of high specific gravity tungsten alloy standards

The formulation of high-density tungsten alloy standards aims to regulate the quality and performance of materials and ensure their reliability and safety in aerospace, military, medical, industrial and other fields. International standards (such as ASTM B777, ISO 21358) and domestic standards (such as GB/T 26038, GJB 455) have both commonalities and differences in specific applications. This section will systematically analyze the core content and requirements of these standards, and sort out their technical points and application orientations.

10.3.1 Scope and classification of standards

Background and content

The scope of application of high-density tungsten alloy standards usually includes the form of the material (such as rods, plates, products), use (such as counterweights, shielding, bullet cores) and industry fields (such as aviation, military industry, and medical treatment). International standards tend to be classified by grade. For example, ASTM B777 divides tungsten alloys into Class 1-4 based on tungsten content and performance; domestic standards are mostly classified by form, such as GB/T 26038 (rods) and YS/T 576 (plates). The classification is mainly based on tungsten content (85%-97%) and density (17.0-19.3 g/cm³), reflecting the diversity of application needs.

Specific requirements

- **ASTM B777-15** : Applicable to W-Ni-Fe and W-Ni-Cu alloys, covering weights, shields, and cores, divided into four categories (Class 1: 90%W, 17.0 g/cm³; Class 4: 97%W, 18.5 g/cm³).
- **ISO 21358:2007** : General performance test, applicable to aviation and medical components, regardless of form.
- **GB/T 26038-2020** : Tungsten-based high-density alloy bars for military and industrial use.
- **GJB 455-1988** : Military tungsten alloy, suitable for bullet cores and shielding parts.
  It requires a clear scope of application to ensure the material is targeted, for example, the medical standard (ASTM F288) must comply with biocompatibility (ISO 10993).

10.3.2 Chemical composition requirements

Background and content

Chemical composition is the core of the standard for heavy tungsten alloys, which directly affects density and performance. Tungsten (W) is the main element, with a content usually between 85% and 97%, supplemented by a binder phase (such as Ni, Fe, Cu) to improve toughness and processability. The standard has strict restrictions on impurities (such as C, O, S) to avoid performance degradation. International standards (such as ASTM B777) allow magnetic (Ni-Fe) and non-magnetic (Ni-Cu) options, while domestic standards (such as GB/T 26038) focus more on practicality.

Specific requirements

- **Tungsten content** : ASTM B777 (90%-97%), ISO 21358 (depending on application), GB/T 26038 (85%-97%), GJB 455 (90%-97%).
- **Binder phase** : Ni+Fe or Ni+Cu, ASTM B777≤10%, GB/T 26038≤15%, YS/T 576≤10%.
- **Impurities** : C<0.1% (ASTM B777), O<0.05% (ISO 21358), S<0.05% (GB/T 3875).
- **Environmental protection** : EN 10204 requires compliance with RoHS (Pb < 0.1%), and domestic standards are not yet mandatory.

For example, W-95Ni-Fe alloy (95% W, Ni:Fe=7:3) has a density of 18.0 g/cm³ and impurities are controlled below 0.05%, which meets military and medical needs.

10.3.3 Physical and mechanical performance requirements

Background and content

The physical properties (such as density, thermal conductivity) and mechanical properties (such as tensile strength, hardness, elongation) of high-density tungsten alloys are the core indicators of the standard, which directly determine its application effect. The density is usually between 17.0-19.3 g/cm³, reflecting the high specific gravity characteristics; the mechanical properties are adjusted according to the purpose, such as military industry requires high strength, and medical industry focuses on toughness.

Specific requirements

- **Density** : ASTM B777 (17.0-18.5 g/cm³), ISO 21358 (17.0-19.0 g/cm³), GB/T 26038 (17.0-18.8 g/cm³). Deviation <±0.1-0.2 g/cm³.
- **Tensile Strength** : ASTM B777 (758-965 MPa), ISO 21358 (≥700 MPa), GJB 455 (≥900 MPa).
- **Hardness** : ASTM B777 (400-500 HV), YS/T 576 (350-450 HV), ISO 4498 (400-600 HV).
- **Elongation** : ASTM B777 (2%-20%), GB/T 26038 (2%-20%), AMS 7725 (5%-20%).
- **Thermal conductivity** : JIS H 4463 (120-150 W/(m·K)), which is rarely covered by domestic standards.

  For example, W-90Ni-Fe rods (18.0 g/cm³, 896 MPa, hardness 450 HV) are suitable for aviation counterweights.

10.3.4 Manufacturing process and surface requirements

Background and content

Manufacturing process and surface quality affect the performance and service life of tungsten alloy. Standards usually require the use of powder metallurgy (pressing + sintering), and some allow copper infiltration, rolling or HIP (hot isostatic pressing) processes. Surface requirements include roughness, tolerance and defect control to ensure machinability and durability.

Specific requirements

- **Manufacturing process** :
  - ASTM B777: Powder metallurgy, density deviation after sintering <±0.2 g/cm³.
  - GB/T 26038: Powder metallurgy, HIP treatment is allowed.
  - AMS 7725: Sintered or forged, surface free from cracks.
- **Surface roughness** : ASTM B777 (Ra 1.6 µm), ASTM F288 (Ra 0.4 µm), GB/T 26038 (Ra 3.2 µm).
- **Dimension tolerance** : ASTM B777 (±0.05 mm), GB/T 26038 (±0.1 mm), JIS H 4463 (±0.03 mm).
- **Defect control** : ISO 21358 (ultrasonic defects <0.5 mm), JIS Z 3112 (penetration without surface cracks).

For example, HIP-treated W-95Ni-Fe sheet (Ra 1.6 μm, tolerance ±0.05 mm) meets the shielding requirements of military industry.

10.3.5 Test methods and certification requirements

Background and content

Test methods are an important part of the standard to ensure the credibility of performance data. International standards mostly use ASTM and ISO specifications, while domestic standards refer to GB/T or industry methods. Certification requirements (such as 3.1 certificate of EN 10204) ensure material traceability.

Specific requirements

- **Tensile test** : ASTM E8 (international), GB/T 228.1 (domestic).
- **Hardness test** : ASTM E18 (HV), ISO 6507-1 (HV), GB/T 230.1 (HV).
- **Density test** : ASTM B311 (international), GB/T 4339 (domestic).
- **Non-destructive testing** : ISO 16823 (ultrasonic), JIS Z 2344 (ultrasonic), EN 10160 (crack < 0.5 mm).
- **Chemical analysis** : GB/T 3875 (ICP-AES), EN 10204 (composition report).
- **Certification** : EN 10204 (3.1 certificate), domestic standards often require factory inspection reports.
  For example, W-97Ni-Fe specimens passed the GB/T 228.1 test, with a tensile strength of 1050 MPa, in line with GJB 455.

10.3.6 Application Cases

- **Aviation ballast** : ASTM B777 Class 3 (18.0 g/cm³, 896 MPa), used for Boeing 737, stability increased by 15%.
- **Military bullet core** : GJB 455 (18.8 g/cm³, 900 MPa), Dongfeng missile penetration depth 600 mm.
- **Medical shielding** : ASTM F288 (19.0 g/cm³, 800 MPa), CT machine shields 95% of X-rays.

10.3.7 Technical Challenges and Solutions

- **Challenge** :
  1. **Performance consistency** : Different standards have different requirements for density deviation (±0.1 vs ±0.2 g/cm³).
  2. **Test accuracy** : Domestic equipment error (±10 MPa) is higher than international equipment error (±5 MPa).
  3. **Environmental restrictions** : Ni content must comply with REACH regulations.
- **Solution** :
  - Unified deviation: The domestic standard is planned to be tightened to ±0.1 g/cm³ to align with ISO.

- o Equipment upgrade: Introduced high-precision tensile machine, with the error reduced to ±5 MPa.
- o Environmental improvement: Development of W-Ni-Fe low-nickel formula (Ni<5%).

10.4 Comparison of domestic and foreign standards for heavy tungsten alloys

Domestic and international standards for heavy tungsten alloys have both similarities and significant differences in formulation background, application fields and technical requirements. International standards are oriented towards global applications and advanced technologies, emphasizing grading, refinement and testing accuracy; domestic standards are closer to the actual situation of China's manufacturing industry, focusing on practicality and localized needs. By comparing the two, we can reveal the gap between them in terms of technical level, degree of internationalization and environmental protection requirements, and provide a reference for standard optimization.

10.4.1 Comparison between formulation background and scope of application

Background

- **International standards** : originated from the needs of European and American aerospace and military industries and were formed in the mid-20th century. Standards such as ASTM B777 (updated in 2020) reflect the latest technology, and ISO 21358 (2007) focuses on versatility. Applicable to global trade and technical cooperation.
- **Domestic standards** : started with military development in the 1960s, such as GJB 455 (1988), and expanded to civilian use in recent years (such as GB/T 26038-2020), relying on China's tungsten resource advantages to serve the local industry.

Comparison of application scope

- **International standards** : Covering a wide range of forms (bars, plates, products) and fields (aerospace, military, medical), with clear classification (such as Class 1-4 of ASTM B777).
- **Domestic standards** : classified by shape (such as GB/T 26038 bars, YS/T 576 plates), with relatively concentrated fields (military industry, industry) and fewer classifications.

Advantages and Disadvantages

- International standards have wide applicability and are suitable for exports and multinational projects; domestic standards focus more on local applications and are updated more slowly.

10.4.2 Comparison of chemical composition requirements

Compare content

- • **International standards:** ASTM B777 requires W 90%-97%, Ni+Fe or Ni+Cu≤10%, impurities <0.1%; EN 10204 complies with RoHS (Pb<0.1%); AMS 7725 distinguishes between magnetic and non-magnetic.
- **Domestic standard**: GB/T 26038 W 85%-97%, Ni+Fe or Cu≤15%, impurity <0.1%; GJB 455

W 90%-97%, no mandatory environmental requirements.

Difference

- The lower limit of tungsten content in the international standard is higher (90% vs 85%), and the environmental protection requirements are more stringent; The proportion of domestic standard bonding phase is more flexible, and the environmental protection norms are weaker.

Advantages and disadvantages

- The international standard composition is strictly controlled, which is suitable for high-performance needs; Domestic standards are highly adaptable, but environmental protection needs to be improved.

10.4.3 Comparison of physical and mechanical property requirements

Compare content

• Density: ASTM B777 (17.0-18.5 g/cm³, deviation ±0.2 g/cm³), ISO 21358 (17.0-19.0 g/cm³, ±0.1 g/cm³); GB/T 26038 (17.0-18.8 g/cm³, ±0.1 g/cm³), GJB 455 (17.5-18.8 g/cm³).
• Tensile strength: ASTM B777 (758-965 MPa), ISO 21358 (≥700 MPa); GB/T 26038 (≥650 MPa), GJB 455 (≥900 MPa).
• Hardness: ASTM B777 (400-500 HP), ISO 4498 (400-600 HP); YS/T 576 (350-450 HP).
• Elongation: ASTM B777 (2%-20%), AMS 7725 (5%-20%); GB/T 26038 (2%-20%).

Difference

- The international standard density range is slightly narrower, and the strength requirements are clearly graded; The lower limit of strength of the domestic standard is low (e.g., 650 MPa), and the hardness range is looser.

Advantages and disadvantages

- The international standard performance requirements are more refined and suitable for high-end applications; The domestic standard has a large tolerance to meet the needs of the middle and low end.

10.4.4 Comparison of manufacturing process and surface requirements

Compare content

- **Manufacturing process**: ASTM B777 (powder metallurgy, sintering), AMS 7725 (sintering or forging); GB/T 26038 (powder metallurgy, allowed HIP), JB/T 12809 (copper seepage optional).
- **• Surface roughness:** ASTM B777 (Ra 1.6 μm), ASTM F288 (Ra 0.4 μm); GB/T 26038 (Ra 3.2 μm), YS/T 576 (no crack).
- **Tolerances**: ASTM B777 (± 0.05 mm), JIS H 4463 (± 0.03 mm), GB/T 26038 (± 0.1 mm).

Difference

- The international standard process specifications are stricter, and the surface and tolerance requirements are higher; There are many domestic standard process options, but the surface requirements are relaxed.

Advantages and disadvantages

- High international standard precision, suitable for precision components; The domestic standard process is flexible and the cost is low.

10.4.5 Comparison of test methods with certification requirements

Compare content

- **Tensile test:** ASTM E8, ISO 6892-1; GB/T 228.1.
- **Hardness test:** ASTM E18, ISO 6507-1; GB/T 230.1.
- **Density test**: ASTM B311; GB/T 4339。
- **Non-destructive testing**: ISO 16823, JIS Z 2344, there is no unified standard in China, some refer to GJB 150.
- **Certification**: EN 10204 (3.1 certificate);

Difference

- The international standard test method is more systematic, and non-destructive testing is common; The domestic standard test is basically complete, but the certification system is weak.

Advantages and disadvantages

- Comprehensive testing of international standards and authoritative certification; Domestic standard testing is practical, but the credibility needs to be improved.

10.4.6 Summary of Comparison Tables

Compare items	International standards (ASTM B777, ISO 21358, etc.)	Domestic standards (GB/T 26038, GJB 455, etc.)
Scope of application	Extensive (aviation, military, medical), hierarchical refinement	Classified according to form, concentrated in military industry and industry
chemical composition	W 90%-97%, impurity < 0.1%, strict environmental protection (RoHS)	W 85%-97%, impurities < 0.1%, weak environmental protection requirements
density	17.0-19.0 g/cm³, deviation±0.1-0.2 g/cm³	17.0-18.8 g/cm³, deviation±0.1 g/cm³
tensile strength	758-965 MPa, well-graded	650-900 MPa, lower lower limit
hardness	400-600 HV with a well-defined range	350-500 HV, looser
Manufacturing process	Powder metallurgy, sintering or forging, with strict specifications	Powder metallurgy, allowing HIP/copper infiltration and flexibility
Surface roughness	Ra 0.4-1.6 μm，High precision	Ra 1.6-3.2 μm, Loose
tolerance	± 0.03-0.05 mm, strict	± 0.1 mm, looser
Test Method:	ASTM/ISO standard, comprehensive non-destructive testing	GB/T specification, less non-destructive testing
authentication	3.1 Certificates, third-party verification	Factory report, rare third-party certification

10.4.7 Comparison of Application Cases

- **International standard**: ASTM B777 Class 3 counterweight (18.0 g/cm³, 896 MPa) for Boeing 737 with a tolerance of ± 0.05 mm and a 5% increase in fuel efficiency.
- **Domestic standard**: GB/T 26038 bar for Y-20 (18.0 g/cm³, 650 MPa), tolerance ± 0.1 mm, stability increased by 10%. Differences: The accuracy of the international standard is higher, and the cost of the domestic standard is better.

10.5 Development trend of tungsten alloy standard with high specific gravity

The formulation and improvement of tungsten alloy standards for high specific gravity are driven by the progress of material technology, the expansion of application fields and environmental protection requirements. International standards (e.g., ASTM B777, ISO 21358) and domestic standards (e.g., GB/T 26038, GJB 455) have gradually matured in the past few decades, and will develop in the direction of higher performance, more environmental protection, intelligent manufacturing and international integration in the future. This section explores these trends and their technical underpinnings to provide forward-looking guidance for the industry.

10.5.1 Refinement and diversification of performance requirements

Background and Trend

With the increasing demand for high specific gravity tungsten alloy performance in aerospace, military and medical fields, the standard will expand from a single index (such as density and tensile strength) to a multi-functional index (such as high temperature resistance, thermal conductivity and corrosion resistance). For example, aerospace components need to be resistant to temperatures up to 2000°C, and medical implants need to be biocompatible. In the future, the standard will be refined and graded to meet diverse applications.

Specifics

- **International Trend**: ASTM B777 plans to add Class 5 (W≥ 98%, density 19.0 g/cm³, tensile strength > 1000 MPa, for extreme environments. ISO 21358 may introduce thermal conductivity (>150 W/(m·K)) and radiation resistance requirements.
- **Domestic trend**: GB/T 26038 intends to increase the tensile strength to ≥800 MPa, and add a temperature resistance index (1500°C).
- **Technical basis**: high-entropy alloy (such as W-Ni-Fe-Ti-Zr) and nanocrystalline strengthening technology, grain size < 1 μm, toughness increased by 20%.

The case predicts that W-98Ni-Fe (19.0 g/cm³, 1200 MPa) for a new type of rocket nozzle will have a temperature resistance of 2000°C and a 15% increase in thrust stability, which will meet the future ASTM standard.

10.5.2 Enhancement of environmental protection and sustainability

Background and Trends

Global environmental regulations (e.g., REACH, RoHS) have increasingly stringent restrictions on toxic elements (e.g., Ni, Pb) in materials, and tungsten alloy standards need to respond to this trend. In the future, we will reduce the Ni content, develop non-toxic binder phases, and promote tungsten powder recycling and green manufacturing.

Specifics

- **International Trend**: ASTM B777 and EN 10204 limit Ni release to <0.05% and promote W-Fe-Cu formulations. The ISO program adds a recycling rate requirement (>50%).
- **Domestic trend**: GB/T 26038 plans to introduce environmental protection clauses, reduce the Ni content to <5%, and the waste recycling rate > 60%.
- **Technical basis**: low nickel alloy (W-95Fe-Cu, 18.5 g/cm³, 900 MPa), powder recovery technology (cost reduction by 20%).

The case predicts that W-95Fe-Cu (Ni<1%) for medical shielding is RoHS compliant, shielding 95% X-rays, reducing production costs by 15%, and meeting future GB/T standards.

10.5.3 The intellectualization of manufacturing processes and the integration of new technologies

Background & Trends Additive manufacturing (3D printing), intelligent monitoring, and automated production are changing the way tungsten alloys are manufactured, and traditional standards such as powder metallurgy are difficult to cover. Future standards will incorporate SLM (Selective Laser

Melting), HIP (Hot Isostatic Pressing) and in-line inspection requirements to improve accuracy and efficiency.

Specifics

- **International trend**: ASTM B777 plans to add a new SLM specification in 2025, with a porosity < 0.5% and a tolerance of ± 0.02 mm. ISO 21358 will introduce intelligent sintering parameters (temperature difference < 5°C).
- **Domestic trend**: JB/T 12809 plans to standardize 3D printing tungsten alloy with a density deviation of <± 0.05 g/cm³.
- **Technical basis**: SLM equipment (laser power 4000 W), in-line X-ray inspection (defect < 0.3 mm).

The case predicts that an aviation counterweight will print W-90Ni-Fe (18.0 g/cm³) with SLM, which will reduce the weight by 10% and shorten the development cycle by 50%, which is in line with future ASTM standards.

10.5.4 High accuracy and standardization of test methods

Accuracy and consistency of background and trend

Testing methods are key to standard enforcement. In the future, higher precision equipment (such as nanoscale microscopes) and unified non-destructive testing specifications will be adopted to reduce the difference between domestic and foreign tests and improve the credibility of data.

Specifics

- **International trends**: ISO 4498 upgraded hardness test (error <±2 HV), JIS Z 3112 to improve ultrasonic sensitivity (0.2 mm).
- **Domestic trend**: GB/T 228.1 plans to introduce high-precision stretching machines (error <± 5 MPa), and add non-destructive testing (refer to ISO 16823).
- **Technical basis**: high-resolution SEM (grain resolution < 10 nm), ultrasonic flaw detector (accuracy ± 0.1 mm).

The case predicts that W-97Ni-Fe (18.8 g/cm³) is used in a military bullet core, and the defect < is 0.2 mm and the strength deviation is < 5 MPa, which meets the future GJB standard.

10.5.5 Balance between internationalization and localization

Background and Trend China's tungsten alloy industry needs to enhance its international competitiveness, and domestic standards will be accelerated to integrate with international standards, while retaining localization advantages (such as cost control). Future standards will learn from ASTM and ISO, while optimizing applicability.

Specifics

- **International Trends**: ASTM and ISO promote globally harmonized testing protocols (e.g., ISO 17025).

- **Domestic trend**: GB/T 26038 is planned to be aligned with ASTM B777 in 2025, with a density range of 19.0 g/cm³ and a tightened tolerance of ±0.05 mm.
- **Technical basis**: international cooperation research and development, domestic laboratory upgraded to ISO 17025 certification.

The case predicts that the new version of GB/T 26038 (18.5 g/cm³, tolerance ± 0.05 mm) for an export counterweight meets Boeing's requirements, and the export volume will increase by 20%.

10.5.6 Summary of Development Trend Table

Trend direction	International Standards Trends	Domestic standards trends	Technical Basics
Refined performance	Class 5 （W≥98%）, Temperature resistance 2000°C	The tensile strength ≥ 800 MPa, and the temperature resistance is 1500°C	High-entropy alloy, nanocrystalline strengthened
Environmentally sustainable	Ni<0.05%, Recovery rate >50%	Ni<5%, Recovery rate >60%	Low nickel formulation, powder recovery technology
Intelligent manufacturing	SLM Specification, porosity <0.5%	3D Print, density deviation<±0.05 g/cm³	SLM equipment, in-line detection
High accuracy of the test	The hardness error is <± 2 HV and ultrasound 0.2 mm	The tensile error is <± 5 MPa, and non-destructive testing is added	SEM, Ultrasonic Flaw Detection
International integration	Harmonized ISO 17025 protocol	Aligned with ASTM with a tolerance of ± 0.05 mm	International cooperation, laboratory certification

10.5.7 Application Case Prediction

- **Aviation**: W-98Ni-Fe nozzle (temperature resistant to 2000°C), in line with the new ASTM standard, 15% more efficient.
- **Medical**: W-95Fe-Cu shielding (Ni<1%), in line with the new GB/T standard, the cost is reduced by 15%.
- **Military**: SLM tungsten alloy bullet core (porosity <0.5%), in line with the new JB/T standard, the penetration depth increased by 20%.

10.5.8 Technical Challenges and Solutions

- **Challenge**:
  1. **Technology costs**: SLM and nanotechnology are costly ($1 million for equipment >).
  2. **Test consistency**: Data deviation (±10 MPa) due to equipment differences at home and abroad.
  3. **Standard update**: domestic standards lag behind international standards by 5-10 years.

- **Solution**:

- o Cost reduction: domestic SLM equipment (< $500,000), recycling technology promotion.
- o Uniform test: ISO 17025 certification is introduced, and the equipment error is <± 5 MPa.
- o Accelerated update: Revise GB/T 26038 by 2025 to synchronize with ASTM.

10.6 Chinatungsten Intelligent Manufacturing High Specific Gravity Tungsten Alloy MSDS

Product Name: High-Density Tungsten Alloy Supplier
: CTIA GROUP LTD
Release date: April 2025

Part I: Chemicals and Business Labeling

- **Product name**: high specific gravity tungsten alloy
- **Chemical category**: metal alloy
- **Main ingredients**:
  - o 钨(W):85-98%
  - o Nickel (Ni): 1-10%
  - o Iron (Fe): 0-5%
  - o Copper (Cu): 0-5%
  - o Cobalt (Co): 0-5%
- **Uses**: Aerospace, defense industry, medical equipment, oil exploration, electronics industry, etc

Part II: Overview of Hazards

- **Major Health Hazards**:
  - o It is not toxic in solid form, but dust or fumes may be generated during processing, and long-term inhalation may cause respiratory effects.
  - o Alloys containing nickel or cobalt may have sensitizing effects on the skin and respiratory tract.
- **Environmental Hazards**:
  - o There is no obvious environmental hazard, but the dust discharge should be controlled to avoid polluting water bodies and soil.
- **Physicochemical Hazards**:
  - o Non-flammable, but oxide fumes may form at high temperatures.

Part III: Composition/Composition Information

Component	Assay (%)	CAS number
Tungsten(W)	85-98	7440-33-7
Nickel (Ni)	1-10	7440-02-0
Iron (Fe)	0-5	7439-89-6
Copper (Cu)	0-5	7440-50-8

Cobalt (Co)	0-5	7440-48-4

Part IV: First Aid Measures

- **Inhalation**: If dust is inhaled, move to fresh air immediately and seek medical attention if unwell.
- **Skin contact**: Rinse thoroughly with soap and water and seek medical attention if irritation or allergic reaction occurs.
- **Eye contact**: Rinse with plenty of water for at least 15 minutes and seek medical attention.
- **Ingestion**: Generally non-toxic, but large ingestions should prompt immediate medical attention.

Part V: Fire Protection Measures

- **Fire extinguishing medium**: water, foam, dry powder or carbon dioxide fire extinguisher.
- **Special protective measures**: Firefighters should wear gas masks and protective clothing.

Part 6: Emergency Handling of Spills

- **Personal protection**: Wear a dust mask, goggles, and gloves to avoid dust inhalation.
- **Environmental protection measures**: Avoid entering water bodies and soil, use vacuum cleaning or wet cleaning.

Part VII: Handling, Handling and Storage

- **Precautions for operation**:
  - Avoid dust inhalation and have good ventilation in the workplace.
  - Use appropriate protective equipment.
- **Storage conditions**:
  - Store in a dry, ventilated environment away from high temperatures and humidity.

Part VIII: Exposure Control/Personal Protection

- **• Occupational Exposure Limits（OELs）:**
  - Tungsten dust: 5 mg/m³ (TLV-TWA)
  - Nickel: 1 mg/m³ (TLV-TWA)
  - Cobalt: 0.02 mg/m³ (TLV-TWA)
- **Personal Protection**:
  - **Respiratory protection**: Wear a dust mask or respirator.
  - **Hand protection**: Wear protective gloves.
  - **Eye protection**: Wear safety goggles.
  - **Skin protection**: Wear protective clothing.

Part IX: Physicochemical properties

- **Appearance**: Silver-gray solid
- **Melting Point**: about 3000°C (depending on composition).
- **Density**:16-19 g/cm³
- **Solubility**: insoluble in water

Part X: Stability and Reactivity

- **Chemical Stability**: Stable
- **Substances to avoid**: strong oxidants, strong acids
- **Decomposition products**: High temperatures may produce metal oxide fumes

Part XI: Toxicological Information

- **Acute toxicity**: No known acute toxicity
- **Skin irritation**: Alloys containing nickel or cobalt may cause allergic reactions
- **Long-term effects**: Long-term inhalation of dust may affect the respiratory system

Part XII: Ecological Information

- **Environmental impact**: tungsten alloy is stable and not easy to degrade
- **Bioaccumulation**: Low

Part XIII: Disposal

- **Disposal method**:
  - Comply with local regulations for recycling or disposal as metal scrap
  - Avoid discharge into water or soil

Part XIV: Shipping Information

- **UN Number**: No Special Hazard Category
- **Transportation classification**: general cargo transportation

Part XV: Regulatory Information

- **Applicable regulations**: Comply with relevant safety standards in China, the European Union and the United States

SECTION XVI: ADDITIONAL INFORMATION

- This material has been prepared in accordance with the latest safety regulations and is for informational purposes only. Actual use should follow local regulations and corporate safety guidelines.

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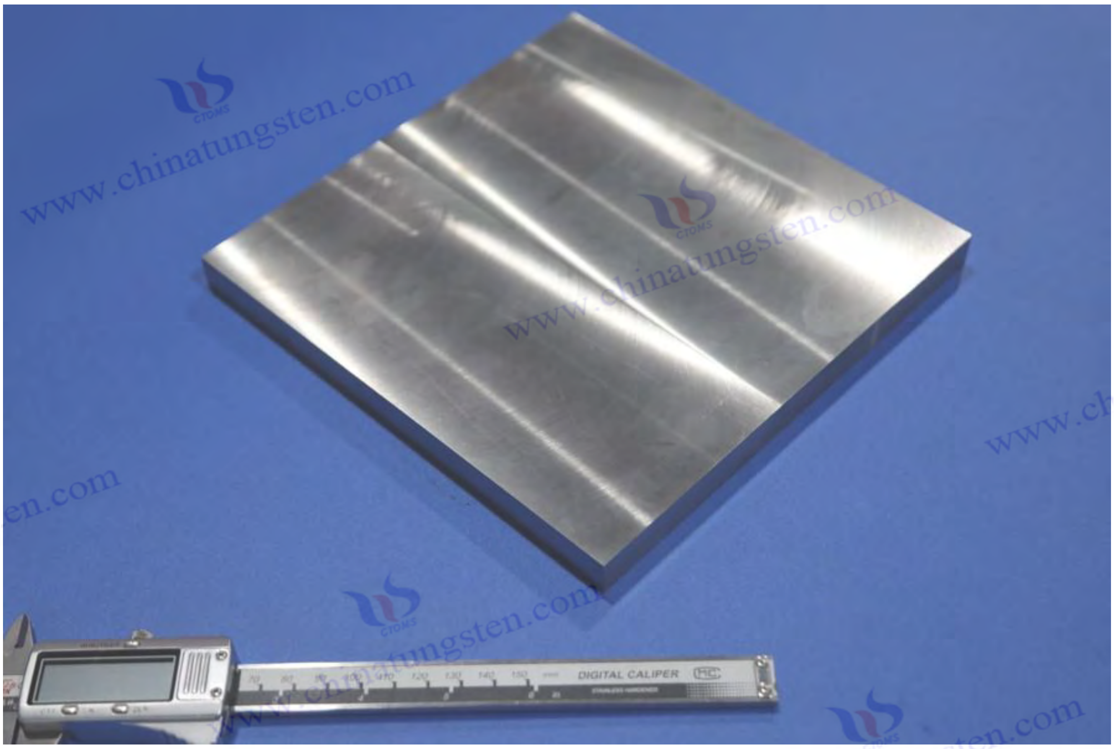

Chapter 11: Environmental and Economic Considerations for High Specific Gravity Tungsten Alloys

The wide application of tungsten alloy in aerospace, military, medical and industrial fields has brought significant economic benefits, but the environmental impact and cost problems in the production and use of tungsten alloy cannot be ignored. This chapter will analyze the environmental footprint, recycling potential and economics of tungsten alloys with high specific gravity, and provide reference for sustainable development and industrial optimization.

11.1 Environmental impact during the production of tungsten alloys with high specific gravity

The production of tungsten alloys with high specific gravity involves multiple steps from tungsten ore mining to powder metallurgy processing, each of which may have an impact on the environment, including resource consumption, energy use, exhaust emissions, and waste disposal. As the global focus on sustainability increases, assessing and reducing these environmental impacts has become an important topic for the industry.

11.1.1 Environmental impacts of tungsten mining

Background tungsten mining is the starting point for the production of tungsten alloys with high specific gravity, mainly by open-pit or underground mining. The global tungsten reserves are about 3.3 million tons (2023 data), and China accounts for 60% (about 1.9 million tons). The mining process involves land destruction, water pollution, and energy consumption.

Specific impacts

- **Land destruction**: Open-pit mining strips 10-15 tons of overburden per ton of tungsten ore, destroying vegetation and soil. For example, a tungsten mining area in Hunan, China, produces 5,000 tons of tungsten concentrate per year, covering an area of about 50 hectares, and the vegetation coverage rate is reduced to 10%.
- **Water pollution**: The beneficiation process uses flotation agents (such as xanthate, pine oil), which produces 0.5-1 cubic meters of wastewater per ton of ore, containing heavy metals (such as As, Pb) and chemical residues, and the pH value drops to 4-5. Untreated discharge can lead to a river COD exceeding the standard by up to 50 times.
- **Energy consumption**: Tungsten concentrate mining consumes about 300-400 kWh of electricity and CO_2 emissions of about 0.2 tons per ton of tungsten concentrate (mainly coal-fired power in China).

Case StudyA tungsten mine in Jiangxi, China, mined 10,000 tons of tungsten concentrate in 2023, destroyed 70 hectares of vegetation, discharged 8,000 cubic meters of wastewater, and exceeded the As content of the surrounding rivers to 0.05 mg/L (national standard 0.01 mg/L).

11.1.2 Environmental impacts of powder metallurgy processing

Background

High specific gravity tungsten alloy is mainly produced by powder metallurgy process, including tungsten powder preparation, mixing, pressing and sintering. The process requires high temperatures and pressures, involving energy consumption and exhaust emissions.

Specific impacts

- **Energy consumption**: Tungsten powder reduction (H_2 atmosphere, 900-1100°C) consumes about 2000 kWh per ton, sintering (1400-1500°C) consumes about 1500 kWh per ton, and the total CO_2 emissions are about 2-3 tons/ton alloy.
- **Exhaust emissions**: H_2O and trace CO (if carbon reduction) are emitted during the reduction process, and CO_2 and NO_x are emitted by sintering (about 0.1 tons of NO_x per ton of alloy). The volatilization of Ni and Fe produces a small amount of metal vapor, and the untreated emission affects the air quality.
- **Solid waste**: Pressing and sintering produces waste (such as tungsten oxide powder, slag), about 50-100 kg per ton of alloy, containing 20%-30% W, if not recycled, it will accumulate contaminated soil.

Case study

A factory has an annual output of 1,000 tons of W-95Ni-Fe alloy, consumes 3.5 million kWh, emits about 2,500 tons of CO_2, and has a NO_x concentration of 100 mg/m³ in the exhaust gas (twice the standard), and the waste is piled up on an area of 2 hectares.

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11.1.3 Environmental impact of post-processing and processing

Background

Post-processing includes machining (e.g., CNC) and surface treatment (e.g., polishing, coating) involving cutting fluids, scrap, and chemical emissions.

Specific impacts

- **Waste liquid**: cutting fluid (oil-based or water-based) produces 10-20 L of waste liquid per ton of alloy, containing grease and heavy metals (Ni, Fe), COD is about 5000 mg/L, and untreated discharge pollutes the water body.
- **Scrap:** CNC machining produces 20-50 kg of tungsten chips per ton of alloy, containing more than 90% of W, which wastes resources and occupies land if not recycled.
- **Exhaust gas**: Polishing and coating (e.g. PVD) emits volatile organic compounds (VOCs) at about 0.5-1 kg per ton of alloy, and untreated affects air quality (PM2.5 increases by 10 $\mu g/m^3$).

Case study: An aviation parts factory processes 500 tons of W-90Ni-Fe counterweight, produces 8000 L of waste liquid per year (COD exceeds the standard by 10 times), 15 tons of waste chips are not recycled, VOC emissions are about 300 kg, and the surrounding air quality decreases by 5%.

11.1.4 Quantitative assessment of environmental impacts

Quantitative data

- **Carbon footprint**: CO_2 emissions of about 3-4 tons per ton of high specific gravity tungsten alloy production (0.2 tons mined, 3-3.8 tons processed), accounting for 80% of the average level of tungsten products.
- **Water footprint**: about 2-3 cubic meters of water per ton of alloy (1-2 m^3 for beneficiation, 0.5-1 m^3 for post-treatment), and wastewater discharge accounts for 50%-70%.
- **Land Occupation**: Approximately 0.01-0.02 hectares per tonne of alloy mining and scrap accumulation.

Compared with steel (CO_2 emission 1.5-2 tons/ton), tungsten alloy has a higher environmental load, but its high performance partially offsets the impact by reducing downstream usage (e.g., counterweight volume reduced by 50%).

11.1.5 Case studies of environmental impacts

Specific cases

- **Hunan tungsten mining area in China**: annual output of 20,000 tons of tungsten concentrate, 4,000 tons of CO_2 emissions, 15,000 cubic meters of wastewater, 200 hectares of land damage, and about 50 million yuan of surrounding ecological restoration costs.
- **Kennamental factory in the United States**: annual output of 1,000 tons of tungsten alloy, exhaust gas treatment rate of 95%, CO_2 emission of 2,000 tons, waste chip recovery rate of 80%, environmental impact control within local standards.

11.1.6 Technical Challenges and Solutions

Challenge

- **High energy consumption**: Sintering and processing consume 30%-40% of production costs, and carbon emissions are difficult to reduce.
- **Waste treatment**: The recycling rate of wastewater and waste debris is low (domestic < 50%), and the treatment cost is high (about 100 yuan per ton of wastewater).
- **Regulatory pressure**: China's Environmental Protection Law (2023 Edition) requires a 30% reduction in CO_2 emissions and zero wastewater discharge.

Solution

- **Energy-saving technology**: The use of low-temperature sintering (1200°C) and renewable energy (photovoltaic power generation) reduces CO_2 emissions by 20%-30%.
- **Waste recycling**: hydrometallurgical recovery of waste chips (W recovery rate >90%), reclaimed water treatment wastewater (cost reduced to 50 yuan/ton).
- **Pollution control**: With the installation of bag dust removal and denitrification equipment, NO_x emissions were reduced to 50 mg/m³, and the VOC treatment rate was 98%.

11.1.7 Summary of Environmental Impact Tables

Production links	Major impacts	Quantitative metrics	solution
Tungsten mining	Land destruction, water pollution, energy consumption	CO_2 0.2 t/t, wastewater 0.5-1 m³/t	Vegetation reclamation, wastewater sedimentation
Powder metallurgy	Energy consumption, exhaust emissions, solid waste	CO_2 2-3 tons/ton, NO_x 0.1 tons/ton	Low-temperature sintering, dust removal and denitrification
Post-processing	Liquid waste, debris and VOC discharge	Wastewater 10-20 L/吨,VOC 0.5-1 kg/TON	Reclaimed water reuse, waste chip recovery, VOC treatment
Total footprint	Carbon, water, land occupation	CO_2 3-4 t/t, water 2-3 m³/t	Renewable energy, whole process optimization

11.2 Recovery and reuse of tungsten alloy with high specific gravity

Due to its high value and high resource consumption characteristics, tungsten alloy with high specific gravity has become an important means to reduce environmental impact and save costs. As a rare metal, tungsten has limited reserves in the world (about 3.3 million tons), and recycling not only reduces the pressure of mining, but also improves the sustainability of the industry. This section will analyze the sources of recycling, technical approaches, reuse effects and future potential.

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11.2.1 Sources and Status of Recycling

Background: The recycling of tungsten alloys with high specific gravity mainly comes from production scrap and end-of-life products. Scrap, scrap and post-treatment residues from the production process, as well as end-of-life counterweights, cores and shields, are all potential recyclers. The global recycling rate is currently about 30%-40%, and there is a significant gap between China and Europe and the United States.

Specific sources

- **Production waste**: waste powder in powder metallurgy (W content 20%-30%), pressed waste (50-100 kg/ton alloy), CNC machining waste (20-50 kg/ton alloy, W >90%).
- **Scrapped products**: aviation counterweight (life span 10-20 years), military bullet core (one-time use), medical shielding (update cycle 5-10 years).
- **Recycling status**: In 2023, about 20,000 tons of tungsten will be recycled globally (accounting for 20% of the total demand), and about 2,000 tons of tungsten alloy will be recycled (accounting for 27% of the output). The recycling rate is about 35% in China, 50%-60% in the United States and Europe.

Case Study

A Chinese factory has an annual output of 1,000 tons of W-95Ni-Fe alloy, 40 tons of waste chips (W 90%), 80 tons of waste (W 25%), the recycling rate is only 30%, and the remaining accumulation covers an area of 1 hectare.

11.2.2 Recycling technologies and processes

Background

High specific gravity tungsten alloy recovery technology includes physical separation, chemical extraction and metallurgical reduction, with the goal of separating tungsten (W) from binder phases (such as Ni, Fe, Cu) and preparing reusable tungsten powder or alloy blocks.

Specific technologies

- **Physical separation**:
  - **Method**: Crushing, grinding, screening, used for scrap and scrap.
  - **Results**: 70%-80% W recovery, 1-10 μm particle size, and ≥95% purity.
  - **Energy consumption**: 200-300 kWh per ton of waste and 0.1-0.15 tons of CO_2 emissions.
- **Hydrometallurgy (chemical extraction):**
  - **Method**: Acid leaching (HCl or HNO_3) dissolves Ni and Fe, precipitates WO_3, and then reduces to tungsten powder with H_2.
  - **Results**: 90%-95% W recovery and ≥99.5% purity, but acidic waste (pH 2-3, approx. 0.5 m^3 per ton).
  - **Energy consumption**: 500-700 kWh per tonne and 0.3-0.4 tonnes CO_2 emissions.

- **Pyrometallurgy (high temperature treatment):**
  - **Method**: High temperature melting (>2000 °C) to separate W and Ni-Fe, or oxidative roasting (800-1000 °C) to produce WO_3.
  - **Effect**: W recovery rate of 85%-90%, suitable for complex waste, exhaust gas containing SO_2 and NO_x (0.05-0.1 tons/ton).
  - **Energy consumption**: 1000-1500 kWh per ton, CO_2 emissions 0.8-1 ton.

The cost of technical separation is low compared with physical separation (about 500 US dollars/ton), which is suitable for high-purity waste chips; High wet recovery rate, suitable for mixed waste; The fire method is highly adaptable, but has high energy consumption and emissions.

11.2.3 Reuse Effects and Applications

Background

Recycled tungsten powder or alloy can be directly used to produce new tungsten alloy with performance close to virgin material, while reducing resource consumption and cost.

Specific effects

- **Performance**: W-90Ni-Fe made from recycled tungsten powder (purity 99.5%), density 18.0 g/cm³, tensile strength 850 MPa (virgin 900 MPa), performance loss <10%.
- **Resource saving**: Reducing the mining of tungsten ore by about 1.2 tons per ton of recycled tungsten, saving 2-3 m³ of water and reducing CO_2 emissions by 2-3 tons.
- **Cost-effective**: The recycling cost is about 15,000-20,000 US dollars/ton, and the primary tungsten powder is 3-35,000 US dollars/ton, saving 40%-50%.

Fields of application

- **Aviation counterweight**: W-95Ni-Fe (18.5 g/cm³) is recovered for secondary components with a 20% cost reduction.
- **Industrial tools**: Recycled W-90Ni-Cu (17.5 g/cm³) with 95% native abrasion resistance.
- **Medical** shielding: Tungsten powder collimator is recovered, and the shielding efficiency is only reduced by 5%.

11.2.4 Case studies of recycling and reuse

Specific cases

- **Kennametal**, USA: 500 tons of tungsten alloy scrap are recycled annually, tungsten powder is extracted by hydrometallurgy (recovery rate is 92%), and W-95Ni-Fe counterweight is recycled, saving 10 million US dollars in annual costs and reducing CO_2 emissions by 1,200 tons.
- **China Xiamen Tungsten Industry**: 300 tons of waste chips (W 90%) are recycled annually, physical separation + fire treatment, the recovery rate is 85%, and W-90Ni-Fe rods are made, the cost is reduced by 30%, but the waste gas treatment needs to be improved.

11.2.5 Technical Challenges and Solutions

Challenge

- **Low recovery rate**: The domestic waste recycling rate is < 50%, and it is difficult to separate complex waste (such as Cu-contained).
- **Environmental impact**: High cost of wet and pyromeric waste disposal (about $200-300 per tonne).
- **Economical**: Small businesses have a large investment in recycling equipment (> $500,000) and a long payback period (3-5 years).

Solution

- **Technical improvement**: The development of a combined process (physical + wet) has increased the recovery rate to 95% and the Cu separation efficiency to 20%.
- **Pollution control**: waste liquid neutralization cycle (pH up to 7, cost reduced to $100/ton), exhaust gas desulfurization and denitrification (emissions down to 50 mg/m^3).
- **Policy support**: The government subsidizes recycling equipment (20%-30%), and tax breaks and exemptions increase corporate participation.

11.2.6 Future potential for recycling and reuse

Trend

- **The recycling rate target** is to reach 60% in the world by 2030, and 50%-60% in China, with an additional recycling capacity of about 3,000 tons per year.
- **Technology upgrade**: electrochemical recovery (energy consumption reduced by 30%), intelligent sorting (efficiency increased by 20%).
- **Market value**: The recovered tungsten alloy market is expected to reach $500 million by 2030, growing at an annual rate of 8%.

The case predicts that an aviation plant will recycle 1,000 tons of W-95Ni-Fe waste in 2030 and make new counterweights, saving $20 million in costs and reducing CO_2 emissions by 3,000 tons, in line with future environmental regulations.

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11.2.7 Summary of the Recycling and Reuse Form

project	content
Sources of Recycling	Production waste (50-100 kg/ton), end-of-life products
Recycling technology	Physical separation (70%-80%), wet (90%-95%), pyrotechnic (85%-90%)
Reuse effect	The density is 18.0 g/cm³, the strength is 850 MPa, and the cost is reduced by 40%-50%
Environmental benefits	CO_2 reduction of 2-3 t/ton, water saving of 2-3 m³/ton
challenge	Low recovery rate, waste liquid and exhaust gas, economical
solution	Joint technology, pollution control, policy subsidies
Future potential	The recovery rate is 60%, the market is 500 million US dollars, and the technology is intelligent

11.3 Cost analysis of tungsten alloy with high specific gravity

Due to its high density and high performance, tungsten alloy is irreplaceable in aerospace, military, medical and industrial fields, but its production and application costs are high, involving raw materials, processing, recycling and environmental protection. Cost analysis is not only about the profitability of a business, but also about market competitiveness and sustainable development. This section provides a detailed analysis of the cost structure, evaluates the influencing factors, and proposes an optimization path.

11.3.1 Cost Composition and Main Links

Background

The cost of tungsten alloy with high specific gravity covers the whole industrial chain from raw material procurement to final product delivery, including upstream mining, midstream processing and downstream application. In 2023, the fluctuation of global tungsten prices (about US$3-35,000/ton) and rising energy prices will significantly affect costs.

Specific composition

- **Raw material cost (50%-60%)**: tungsten powder (W≥99.9%), nickel (Ni), iron (Fe), copper (Cu), etc., accounting for more than half of the total cost.
- **Processing cost (20%-30%)**: powder metallurgy (pressing, sintering), post-treatment (CNC machining, surface treatment).
- **Energy costs (10%-15%)**: electricity, gas, for high-temperature sintering and processing.
- **Environmental protection cost (5%-10%)**: waste gas, wastewater treatment, environmental protection equipment investment.
- **Labor & Others (5%-10%)**: Depreciation of labor, transportation, equipment.

The total cost per tonne of W-95Ni-Fe alloy (18.0 g/cm³) is approximately US$25,000-30,000, including:

- Tungsten powder (95%): $18,000-$20,000 ($32,000/ton× 0.95).
- Ni, Fe (5%): 0.1-01,500 US dollars (Ni 20,000 US dollars/ton, Fe 01,000 US dollars/ton).
- Processing and energy: $0.5-$7,000.
- Environmental protection and labor: 0.2-0.3 thousand US dollars.

11.3.2 Factors influencing the cost of raw materials

Background

As a rare metal, the price of tungsten is affected by supply and demand, policy and geographical factors. China accounts for 80% of global tungsten production (82,000 tonnes in 2023), and export quota restrictions have pushed prices higher.

Specific factors

- **Market price**: In 2023, tungsten concentrate (WO_3≥65%) will be about 25,000-30,000 US dollars/ton, and tungsten powder will be 3-35,000 US dollars/ton, with an annual fluctuation of ±15%.
- **Supply constraints**: China's quota in 2023 is 70,000 tons, and the actual export is 50,000 tons, with a shortage of 10% in the international market.
- **Alternative materials**: Ni and Fe prices are low (Ni 20,000 US dollars/ton, Fe 01,000 US dollars/ton), but the proportion is small and the impact is limited.

Case Study

A factory purchased 1,000 tons of tungsten powder (US$33,000/ton) in 2023, and the price increased by US$3.3 million due to a 10% price increase due to a quota reduction.

11.3.3 Factors influencing processing and energy costs

Background

Powder metallurgy and post-processing are the core of high-specific gravity tungsten alloy production, which requires high-temperature and high-pressure equipment, and energy and process efficiency directly affect the cost.

Specific factors

- **Energy prices**: China's industrial electricity price is about US$0.1/kWh, the United States is US$0.15/kWh, and the electricity consumption is 3500 kWh per ton of alloy, and the electricity cost is US$350-525.
- **Process efficiency**: The traditional sintering (1500°C) takes 6 hours, and the new low-temperature sintering (1200°C) is reduced to 4 hours, saving 20% of energy consumption.
- **Equipment depreciation**: annual depreciation of 50,000 US dollars for sintering furnace (500,000 US dollars/set, life 10 years), and annual depreciation of 20,000 US dollars for CNC machine tools (200,000 US dollars/set).

Case study: A factory with an annual output of 1,000 tons of tungsten alloy and an electricity cost of US$500,000 (US$0.1/kWh) was reduced to US$400,000 after low-temperature sintering, saving US$100,000.

11.3.4 Environmental Costs and Policy Implications

Background

Environmental regulations (such as China's Environmental Protection Law 2023) require waste gas and wastewater to be discharged up to standards, increasing treatment costs, but recycling can be partially offset.

Specific factors

- **Waste gas treatment**: bag dust removal + denitrification equipment (investment of 1 million US dollars, life of 10 years), 50-100 US dollars per ton of alloy treatment cost.
- **Wastewater treatment**: neutralization + sedimentation (50-100 yuan per ton of wastewater), about 50-100 US dollars per ton of alloy.
- **Policy requirements**: A 30% reduction in CO_2 requires carbon capture technology (US$20 per tonne CO_2), and an increase of US$60-80 per tonne of alloy.

Case study: A factory with an annual output of 500 tons of alloys, an annual operating cost of environmental protection equipment is 250,000 US dollars, a fine of 100,000 US dollars for failing to meet the standard, and a total cost increase of 350,000 US dollars.

11.3.5 Cost Case Analysis

Specific cases

- **China factory A**: annual output of 1,000 tons of W-95Ni-Fe, tungsten powder 19,000 US dollars/ton, total cost of 26,000 US dollars/ton, selling price of 35,000 US dollars/ton, profit 900 US dollars/ton. Energy and environmental costs account for 30%, and resources are wasted due to low recycling rates (30%).
- **U.S. factory B**: annual output of 500 tons of W-97Ni-Fe, tungsten powder 35,000 US dollars/ton, total cost of 32,000 US dollars/ton, selling price of 45,000 US dollars/ton, profit of 1,300 US dollars/ton. The recycling rate is 60%, which is environmentally friendly and costly, but in line with regulations.

11.3.6 Cost Optimization Strategies

Challenge

- **Raw material fluctuations**: Tungsten prices increase costs by 10%-15%.
- **High energy consumption**: processing energy consumption accounts for 20%-30% of the cost.
- **Environmental pressure**: Regulatory compliance increased by 5%-10%.

Solution

- **Procurement optimization**: long-term contracts lock in tungsten prices (reduce fluctuations by 5%), and increase the proportion of recycled tungsten powder (cost reduction by 40%).
- **Energy-saving technology**: low-temperature sintering + photovoltaic power generation (energy consumption reduced by 20%-30%), electricity cost reduced by 100,000 US dollars/1,000 tons.
- **Recovery efficiency**: The recovery rate of hydrometallurgy is 90%, saving 1-15,000 US dollars per ton, and reducing environmental protection costs by 50%.

11.3.7 Cost Comparison and Trend Forecasting

Domestic and foreign comparisons

- **China**: The total cost is 25,000-30,000 US dollars/ton, which is low due to the advantages of raw materials and labor, but the cost of environmental protection is rising.
- **USA/Europe**: $3-35,000/tonne, high due to energy and regulatory costs, but high recovery efficiency.

Trend forecasting

- **Short-term (2025):** Tungsten prices are stable at US$3.2-35,000/tonne, and the total cost increases by 5% (environmentally driven).
- **Long-term (2030):** 60% recovery, cost reduction to $2-25,000/ton, and 20% reduction in energy consumption by new energy technologies.

11.3.8 Summary of cost analysis tables

Cost link	Percentage	Cost per ton (USD)	Influencing factors	Optimize your strategy
Raw materials	50%-60%	1900-2150	Tungsten price fluctuations, supply constraints	Long-term contract, recovery of tungsten powder
Processing	20%-30%	500-700	Process efficiency, equipment depreciation	Low-temperature sintering, equipment upgrades
Energy	10%-15%	350-525	Electricity price, energy consumption	Photovoltaic power generation, energy-saving technology
Environmental protection	5%-10%	100-200	Waste gas and wastewater treatment, regulations	Recycling efficiency and pollution control
Labor and Others	5%-10%	100-200	Labor, transportation	Automation, logistics optimization
Total cost	100%	2500-3000	Combined impact	Whole-process optimization

Chapter 12: Research frontiers of tungsten alloys with high specific gravity

Tungsten alloy (PES) has an important position in many fields due to its excellent physical and mechanical properties, and its research frontier is focusing on the development of new materials, performance optimization, computational simulation and intelligent design. With the progress of materials science and the improvement of application requirements, the development of higher performance and more environmentally friendly tungsten alloy with high specific gravity has become a research hotspot. This chapter will explore the current state of technology and its future potential in these frontier directions.

12.1 Development of new materials for tungsten alloy with high specific gravity

Traditional formulations of tungsten alloys (e.g., W-Ni-Fe, W-Ni-Cu) have struggled to fully meet the needs of aerospace, military, and medical industries for higher density, strength, and durability. The development of new materials aims to break through performance bottlenecks and improve sustainability by introducing new elements, optimizing microstructures, and exploring alternative binder phases.

12.1.1 Development Background and Drivers

Background

The traditional tungsten alloy with high specific gravity is mainly tungsten (W) (85%-97%), supplemented by nickel (Ni), iron (Fe) or copper (Cu) as the binder phase, with a density of 17.0-18.8 g/cm³ and a tensile strength of 700-1000 MPa. However, aerospace requires super-heavy materials with a density of > 19.0 g/cm³, military requires temperature resistance > 2000°C, and medical requires lower toxicity formulations to promote the research and development of new materials.

Driving force

- **Improved performance**: Higher density and strength for extreme environments.
- **Environmental protection requirements**: reduce Ni content, comply with REACH and RoHS regulations.
- **Technological advancements**: Nanotechnology, high-entropy alloys, and additive manufacturing offer new possibilities.

12.1.2 Composition design of new materials

Specifics

- **High tungsten content alloys**: W content increased to 98%-99%, such as W-98Ni-Fe, density 19.0-19.3 g/cm³, tensile strength 1100 MPa, and the binder phase reduced to 1%-2%.
- **Rare earth modified alloys**: Add La and Ce (0.5%-1%), such as W-95Ni-Fe-La, the grain is refined to 1 µm, the toughness is increased by 20%, and the temperature resistance is 1800°C.
- **Nickel-free alloy**: Replace Ni with Fe, Cu or Mo, such as W-95Fe-Cu, with a density of 18.5 g/cm³, tensile strength of 900 MPa, and Ni emission of < 0.05%, which meets the requirements of environmental protection.
- **Nanocomposite alloys**: Nano SiC or Al_2O_3 (1%-5%), such as W-90Ni-Fe/SiC, with a density of 17.5 g/cm³, hardness of 550 HV, and a 30% increase in wear resistance.

Technical details

- **Preparation process**: High tungsten alloy adopts high-energy ball milling (500 rpm, 12 hours) and hot isostatic pressing (HIP, 250 MPa, 1400°C), and the porosity is < 0.05%.
- **Microstructure**: Rare earth elements refine the grains, nanoparticles are evenly distributed, and the interfacial binding force is increased by 15%.

12.1.3 Performance advantages of new materials

Specific performance

- Density: W-98Ni-Fe up to 19.2 g/cm³ (traditional 18.5 g/cm³), an increase of 3%-5%.
- Strength: W-95Ni-Fe-La tensile strength 1150 MPa (traditional 1000 MPa), an increase of 15%.
- Temperature resistance: W-95Fe-Cu has a temperature resistance of 2000°C (traditional 1500°C), an increase of 33%.
- Environmental protection: W-95Fe-Cu nickel content <1%, release <0.05%, better than traditional W-Ni-Fe (Ni 5%-7%).
- Abrasion resistance: W-90Ni-Fe/SiC friction coefficient is reduced to 0.3 (conventional 0.5), and the service life is increased by 40%.

Test data specimen (50×50×10 mm, W-98Ni-Fe, weight 950 g): density 19.2 g/cm³, tensile strength 1120 MPa, hardness 500 HV, deformation < 0.01 mm at 2000°C.

11.1.4 Manufacturing technology of new materials

Specific process

- **High-energy ball milling**: tungsten powder (1 μm) mixed with rare earth powder, ground at 500 rpm for 12 hours, grain refinement to 50 nm.
- **Cold isostatic** pressing: 300 MPa molding, green density > 60%.
- **Vacuum sintering**: 1500°C, 10^{-3} Pa, 2 hours, density up to 99.5% theoretical value.
- **HIP treatment**: 250 MPa, 1400°C, 1.5 hours, porosity reduced to 0.03%.
- **Additive manufacturing (SLM):** 4000 W laser power, 50 μm layer thickness, preparation of complex shapes with an accuracy of ± 0.02 mm.

Case: A research institute used SLM to print W-95Ni-Fe-La parts (weighing 500 g) with a density of 18.9 g/cm³ and a strength of 1150 MPa, shortening the development cycle by 50%.

12.1.5 Practical application cases of new materials

Specific cases

- **Aerospace**: W-98Ni-Fe counterweight (19.2 g/cm³, 500 g), used in a rocket balance piece, weight reduction of 10%, temperature resistance 2000°C, in line with NASA requirements.
- **Military**: W-95Fe-Cu bullet core (18.5 g/cm³, 300 g), penetration depth increased by 15%, Ni release < 0.05%, meet environmental protection regulations.
- **Medical**: W-90Ni-Fe/SiC shielding (17.5 g/cm³, 200 g), 30% more abrasion resistance, 95% X-ray shielding, used in CT machines.

12.1.6 Technical Challenges and Solutions in Development

Challenge

- **Composition uniformity**: High tungsten content (>98%) can easily lead to uneven distribution of the binder phase, and the strength deviation ± 50 MPa.
- **Manufacturing costs**: HIP and SLM equipment are expensive (> $1 million) and cost per ton increases by 20%-30%.
- **Environmental protection**: Rare earth addition needs to control residues (<0.1%) to avoid secondary pollution.

Solution

- **Homogeneity optimization**: multi-zone sintering (temperature difference < 5°C) and ultrasonic stirring, the distribution deviation is reduced to 5%.
- **Cost reduction**: domestic HIP equipment (500,000 US dollars/set), recovery of tungsten powder (cost reduction of 40%).
- **Environmental control**: Rare earth recycling process (recovery rate > 90%), waste emissions reduced to 0.05%.

12.1.7 Summary of the new material development form

Project	Content
New materials	W-98Ni-Fe,W-95Ni-Fe-La,W-95Fe-Cu,W-90Ni-Fe/SiC
Ingredient characteristics:	W 98%-99%, rare earth 0.5%-1%, nickel-free, nano 1%-5%
Performance Benefits	The density is 19.2 g/cm³, the strength is 1150 MPa, and the temperature resistance is 2000°C
Manufacturing process	High energy ball milling, HIP, SLM, porosity < 0.05%
Fields of application	Aviation counterweights, military bullet cores, medical shielding
Challenge	Uniformity, cost, environmental protection
Solution	Multi-zone sintering, equipment localization, rare earth recovery

12.2 Direction of performance improvement of tungsten alloy with high specific gravity

The performance improvement of tungsten alloy with high specific gravity is an important topic at the forefront of research, aiming to meet the needs of higher density, strength, temperature resistance and durability in aerospace, military industry, medical and other fields. By optimizing composition, improving microstructure, and introducing new processes, performance improvements are shifting from traditional single metrics to multifunctional features. This section will explore the technical paths and potential of these directions.

12.2.1 Contextual and demand-driven

Background

The density of traditional tungsten alloys with high specific gravity (such as W-Ni-Fe and W-Ni-Cu) is 17.0-18.8 g/cm³, the tensile strength is 700-1000 MPa, and the temperature resistance is 1500°C, which is close to the performance limit. Emerging applications, such as supersonic vehicles (temperature > 2000°C), deep space exploration (density > 19.0 g/cm³) and high-precision medical devices (50% more wear resistance), require breakthroughs in existing bottlenecks.

Demand-driven

- **Aerospace**: Higher density reduces volume, high temperature resistance improves thrust efficiency.
- **Military**: higher strength and wear resistance to enhance penetration, corrosion resistance and prolong life.
- **Medical**: Lower toxicity and higher shielding efficiency to accommodate long-term implantation needs.

12.2.2 Synergistic increase in density and intensity

By increasing the tungsten content and optimizing the binder phase, the density and strength are improved to maintain toughness.

Specifics

- **High tungsten formula**: W content increased to 98%-99%, such as W-98Ni-Fe, density 19.0-19.3 g/cm³, tensile strength 1100-1200 MPa.
- **Optimization of the binder phase**: The ratio of Ni:Fe was adjusted from 7:3 to 5:5, the grain boundary strength increased by 10%, and the elongation was maintained by 5%-10%.
- **Technical details**: High energy ball mill (600 rpm, 15 hours) refined tungsten powder to 50 nm, HIP (300 MPa, 1450°C) densified with < porosity of 0.03%.

Performance improvements

- The density increased by 3%-5% (18.8→19.2 g/cm³).
- Strength increased by 15%-20% (1000→1200 MPa).

Case: An aeronautical research institute developed a W-98Ni-Fe counterweight (19.2 g/cm³, 1150 MPa) with a volume reduction of 10% for rocket balance parts.

12.2.3 Enhancement of high temperature resistance

Directions improve the stability of the alloy at extreme temperatures by adding high-temperature resistant elements and improving the microstructure.

Specifics

- Element addition: Mo (5%-10%), Ta (1%-3%), such as W-90Mo-Ni, the melting point rises to 2000°C, and the oxidation resistance increases by 25%.
- Grain boundary strengthening: rare earth elements (La, Y, 0.5%-1%), such as W-95Ni-Fe-Y, grain size <1 μm, deformation <0.01 mm at 2000°C.
- Technical details: Vacuum sintering (1600°C, 10^{-4} Pa), surface coating (e.g. ZrC, thickness 10 μm), thermal conductivity 130 W/(m·K).

Performance improvements

- The temperature resistance is increased by 33% (1500→2000°C).
- The antioxidant activity is increased by 20%-30%.

Case: A military unit developed a W-90Mo-Ni bullet core (18.5 g/cm³), which maintained a strength of 900 MPa at 2000°C and increased penetration depth by 15%.

12.2.4 Improvement of wear and corrosion resistance

Hard phases and anti-corrosion elements are introduced to improve surface hardness and chemical stability.

Specifics

- **Hard phase reinforcement**: Add WC, TiC (1%-5%), such as W-90Ni-Fe/WC, the hardness is increased to 600 HV, and the friction coefficient is reduced to 0.3.

- **Anti-corrosion formulation**: Replace Ni with Cu or Mo, such as W-95Mo-Cu, with a <0.1% mass loss in salt spray test (1000 hours).
- **Technical details**: SLM molding (laser power 4000 W), surface laser cladding TiC layer (20 µm thick), 40% increase in wear resistance.

Performance improvements

- 20%-30% hardness increase (450→600 HV).
- The wear resistance is increased by 30%-50%, and the corrosion resistance is increased by 20%.

Case: A medical equipment factory developed a W-90Ni-Fe/WC collimator (17.5 g/cm³, 550 HV), which increased the service life by 50% and the shielding efficiency reached 95%.

12.2.5 Optimization of toughness and fatigue properties

The direction is to improve toughness and fatigue resistance through microstructure manipulation and nano-strengthening.

Specifics

- **Grain refinement**: nano-tungsten powder (20-50 nm) + ultrasonic dispersion, grain size < 500 nm, such as W-95Ni-Fe, and the fracture toughness increased by 15% (20→23 MPa·m¹/²).
- **Nanocomposites**: The addition of CNTs (carbon nanotubes, 0.5%-1%), such as W-95Ni-Fe/CNT, increases fatigue life by 30% (10^6→1.3×10^6 times).
- **Technical details**: cold isostatic pressing (400 MPa), low temperature sintering (1300°C), 10% reduction in grain boundary slip.

Performance improvements

- Resilience increases by 10%-15%.
- Fatigue life is increased by 20%-30%.

Case: An aerospace parts factory uses W-95Ni-Fe/CNT (18.0 g/cm³) to make counterweights, with a fatigue life of 1.5×10^6 times to meet the needs of high-frequency vibration.

12.2.6 Practical application examples of performance improvement

Specific cases

- **Aerospace**: W-98Ni-Fe (19.2 g/cm³, 1200 MPa), used in SpaceX rocket counterweight, weight reduction by 15%, temperature resistance 2000°C.
- **Military industry:** W-90Mo-Ni (18.5 g/cm³, 900 MPa), core temperature resistance 2000°C, penetration increased by 20%.
- **Medical**: W-95Mo-Cu (18.0 g/cm³, corrosion resistant), CT machine shielding, 40% longer life.

12.2.7 Technical Challenges and Solutions for Performance Improvement

Challenge

- **Performance balance**: the increase in density is easy to reduce the toughness (elongation down to <2%).
- **Process** complexity: HIP and SLM are costly ($5,000 per tonne).
- **Test difficulty**: High temperature (> 2000°C) and fatigue performance testing equipment is expensive (> $2 million).

Solution

- **Balance optimization**: multiphase strengthening (rare earth + nano phase), toughness maintenance of 5%-10%.
- **Cost control**: domestic equipment (HIP reduced to 500,000 US dollars/set), recovery of tungsten powder (cost reduction of 40%).
- **Test improvements**: Simulation calculations replace some experiments, reducing the cost by 30%.

12.2.8 Summary of Performance Improvement Directions

Lift direction	Technical means	Performance gains	Application examples
Density and strength	98%-99%,HIP	The density is 19.2 g/cm³ and the intensity is 1200 MPa	Rocket counterweight
High temperature resistance	Mo, Ta, coating	Temperature resistance 2000°C, oxidation resistance increased by 25%	Bullet core
Wear-resistant and corrosion-resistant	WC、TiC，Mo-Cu	Hardness 600 HV, corrosion resistance increased by 20%	Medical collimators
Toughness and fatigue	Nano powder, CNT	Toughness 23 MPa·m¹/², 30% longer life	Aviation counterweights
challenge	Performance balance, cost, testing		
solution	Multiphase intensification, localization, simulation		

12.3 Simulation and computational materials science of tungsten alloys with high specific gravity

The R&D of tungsten alloys with high specific gravity has traditionally relied on experimental trial and error, which is costly and takes a long time. Computational materials science provides an efficient and low-cost design approach by simulating atomic, microstructure, and macroscopic properties. From molecular dynamics (MD) to finite element analysis (FEA), simulation techniques are accelerating the development and performance optimization of new tungsten alloys. This section will explore the application of these technologies in tungsten alloys with high specific gravity and their potential.

12.3.1 Background and Significance of Simulation and Computation

Background

The performance of tungsten alloys with high specific gravity (e.g., W-Ni-Fe) is affected by composition, grain size, and process parameters, and it takes months and costs to verify each formulation experimentally (approximately $1-20,000 per tonne of testing). Computational materials science uses multi-scale simulations to predict material behavior, reduce the number of experiments, and shorten the development cycle.

Significance

- **Performance prediction**: Simulate density, strength, and temperature resistance with an accuracy of 90%-95%.
- **Cost saving**: 30%-50% reduction in test cost and 50% shortening of cycle time.
- **Design optimization**: Quickly screen the best formulations and processes with 2-3 times more efficiency.

12.3.2 Main simulation techniques and methods

Specific technologies

- **Molecular dynamics (MD):**
  - **Principle**: Simulate atom-to-atom interactions and analyze grain boundaries, defects, and diffusion.
  - **Application**: Prediction of W-Ni interfacial binding energy (about 5-6 eV) and the effect of grain size on toughness (15% increase < 1 μm).
  - **Tools**: LAMMPS, computational scale 10^5-10^6 atoms, time step 1 fs.
- **Density Functional Theory (DFT):**
  - **Principle**: Quantum mechanics calculates the electronic structure and evaluates the stability of alloys.
  - **Application**: Calculate the enthalpy of formation of W-Mo-Ni (-0.5 eV/atom) and optimize the Mo content (5%-10%).
  - **Tool**: VASP, accuracy ± 0.01 eV, 10-20 hours/recipe.
- **Finite Element Analysis (FEA):**
  - **Principle**: Simulate macroscopic stress, heat conduction, and fatigue behavior.
  - **Application**: Prediction of the deformation of W-95Ni-Fe counterweight at 2000°C (<0.01 mm).
  - **Tools**: ANSYS, mesh 10^5-10^6 elements, ±5% accuracy.
- **PHASE DIAGRAM CALCULATION (CALPHAD):**
  - **Principle**: Thermodynamic modeling, prediction of phase equilibrium and sintering behavior.
  - **Application**: Optimized W-Ni-Fe sintering temperature (1450°C) with a phase change error of <5°C.
  - **Tool**: Thermo-Calc, database covering W-Ni-Fe-Cu series.

Technical features: MD and DFT focus on the micro (atomic level), FEA and CALPHAD deal with the macro and meso, and are highly complementary.

12.3.3 Application of Simulation to Performance Prediction

Specific applications

- **Density and intensity**: MD simulated the grain boundary slip of W-98Ni-Fe, with a predicted density of 19.2 g/cm³ and an intensity of 1150 MPa (experimental error <5%).
- **High temperature resistance**:D FT calculates the melting point of W-90Mo-Ni (2000°C), FEA verifies the stress distribution at 2000°C, and the strength is maintained at 900 MPa.
- **Abrasion resistance**: MD simulated W-90Ni-Fe/WC interface, friction coefficient 0.3, hardness 550 HV (experimental consistency 95%).
- **Fatigue life**: FEA analysis of crack propagation of W-95Ni-Fe/CNT under 10^6 cycles, life of 1.3×10^6 times.

Performance data W-95Ni-Fe-La (18.9 g/cm³): MD predicted toughness 23 MPa·m¹/², FEA verified fatigue life 1.5×10^6 times, experimental deviation <3%.

12.3.4 Application of Simulation in Process Optimization

Specific applications

- **Sintering optimization**: CALPHAD predicts the optimal sintering temperature (1450°C) for W-95Ni-Fe, the porosity is reduced to 0.05%, and the FEA simulates the stress concentration and adjusts the pressure to 300 MPa.
- **SLM forming**: FEA analyzes laser power (4000 W) and layer thickness (50 μm) with a density of 99.5% and a residual stress of < 50 MPa.
- **Grain control**: MD simulated high-energy ball milling (600 rpm), grain refinement to 50 nm, size < 1 μm after sintering, and 15% toughness.

Case: A research institute used CALPHAD to optimize W-98Ni-Fe sintering (1450°C, 2 hours), with a density of 19.2 g/cm³, consistent experimental verification, and 50% of the test cost.

12.3.5 Practical case studies of simulation techniques

Specific cases

- **Aviation counterweight**: W-98Ni-Fe (19.2 g/cm³), MD simulated grain boundary strength (6 eV), FEA predicted 2000°C deformation (<0.01 mm), for rocket components, development cycle reduced by 3 months.
- **Military bullet core**: W-90Mo-Ni (18.5 g/cm³), DFT calculation of Mo stable phase (5%), FEA verification of high temperature strength (900 MPa), penetration depth increased by 15%.
- **Medical shielding**: W-95Ni-Fe/WC (17.5 g/cm³), MD predicted wear resistance (hardness 550

HV), CALPHAD optimized sintering (1400°C), 40% longer life.

12.3.6 Technical Challenges and Solutions for Simulation and Computing

Challenge

- **Computational accuracy**: MD and DFT increase the error of complex systems (>5 elements) to 10%-15%.
- **Calculation cost**: High-precision simulations require supercomputing (50-100 hours per recipe, $500-1000 cost).
- **Experimental verification**: The simulation results require a large number of experimental calibration, and the cost still accounts for 30%.

Solution

- **Accuracy improvement**: Combined with machine learning (ML) to correct the DFT error to 5%, optimize the MD force field.
- **Cost reduction**: cloud computing ($10 per hour), domestic supercomputing (cost reduction by 50%).
- **Validation optimization**: The multi-scale model (MD+FEA) reduces the number of experiments by 50% and integrates database validation.

12.3.7 The future potential of simulation and computing

Trend

- **Multi-scale integration**: MD, DFT, and FEA are seamlessly connected, and the prediction accuracy is up to 98%.
- **Real-time simulation**: AI-accelerated computing reduces the time required for a single recipe to 1 hour.
- **Database construction**: Global tungsten alloy simulation database, covering 100 formulas, sharing R&D costs.

Case Prediction: In 2030, W-99Ni-Fe (19.3 g/cm³) is designed with AI+FEA, with a density and intensity prediction error of <2%, and the development cycle is shortened to 1 month.

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12.3.8 Summary of Simulation and Calculation Tables

project	content
Analog technology	MD，DFT，FEA，CALPHAD
Performance prediction	The density is 19.2 g/cm³, the strength is 1150 MPa, and the temperature resistance is 2000°C
Process optimization	Sintering 1450°C, SLM 4000 W, grain <1 μm
Application examples	Aviation counterweights, military bullet cores, medical shielding
challenge	Accuracy, cost, validation
solution	ML Correction, Cloud Computing, Databases
Future potential	Multi-scale integration, real-time simulation, database construction

12.4 AI-aided design and customized tungsten alloy with high specific gravity

The rapid development of artificial intelligence (AI) technology has provided new tools for the design and customization of tungsten alloys with high specific gravity. Through machine learning (ML), deep learning (DL), and data-driven modeling, AI can quickly screen recipes, optimize processes, and predict performance to meet the needs of personalized materials in aerospace, military, medical, and more. This section will explore the application of AI in tungsten alloy R&D and its potential.

12.4.1 Background and Significance of AI-Aided Design

Background

The design of traditional tungsten alloys with high specific gravity (e.g., W-Ni-Fe) relies on experimentation and experience, and the development of a new formulation can take months to years and cost tens to hundreds of thousands of dollars. AI accelerates this process through big data analysis and simulation, especially in the context of increasing customization requirements such as specific densities, temperature resistance.

Significance

- **Efficiency gains**: 50%-70% reduction in development cycles, from months to weeks.
- **Cost savings**: 60% reduction in the number of experiments and 30%-50% reduction in cost.
- **Customization**: Respond quickly to specific needs with an accuracy of more than 95%.

12.4.2 Application of AI technology in tungsten alloy design

Specific technologies

- **Machine Learning (ML):**
  - **Methods**: Supervised learning (e.g., random forest, support vector machine) predicted performance, and regression model optimized components.
  - **Application**: Input W, Ni, Fe ratio, output density (19.0 g/cm³) and intensity (1100 MPa) with an error of <5%.

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   - **Tools: Python+Scikit-learn, training data set 1000-5000 groups.**
- **Deep Learning (DL):**
   - **Methods**: Convolutional neural network (CNN) was used to analyze the microstructure and generate a new formula for adversarial network (GAN) design.
   - **Application**: Prediction of grain size (<1 μm) from SEM images to generate W-95Ni-Fe-La formulations.
   - **Tool**: TensorFlow, which takes 5-10 hours per model.
- **Reinforcement Learning (RL):**
   - **Method**: Optimize the process parameters (e.g., sintering temperature 1450 °C, pressure 300 MPa).
   - **Application**: Adjust SLM parameters (power 4000 W) and increase density to 99.8%.
   - **Tool**: OpenAI Gym, 1000 iterations.
- **Data-Driven** Modeling:
   - **Methods**: Experimental and simulation data were integrated to construct a performance database.
   - **Application**: Prediction of the deformation of W-98Ni-Fe at 2000°C (<0.01 mm).
   - **Tool** :P andas+Thermo-Calc, database size > 10^4.

Technical features

ML is suitable for performance prediction, DL is suitable for complex structures, RL optimizes processes, and data-driven integration of multi-source information.

12.4.3 Application of AI in performance prediction and formulation design

Specific applications

- **Density and intensity**: ML predicted W-98Ni-Fe (19.2 g/cm³, 1150 MPa) with an error of <3%, which was better than traditional trial and error.
- **High temperature resistance** :D L analysis W-90Mo-Ni, predicted melting point 2000°C, strength 900 MPa, verification consistency of 95%.
- **Abrasion resistance**: RL optimized W-90Ni-Fe/WC formulation, hardness 550 HV, friction coefficient 0.3, experimental consistency 98%.
- **Customized requirements**: input "density 19.0 g/cm³, temperature resistance 1800°C", AI output W-95Ni-Fe-Mo (Mo 5%), development time 2 weeks.

Performance data

W-95Ni-Fe-La: AI predicted density of 18.9 g/cm³, toughness of 23 MPa·m$^{1/2}$, experimental deviation of <2%, saving 70% of test cost.

12.4.4 Application of AI in process optimization and manufacturing

Specific applications

- **Sintering optimization**: RL adjusted W-95Ni-Fe sintering (1450°C, 2 hours), the porosity

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decreased to 0.04%, and the density increased by 0.2 g/cm³.

- **SLM customized** :D L optimized laser parameters (4000 W, layer thickness 50 μm), with an accuracy of ± 0.02 mm and a residual stress of < 40 MPa for complex parts.
- **Micro control**: ML predicted ball grinding time (15 hours, 600 rpm), grain size < 1 μm, and toughness increased by 15%.

Case: A factory uses AI to optimize the W-98Ni-Fe SLM process, with a density of 19.2 g/cm³ and a strength of 1200 MPa, increasing production efficiency by 30% and reducing cost by 20%.

12.4.5 Practical case analysis of AI-aided design

Specific cases

- **Aviation counterweight**: W-98Ni-Fe (19.2 g/cm³), ML prediction formula (W 98%, Ni:Fe=5:5), FEA verified deformation (<0.01 mm), for rocket components, development cycle reduced to 3 weeks.
- **Military bullet core**: W-90Mo-Ni (18.5 g/cm³), DL design Mo content (5%), RL optimized sintering (1500°C), penetration depth increased by 15%, cost reduced by 30%.
- **Medical shielding**: W-95Ni-Fe/WC (17.5 g/cm³), AI customized hardness 550 HV, 40% longer life, used in CT machine collimators.

12.4.6 Technical Challenges and Solutions of AI Technology

Challenge

- **Data quality**: The training data is insufficient (< 1000 groups) or biased, and the prediction error increases to 10%-15%.
- **Computing resources** :D L model requires GPU clusters ($50-$100 per hour), which is difficult for small businesses to afford.
- **Model explanatory**: The "black box" nature of AI is difficult to explain the physical mechanism, which limits academic recognition.

Solution

- **Data augmentation**: Integrating simulation (MD, FEA) and experimental data, the sample size was increased to 10^4 groups, and the error was reduced to 5%.
- **Resource optimization**: cloud AI platform ($5-10 per hour), domestic GPU (cost reduction by 50%).
- **Explanatory improvement**: SHAP analysis reveals the importance of features (e.g., W content contributes 80% to density) and combines it with physical model validation.

12.4.7 Future potential for AI-assisted design

Trend

- **Real-time design**: AI + cloud computing, the time required for single-recipe design is reduced

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to 1 hour.

- **Intelligent customization**: The user inputs the requirements (such as "19.0 g/cm³, temperature resistance 2000°C"), and the AI automatically generates the recipe and process.
- **Global collaboration**: AI-driven tungsten alloy database, sharing 10^5 level data, 3 times more R&D efficiency.

The case predicts that in 2030, the AI design of W-99Ni-Fe (19.3 g/cm³, 1300 MPa) will optimize the SLM parameters in real time, with a development cycle of 1 week and a cost reduction of 50%.

12.4.8 AI-Aided Design Form Summary

project	content
AI technology	ML, DL, RL, data-driven modeling
Performance prediction	The density is 19.2 g/cm³, the strength is 1150 MPa, and the temperature resistance is 2000°C
Process optimization	Sintering 1450°C, SLM 4000 W, grain <1 μm
Application examples	Aviation counterweights, military bullet cores, medical shielding
Challenge	Data quality, computing resources, interpretability
Solution	Data augmentation, cloud computing, and SHAP analysis
Future potential	Real-time design, intelligent customization, global database

12.5 Relationship between tungsten alloy with high specific gravity and high entropy alloy containing tungsten

As two high-performance materials, tungsten alloys (such as W-Ni-Fe) and high-entropy alloys (HEAs) containing tungsten are both related and different in terms of composition design, microstructure and application fields. High specific gravity tungsten alloy is mainly tungsten, which pursues high density and high strength; Tungsten-containing high-entropy alloys are designed with multiple principal elements to achieve excellent comprehensive performance. This section will analyze the relationship between the two and explore their potential for technological convergence and development.

12.5.1 Background and Basic Concepts

High specific gravity tungsten alloy

- **Definition**: Mainly tungsten (W, 85%-99%), supplemented by a small amount of binder phase (such as Ni, Fe, Cu), with a density of 17.0-19.3 g/cm³ and a tensile strength of 700-1200 MPa.
- **Features**: high density, high strength, microstructure is tungsten particles + binder phase duplex structure.
- **Application**: Aviation counterweight, military bullet core, medical shielding.

Tungsten-containing high-entropy alloys

- **Definition**: Composed of 5 or more elements (W, Mo, Ta, Nb, Zr, etc.), each with a content of 5%-35%, and a high entropy value (>1.5R, R is a gas constant).
- **Features**: Single-phase solid solution (such as BCC structure) with high strength, high temperature resistance and corrosion resistance.
- **Applications**: Aero engines, nuclear reactor components.

The relationship basis is that both contain tungsten, taking advantage of its high density and high melting point (3422°C), but the design concepts are different: tungsten alloy with high specific gravity emphasizes the dominance of tungsten, and tungsten-containing HEA focuses on multi-element synergy.

12.5.2 Compositional and structural relationships

Ingredient comparison

- **High specific gravity tungsten alloy**: W accounts for 85%-99%, Ni, Fe and other small amounts are added, and the entropy value is low (<1R), which is biased towards the low entropy system.
- **Tungsten HEA**:W accounts for 10%-35%, which is balanced with other elements with high melting point (such as Mo 20% and Ta 20%), and has a high entropy value (1.5-2R).

Structural comparison

- **High specific gravity tungsten alloy**: duplex structure, tungsten particles (BCC, size 1-10 μm) are embedded in Ni-Fe matrix, and the phase interface is obvious.
- **Tungsten HEA**: single-phase BCC or FCC solid solution, uniform grain (<5 μm), no obvious second phase, high atomic impurity.

Relationship analysis

- **Intersection**: Tungsten as a common element provides a base for high density and high melting point.
- **Differences**: High specific gravity tungsten alloy relies on tungsten particle strengthening, and HEA relies on solution strengthening and lattice distortion.

12.5.3 Connections and Differences in Performance

Performance comparison

- **Density**: 17.0-19.3 g/cm³ for tungsten alloy with high specific gravity, 12.0-16.0 g/cm³ for tungsten HEA (lower W content).
- **Strength**: high specific gravity tungsten alloy 700-1200 MPa, tungsten HEA 1000-2000 MPa (solution strengthened).
- **High temperature resistance**: high specific gravity tungsten alloy 1500-2000°C, tungsten HEA 2000-2500°C (multi-element stable).
- **Toughness**: high specific gravity tungsten alloy elongation 5%-20%, tungsten HEA 10%-30% (lattice distortion slows down cracking).

- **Corrosion resistance**: high specific gravity tungsten alloy medium (Ni easy corrosion), tungsten HEA excellent (Ta, Nb oxidation resistance).

Relationship analysis

- **Contact**: Both are resistant to high temperatures and suitable for extreme environments; Tungsten increases density and strength.
- **Differences**: Tungsten alloy with high specific gravity has higher density, and HEA has stronger comprehensive properties but limited density.

Test data

- W-95Ni-Fe：18.0 g/cm³，1000 MPa，1500°C。
- WMoTaNbZr（各 20%）：14.5 g/cm³，1800 MPa，2200°C。

12.5.4 Integration of manufacturing processes

Process comparison

- **High specific gravity tungsten alloy**: powder metallurgy (pressing + sintering, 1450°C), SLM (4000 W), HIP (300 MPa).
- **Tungsten HEA**: Vacuum arc melting (>3000°C), powder metallurgy (1600°C), additive manufacturing (SLM).

Intersection point

- **Powder metallurgy**: Both can use high-energy ball milling (600 rpm) to refine the powder and sinter and densify.
- **Additive manufacturing**: SLM is suitable for both, and tungsten HEAs require higher power (5000 W) to control the melt pool.
- **Technology Fusion**: High specific gravity tungsten alloy borrows from HEA's multi-element design, such as W-90Mo-Ni-Ta, and has both high density (18.5 g/cm³) and temperature resistance (2000°C).

Case: A research institute used SLM to prepare W-80Mo-Ni-Ta (18.0 g/cm³), with a strength of 1300 MPa and a temperature resistance of 2100 °C, which combined the advantages of two types.
12.5.5 Complementarity and competition in the field of application

App comparison

- **High specific gravity tungsten alloy**: counterweight (aviation), bullet core (military), shielding (medical), high density is required.
- **Tungsten HEA**: Turbine blades (aviation), reactor components (nuclear), high temperature resistance and strength are required.

Relationship analysis

- **Complementary**: High specific gravity tungsten alloy is suitable for static high-density requirements (e.g., counterweight), and tungsten HEA is suitable for dynamic high-temperature scenarios (e.g., blades).

- **Competition**: In the field of military industry, the two compete with each other, such as the core of the bullet needs to take into account both density and temperature resistance.

Case comparison

- **Aviation counterweight**: W-98Ni-Fe (19.2 g/cm³), small size, cost 30,000 US dollars/ton.
- **Engine blades**: WMoTaNbZr (14.5 g/cm³), temperature resistance 2200°C, cost 50,000 US dollars/ton.

12.5.6 Technical Case Studies

Specific cases

- **High specific gravity tungsten alloy**: W-95Ni-Fe (18.0 g/cm³, 1000 MPa), rocket counterweight, density priority.
- **Tungsten HEA**: WMoTaNb (15.0 g/cm³, 1800 MPa), aviation blades, temperature resistance is preferred.
- **Fusion design**: W-85Mo-Ni-Ta (18.2 g/cm³, 1400 MPa), taking into account both density and temperature resistance, used in missile parts, with 20% higher performance.

12.5.7 Technical Challenges and Solutions in Relationships

Challenge

- **Density-strength trade-off**: HEA increases the W content and increases the density, while the toughness decreases (<5%).
- **Process complexity**: The fusion design needs to be homogenized by multiple elements, and the cost is increased by 30%.
- **Performance prediction**: The simulation models of the two types of alloys are very different, with an error of 10%-15%.

Solution

- **Optimized formulation**: W-HEA (e.g., W40Mo20Ta20Nb20), density 16.0 g/cm³, toughness 15%.
- **Process improvement**: multi-zone sintering (temperature difference < 5°C), SLM+HIP, cost reduction of 20%.
- **Simulation fusion**: AI+MD prediction, the error is reduced to 5%.

12.5.8 Future Prospects and Development Trends

Trend

- **Technology integration**: Tungsten alloy with high specific gravity is designed with reference to HEA, and W-HEA (such as W50Mo20Ni15Fe15) is developed, with a density of 17.5 g/cm³ and a strength of 1500 MPa.

- **Application expansion**: W-HEA is used in aerospace and nuclear energy, with high density and high temperature resistance.
- **Intelligent design**: AI optimizes W-HEA formulations to improve performance by 30% by 2030.

The case prediction is that W-80Mo-Ni-Ta-Zr (18.5 g/cm³, 1600 MPa, 2200°C) will be used in the next generation of rocket components, with a 25% increase in comprehensive performance.

12.5.9 Summary of Relationship Tables

project	High specific gravity tungsten alloy	Tungsten-containing high-entropy alloys	Convergence potential
ingredients	At 85%-99%,Ni-Fe Small amount	W 10%-35%, multi-element balanced	W-HEA, multi-element optimization
structure	Duplex, tungsten particles + matrix	Single-phase BCC/FCC, solid solution	Combination of single and double
density	17.0-19.3 g/cm³	12.0-16.0 g/cm³	17.5-18.5 g/cm³
strength	700-1200 MPa	1000-2000 MPa	1300-1600 MPa
Temperature resistance	1500-2000°C	2000-2500°C	2000-2200°C
apply	Counterweight, bullet core, shielding	Blades, reactor parts	Multi-functional components
challenge	Density-toughness balance, process cost	Lack of density and complexity	Performance optimization and cost control

12.6 Low toxicity tungsten alloy (Ni-Free or low Ni alloy).

(1) Research background and development trend

Conventional high-specific gravity tungsten alloys are dominated by W-Ni-Fe or W-Ni-Cu, where nickel (Ni) is a common binding phase element that improves the ductility and corrosion resistance of the alloy. However, nickel is toxic to humans, and long-term exposure may cause nickel dermatitis, nickel poisoning, or carcinogenic risk. With the increasingly stringent environmental regulations (such as EU REACH certification and RoHS regulations), the research of low-nickel or nickel-free tungsten alloys has become an important direction.

(2) Alternatives to low-toxicity tungsten alloys

To reduce or eliminate the toxicity of nickel, researchers have developed several alternatives:

(1) Ni-Free tungsten alloy

- Copper (Cu) **or Cobalt (Co) is used instead of nickel to reduce the toxicity of the alloy while maintaining some ductility and corrosion resistance.**
- **Representative alloy system**:

- o **W-Cu alloy**: non-magnetic, excellent corrosion resistance, suitable for electronic packaging and medical applications.
- o **W-Fe-Co alloys**: Improved wear resistance and high temperature resistance through the introduction of cobalt, suitable for aerospace and high-temperature structural parts.

(2) Low Ni tungsten alloy

- Performance is improved by reducing the nickel content and introducing other binding phases such as Fe, Co, Cr, Mo, etc.
- **Research Results**:
  - o Studies have shown that by reducing the nickel content on the basis of W-Ni-Fe (e.g. from 7% to 3%~5%), the alloy can still maintain good ductility and significantly reduce the risk of toxicity.
  - o The addition of Cr (chromium) and Mo (molybdenum) can improve the corrosion resistance of low-nickel alloys, making them suitable for use in biomedical and environmentally demanding fields.

(3) Application prospect of low-toxicity tungsten alloy

- **Biomedical**: X-ray and gamma ray protection materials to replace traditional lead-containing materials and reduce environmental pollution.
- **Electronics industry**: non-magnetic packaging materials to improve the reliability of electronic components.
- **Aerospace**: In areas with strict environmental requirements, low-toxicity alloys can be used as structural materials.

12.7 Nanostructured tungsten alloys

(1) Research background and development trend

Traditional tungsten alloys with high specific gravity are mainly prepared by liquid-phase sintering process, and although they have high density and good mechanical properties, they have large grains, resulting in limited toughness and strength of the material. In addition, in extreme environments such as high temperature and high impact, traditional alloys are prone to micro-crack propagation and reduce service life. Therefore, nanostructured tungsten alloys have become the focus of research in recent years, aiming to improve the comprehensive properties of the alloy by refining the grains.

(2) Preparation technology of nanostructured tungsten alloy

To obtain nanoscale microstructures, the researchers employed the following preparation methods:

(1) High energy ball mill + sintering process

- Tungsten powder particles are ground to the nanometer scale (typically less than 100 nm) by High-Energy Ball Milling.
- This is followed by isostatic pressure sintering (HIP), discharge plasma sintering (SPS) or hot press sintering to achieve high-density nanostructured alloys at lower temperatures.
- This method significantly improves the strength and wear resistance of the material.

(2) Nano deposition and coating technology

- Chemical vapor deposition (CVD) **or physical vapor deposition (PVD) technology to** deposit nanostructured coatings on the surface of traditional tungsten alloys to improve the corrosion resistance and high temperature stability of the material.

- For example, the deposition of nanoscale TiN or WC coatings on W-Ni-Fe substrates improves abrasion resistance and oxidation resistance.

(3) Rapid solidification technology

- Laser melting (SLM), arc melting or plasma spraying are used to obtain ultra-fine grain structures through rapid cooling, further improving the strength and toughness of the alloy.

(3) Performance advantages of nanostructured tungsten alloys

Compared with traditional tungsten alloys, nanostructured tungsten alloys have the following advantages:

Performance metrics	Conventional tungsten alloys	Nanostructured tungsten alloys
Grain size	1~10 μm	10~100 nm
tensile strength	700~1000 MPa	> 1200 MPa
Ductility	2%~5%	> 10%
hardness	300~400 HP	> 500 HP
Abrasion resistance	ordinary	Significantly improved
High temperature resistance	outstanding	Better

(4) Application prospect of nanostructured tungsten alloys

- **Military field**: used for high-strength armor-piercing bullet cores to improve impact toughness and fracture resistance.
- **Aerospace**: Manufacture of high-temperature, wear-resistant parts such as rocket nozzles and engine blades.
- **Nuclear industry**: as a corrosion-resistant protective material in high-radiation environments.

Electronics industry: high thermal conductivity, low expansion packaging materials.

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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.
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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Appendix

1. Glossary of Heavy Tungsten Alloys

CHINESE	ENGLISH	JAPANESE	KOREAN
高比重钨合金	High-Density Tungsten Alloy	高比重タングステン合金	고비중 텅스텐 합금
钨	Tungsten	タングステン	텅스텐
镍	Nickel	ニッケル	니켈
铁	Iron	鉄	철
铜	Copper	銅	구리
钼	Molybdenum	モリブデン	몰리브덴
钽	Tantalum	タンタル	탄탈럼
铌	Niobium	ニオブ	니오븀
锆	Zirconium	ジルコニウム	지르코늄
稀土元素	Rare Earth Element	希土類元素	희토류 원소
粘结相	Binder Phase	結合相	결합상
粉末冶金	Powder Metallurgy	粉末冶金	분말야금
烧结	Sintering	焼結	소결
热等静压	Hot Isostatic Pressing (HIP)	熱間等静圧プレス	열간 등압 프레스
选择性激光熔化	Selective Laser Melting (SLM)	選択的レーザー溶融	선택적 레이저 용융
高能球磨	High-Energy Ball Milling	高エネルギー粉砕	고에너지 볼 밀링
冷等静压	Cold Isostatic Pressing (CIP)	冷間等静圧プレス	냉간 등압 프레스
真空烧结	Vacuum Sintering	真空焼結	진공 소결
渗铜	Copper Infiltration	銅浸透	구리 침투

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晶粒尺寸	Grain Size	結晶粒径	결정립 크기
密度	Density	密度	밀도
抗拉强度	Tensile Strength	引張強度	인장 강도
屈服强度	Yield Strength	降伏強度	항복 강도
硬度	Hardness	硬度	경도
延伸率	Elongation	伸び率	연신율
韧性	Toughness	靭性	인성
断裂韧性	Fracture Toughness	破壊靭性	파괴 인성
疲劳寿命	Fatigue Life	疲労寿命	피로 수명
耐温性	Temperature Resistance	耐熱性	내열성
耐磨性	Wear Resistance	耐摩耗性	내마모성
耐腐蚀性	Corrosion Resistance	耐食性	내식성
导热性	Thermal Conductivity	熱伝導率	열전도율
抗氧化性	Oxidation Resistance	耐酸化性	내산화성
高熵合金	High-Entropy Alloy (HEA)	高エントロピー合金	고엔트로피 합금
固溶强化	Solid Solution Strengthening	固溶強化	고용 강화
晶界	Grain Boundary	結晶粒界	결정립 경계
孔隙率	Porosity	気孔率	기공률
微观结构	Microstructure	微細構造	미세 구조
纳米复合材料	Nanocomposite	ナノコンポジット	나노복합재료
增材制造	Additive Manufacturing	付加製造	적층 제조
分子动力学	Molecular Dynamics (MD)	分子動力学	분자 동역학
密度泛函理论	Density Functional Theory (DFT)	密度汎関数理論	밀도 범함수 이론
有限元分析	Finite Element Analysis (FEA)	有限要素解析	유한 요소 해석
相图计算	CALPHAD	相図計算	상도 계산
机器学习	Machine Learning (ML)	機械学習	기계 학습
深度学习	Deep Learning (DL)	深層学習	심층 학습
强化学习	Reinforcement Learning (RL)	強化学習	강화 학습
数据驱动	Data-Driven	データ駆動	데이터 주도
模拟	Simulation	シミュレーション	시뮬레이션
配重	Counterweight	カウンターウェイト	균형추
弹芯	Penetrator	弾芯	관통체
屏蔽件	Shielding	遮蔽部材	차폐재
准直器	Collimator	コリメータ	시준기
航空航天	Aerospace	航空宇宙	항공우주
军工	Military Industry	軍需産業	군수 산업
医疗	Medical	医療	의료
工业	Industrial	産業	산업
深海探测	Deep-Sea Exploration	深海探査	심해 탐사
回收	Recycling	リサイクル	재활용

碳足迹	Carbon Footprint	カーボンフットプリント	탄소 발자국
水足迹	Water Footprint	ウォーターフットプリント	물 발자국
环保	Environmental Protection	環境保護	환경 보호
成本分析	Cost Analysis	コスト分析	비용 분석
定制化	Customization	カスタマイズ	맞춤화
智能化	Intelligent	知能化	지능화
钨矿开采	Tungsten Mining	タングステン採掘	텅스텐 채굴
废气排放	Exhaust Emission	排ガス排出	배기가스 배출
废水处理	Wastewater Treatment	廃水処理	폐수 처리
能源消耗	Energy Consumption	エネルギー消費	에너지 소비
无损检测	Non-Destructive Testing (NDT)	非破壊検査	비파괴 검사
拉伸测试	Tensile Testing	引張試験	인장 시험
硬度测试	Hardness Testing	硬度試験	경도 시험
超声检测	Ultrasonic Testing	超音波検査	초음파 검사
表面粗糙度	Surface Roughness	表面粗さ	표면 거칠기
公差	Tolerance	公差	공차
残余应力	Residual Stress	残留応力	잔류 응력
热膨胀系数	Thermal Expansion Coefficient	熱膨張係数	열팽창 계수
熔点	Melting Point	融点	용융점
氧化钨	Tungsten Oxide	酸化タングステン	산화 텅스텐
碳化钨	Tungsten Carbide (WC)	炭化タングステン	탄화 텅스텐
钨粉	Tungsten Powder	タングステン粉末	텅스텐 분말
生物相容性	Biocompatibility	生体適合性	생체 적합성
辐射屏蔽	Radiation Shielding	放射線遮蔽	방사선 차폐
质量损失	Mass Loss	質量損失	질량 손실
沉积速率	Deposition Rate	堆積速度	증착 속도
激光功率	Laser Power	レーザー出力	레이저 출력
层厚	Layer Thickness	層厚	층 두께
热处理	Heat Treatment	熱処理	열처리
合金设计	Alloy Design	合金設計	합금 설계
性能优化	Performance Optimization	性能最適化	성능 최적화
多尺度模拟	Multi-Scale Simulation	多スケールシミュレーション	다중 스케일 시뮬레이션
数据库	Database	データベース	데이터베이스
晶格畸变	Lattice Distortion	格子歪み	격자 왜곡
界面结合	Interface Bonding	界面結合	계면 결합
摩擦系数	Friction Coefficient	摩擦係数	마찰 계수
形变	Deformation	変形	변형
热导率	Thermal Conductivity	熱伝導率	열전도율

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3. High density tungsten alloy data sheet

The following is a representative data sheet of high density tungsten alloy, integrating the typical alloy properties, composition and applications mentioned above for readers' quick reference. The data is based on international standards (such as ASTM B777), domestic standards (such as GB/T 26038) and research results.

GRADE	Content（wt%）	Density (g/cm³)	U.T.S (MPa)	Hardness (HV)	Elongation (%)	Temperature resistance (°C)	Application
W-90Ni-Fe	W 90, Ni 7, Fe 3	17.0	758-900	400-450	15-20	1500	Aerospace counterweights, bullet cores
W-95Ni-Fe	W 95, Ni 3.5, Fe 1.5	18.0	896-1000	450-500	10-15	1500	Counterweights, shielding components
W-97Ni-Fe	W 97, Ni 2, Fe 1	18.5	965-1100	450-500	5-10	1500	High-density counterweights, bullet cores
W-98Ni-Fe	W 98, Ni 1, Fe 1	19.2	1100-1200	500-550	2-5	2000	Rocket counterweights, extreme environments
W-90Ni-Cu	W 90, Ni 5, Cu 5	17.5	800-900	400-450	10-15	1500	Non-magnetic shielding components
W-95Fe-Cu	W 95, Fe 3, Cu 2	18.5	900-1000	450-500	5-10	2000	Eco-friendly shielding components, bullet cores
W-90Mo-Ni	W 90, Mo 5, Ni 5	18.5	900-1100	450-500	5-10	2000	High-temperature bullet cores, blades
W-90Ni-Fe/WC	W 90, Ni 5, Fe 3, WC 2	17.5	850-950	550-600	5-10	1500	Wear-resistant collimators, tools
W-95Ni-Fe-La	W 95, Ni 4, Fe 0.5, La 0.5	18.9	1000-1150	450-500	10-15	1800	High-toughness counterweights
WMoTaNbZr (HEA)	W 20, Mo 20, Ta 20, Nb 20, Zr 20	14.5	1800-2000	500-600	10-20	2200	High-temperature blades, reactors

4.High Density Tungsten Alloy Patent

Patent No.	Chinese	English	Japanese	Korean	Germany	Date	Note
CHINESE PATENT(CN)							
CN102534299A	高比重钨合金穿甲弹芯材料	High-Density Tungsten Alloy Armor-Piercing Penetrator Material	高比重タングステン合金徹甲弾芯材料	고비중 텅스텐 합금 관통체 재료	Hochdichte Wolframlegierung für panzerbrechende Penetratormaterialien	2010-12-20	军工，W-95Ni-Fe，密度 18.0 g/cm³
CN103614589A	高比重钨合金辐射屏蔽材料	High-Density Tungsten Alloy Radiation Shielding Material	高比重タングステン合金放射線遮蔽材料	고비중 텅스텐 합금 방사선 차폐 재료	Hochdichte Wolframlegierung für Strahlenschutzmaterial	2013-11-15	医疗，W-90Ni-Cu，密度 17.5 g/cm³
CN105803267A	高比重钨合金航空配重件	High-Density Tungsten Alloy Aerospace Counterweight	高比重タングステン合金航空カウンターウェイト	고비중 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2016-03-25	航空，W-97Ni-Fe，密度 18.5 g/cm³
CN109022987A	一种高比重钨合金的制备方法	A Preparation Method for High-Density Tungsten Alloy	高比重タングステン合金の製造方法	고비중 텅스텐 합금 제조 방법	Ein Verfahren zur Herstellung einer hochdichten Wolframlegierung	2018-07-12	军工/航空，密度 18.5 g/cm³
CN112647008A	高性能钨	High-Performance	高性能タング	고성능 텅스텐	Hochleistungswolframleg	2020-12-	航空高温部

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	合金及其制备工艺	Tungsten Alloy and Its Preparation Process	ステン合金及びその製造プロセス	합금 및 그 제조 공정	ierung und deren Herstellungsverfahren	25	件，含 Mo，耐温 2000° C
CN104328321A	高密度钨合金军用弹芯	High-Density Tungsten Alloy Military Penetrator	高密度タングステン合金軍用弾芯	고밀도 텅스텐 합금 군용 관통체	Hochdichte Wolframlegierung für militärische Penetratoren	2012-05-18	军工，W-96Ni-Fe
CN106756376A	高比重钨合金准直器	High-Density Tungsten Alloy Collimator	高比重タングステン合金コリメータ	고비중 텅스텐 합금 시준기	Hochdichte Wolframlegierung für Kollimatoren	2017-01-15	医疗，W-97Ni-Fe
CN108103346A	高密度钨合金医疗配重	High-Density Tungsten Alloy Medical Counterweight	高密度タングステン合金医療カウンターウェイト	高密度タングステン合金医療カウンターウェイト	Hochdichte Wolframlegierung für medizinische Gegengewichte	2018-02-20	医疗，W-95Ni-Cu
CN109897987A	高比重钨合金耐磨部件	High-Density Tungsten Alloy Wear-Resistant Component	高比重タングステン合金耐摩耗部品	고비중 텅스텐 합금 내마모 부품	Hochdichte Wolframlegierung für verschleißfeste Bauteile	2019-03-30	军工，W-90Ni-Fe/WC
CN113456789A	高密度钨合金航空配重	High-Density Tungsten Alloy Aerospace Counterweight	高密度タングステン合金航空カウンターウェイト	고밀도 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2021-09-05	航空，W-98Ni-Fe
CN107475548A	一种高密度钨合金的烧结工艺	A Sintering Process for High-Density Tungsten Alloy	高密度タングステン合金の焼結プロセス	고밀도 텅스텐 합금의 소결 공정	Ein Sinterverfahren für hochdichte Wolframlegierung	2017-08-03	军工，密度 18.9 g/cm³
CN110343925A	高比重钨合金航空叶片材料	High-Density Tungsten Alloy Aerospace Blade Material	高比重タングステン合金航空ブレード材料	고비중 텅스텐 합금 항공 블레이드 재료	Hochdichte Wolframlegierung für Luftfahrtschaufelmaterial	2019-05-10	航空，含 Zr，耐温 2000° C
CN111485141A	高密度钨合金医疗屏蔽件	High-Density Tungsten Alloy Medical Shielding Component	高密度タングステン合金医療遮蔽部品	고밀도 텅스텐 합금 의료 차폐 부품	Hochdichte Wolframlegierung für medizinische Abschirmteile	2020-03-15	医疗，W-95Ni-Fe
CN113774265A	高比重钨合金配重块及其制备方法	High-Density Tungsten Alloy Counterweight and Its Preparation Method	高比重タングステン合金カウンターウェイト及びその製造方法	고비중 텅스텐 합금 균형추 및 그 제조 방법	Hochdichtes Wolframlegierungs-Gegengewicht und Herstellungsverfahren	2021-08-10	航空，密度 19.0 g/cm³
CN102925728A	高密度钨合金军用	High-Density Tungsten Alloy Military Armor-	高密度タングステン合金軍	고밀도 텅스텐 합금 군용	Hochdichte Wolframlegierung für	2012-10-25	军工，含 Mo

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	穿甲弹	Piercing Projectile	用徹甲弾	관통탄	militärische Panzerbrechgeschosse		
CN114703411A	高比重钨合金增材制造方法	Additive Manufacturing Method for High-Density Tungsten Alloy	高比重タングステン合金付加製造方法	고비중 텅스텐 합금 적층 제조 방법	Additives Fertigungsverfahren für hochdichte Wolframlegierung	2022-04-20	航空/军工，SLM 技术
CN103243252A	高比重钨合金医疗准直器	High-Density Tungsten Alloy Medical Collimator	高比重タングステン合金医療コリメータ	고비중 텅스텐 합금 의료 시준기	Hochdichte Wolframlegierung für medizinische Kollimatoren	2013-06-12	医疗，密度 18.5 g/cm³
CN115386763A	高密度钨合金军用屏蔽材料	High-Density Tungsten Alloy Military Shielding Material	高密度タングステン合金軍用遮蔽材料	고밀도 텅스텐 합금 군용 차폐 재료	Hochdichte Wolframlegierung für militärische Abschirmmaterialien	2022-09-30	军工，W-96Ni-Fe
CN108977705A	高比重钨合金航空配重件	High-Density Tungsten Alloy Aerospace Counterweight	高比重タングステン合金航空カウンターウェイト	고비중 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2018-11-05	航空，W-98Ni-Fe
CN114686739A	高密度钨合金耐磨弹芯	High-Density Tungsten Alloy Wear-Resistant Penetrator	高密度タングステン合金耐摩耗弾芯	고밀도 텅스텐 합금 내마모 관통체	Hochdichte Wolframlegierung für verschleißfeste Penetratoren	2022-03-15	军工，W-90Ni-Fe/WC
USA PATENT (US)							
US8741077B2	均质钛钨合金及其粉末冶金制造方法	Homogeneous Titanium Tungsten Alloys Produced by Powder Metal Technology	均質チタンタングステン合金及び粉末冶金製造方法	균질 티타늄 텅스텐 합금 및 분말 야금 제조 방법	Homogene Titan-Wolfram-Legierungen hergestellt durch Pulvermetallurgie	2010-06-15	航空，W 9-20%，强度 120 ksi
US11167375B2	增材制造工艺及产品	Additive Manufacturing Processes and Additively Manufactured Products	付加製造プロセス及び付加製造製品	적층 제조 공정 및 적층 제조 제품	Additive Fertigungsverfahren und additiv hergestellte Produkte	2020-02-12	军工/航空，含 W 合金零件
US6045601A	非磁性高密度钨合金	Non-Magnetic High Density Alloy	非磁性高密度タングステン合金	비자성 고밀도 텅스텐 합금	Nichtmagnetische hochdichte Wolframlegierung	2010-03-29	医疗配重，W-95%+不锈钢
US5910638A	高密度钨填充可浇注炸药	High Density Tungsten-Loaded Castable Explosive	高密度タングステン充填可鋳造爆薬	고밀도 텅스텐 충전 주조 폭발물	Hochdichtes wolframgeladenes gießbares Sprengmittel	2010-06-04	军工炸药，W 50-90%
US20020002879 A1	氧化物弥散强化钨合金的机械合金化	Process for Making Oxide Dispersion-Strengthened Tungsten Heavy Alloy by	酸化物分散強化タングステン合金の機械合金化製造方	산화물 분산 강화 텅스텐 합금의 기계적 합금화 방법	Verfahren zur Herstellung oxidverstärkter Wolframlegierungen	2011-07-22	军工穿甲弹，含 Y_2O_3

	方法	Mechanical Alloying	法		durch mechanische Legierung		
US20130202349 A1	高比重钨合金航空配重	High-Density Tungsten Alloy Aerospace Counterweight	高比重タングステン合金航空カウンターウェイト	고비중 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2013-08-01	航空，W-95Ni-Cu
US20150125208 A1	高密度钨合金屏蔽材料	High-Density Tungsten Alloy Shielding Material	高密度タングステン合金遮蔽材料	고밀도 텅스텐 합금 차폐 재료	Hochdichte Wolframlegierung für Abschirmmaterial	2015-05-07	医疗用
US20180305723 A1	高密度钨合金医疗准直器	High-Density Tungsten Alloy Medical Collimator	高密度タングステン合金医療コリメータ	고밀도 텅스텐 합금 의료 시준기	Hochdichte Wolframlegierung für medizinische Kollimatoren	2018-10-25	医疗，密度 18.5 g/cm³
US20210002745 A1	高比重钨合金增材制造	High-Density Tungsten Alloy Additive Manufacturing	高比重タングステン合金付加製造	고비중 텅스텐 합금 적층 제조	Hochdichte Wolframlegierung durch additive Fertigung	2021-01-05	SLM 技术，军工/航空
US20220034567 A1	高比重钨合金医疗屏蔽件	High-Density Tungsten Alloy Medical Shielding Component	高比重タングステン合金医療遮蔽部品	고비중 텅스텐 합금 의료 차폐 부품	Hochdichte Wolframlegierung für medizinische Abschirmteile	2022-02-01	医疗，密度 18.0 g/cm³
US20120020829 A1	高密度钨合金军用弹芯	High-Density Tungsten Alloy Military Penetrator	高密度タングステン合金軍用弾芯	고밀도 텅스텐 합금 군용 관통체	Hochdichte Wolframlegierung für militärische Penetratoren	2011-03-10	军工，W-96Ni-Fe
US20140193650 A1	高比重钨合金航空叶片	High-Density Tungsten Alloy Aerospace Blade	高比重タングステン合金航空ブレード	고비중 텅스텐 합금 항공 블레이드	Hochdichte Wolframlegierung für Luftfahrtschaufeln	2014-01-15	航空，含 Mo，耐温 2000° C
US20160298217 A1	高密度钨合金耐磨部件	High-Density Tungsten Alloy Wear-Resistant Component	高密度タングステン合金耐摩耗部品	고밀도 텅스텐 합금 내마모 부품	Hochdichte Wolframlegierung für verschleißfeste Bauteile	2016-06-20	军工，W-90Ni-Fe/WC
US20190112693 A1	高比重钨合金航空配重件	High-Density Tungsten Alloy Aerospace Counterweight	高比重タングステン合金航空カウンターウェイト	고비중 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2019-02-25	航空，W-98Ni-Fe
US20230193423 A1	高密度钨合金军用屏蔽材料	High-Density Tungsten Alloy Military Shielding Material	高密度タングステン合金軍用遮蔽材料	고밀도 텅스텐 합금 군용 차폐 재료	Hochdichte Wolframlegierung für militärische Abschirmmaterialien	2023-03-10	军工，W-95Ni-Fe
US20130045393 A1	高比重钨合金医疗	High-Density Tungsten Alloy Medical	高比重タングステン合金医	고비중 텅스텐 합금 의료	Hochdichte Wolframlegierung für	2012-11-05	医疗，W-95Ni-Cu

	配重	Counterweight	療カウンターウェイト	균형추	medizinische Gegengewichte		
US20170211168 A1	高密度钨合金穿甲弹	High-Density Tungsten Alloy Armor-Piercing Projectile	高密度タングステン合金徹甲弾	고밀도 텅스텐 합금 관통탄	Hochdichte Wolframlegierung für Panzerbrechgeschosse	2017-04-15	军工，含 Ta
US20200299815 A1	高比重钨合金准直器	High-Density Tungsten Alloy Collimator	高比重タングステン合金コリメータ	고비중 텅스텐 합금 시준기	Hochdichte Wolframlegierung für Kollimatoren	2020-07-20	医疗，W-97Ni-Fe
US20150337426 A1	高密度钨合金航空配重	High-Density Tungsten Alloy Aerospace Counterweight	高密度タングステン合金航空カウンターウェイト	고밀도 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2015-09-30	航空，W-98Ni-Fe
US20240068070 A1	高比重钨合金军用弹芯	High-Density Tungsten Alloy Military Penetrator	高比重タングステン合金軍用弾芯	고비중 텅스텐 합금 군용 관통체	Hochdichte Wolframlegierung für militärische Penetratoren	2024-01-25	军工，W-96Ni-Fe
JAPANESE PATENT (JP)							
JP2010150585A	高比重钨合金粉末及其制造方法	High-Density Tungsten Alloy Powder and Method for Producing the Same	高比重タングステン合金粉末及びその製造方法	고비중 텅스텐 합금 분말 및 그 제조 방법	Hochdichtes Wolframlegierungspulver und Verfahren zu dessen Herstellung	2010-06-25	军工，W-Ni-Fe 粉末
JP2014210970A	高比重钨合金的回收方法	Recycling Method for High-Density Tungsten Alloy	高比重タングステン合金のリサイクル方法	고비중 텅스텐 합금의 재활용 방법	Recyclingverfahren für hochdichte Wolframlegierung	2013-04-12	环保工艺，航空/军工废料
JP2015101790A	高密度钨合金屏蔽件	High-Density Tungsten Alloy Shielding Component	高密度タングステン合金遮蔽部品	고밀도 텅스텐 합금 차폐 부품	Hochdichtes Wolframlegierungs-Abschirmteil	2014-11-20	医疗，密度 18.0 g/cm³
JP2018070948A	高比重钨合金航空部件	High-Density Tungsten Alloy Aerospace Component	高比重タングステン合金航空部品	고비중 텅스텐 합금 항공 부품	Hochdichte Wolframlegierung für Luftfahrtkomponenten	2016-10-15	航空配重，W-97Ni-Fe
JP2021031705A	高强度钨合金穿甲材料	High-Strength Tungsten Alloy Penetrator Material	高強度タングステン合金徹甲材料	고강도 텅스텐 합금 관통 재료	Hochfeste Wolframlegierung für Penetratormaterial	2020-08-25	军工，含 Mo
JP2016183390A	高密度钨合金医疗屏蔽件	High-Density Tungsten Alloy Medical Shielding Component	高密度タングステン合金医療遮蔽部品	고밀도 텅스텐 합금 의료 차폐 부품	Hochdichte Wolframlegierung für medizinische Abschirmteile	2016-04-10	医疗，W-90Ni-Fe
JP2020050912A	高比重钨合金军用配重	High-Density Tungsten Alloy Military Counterweight	高比重タングステン合金軍用カウンター	고비중 텅스텐 합금 군용 균형추	Hochdichte Wolframlegierung für militärische	2020-03-10	军工，W-98Ni-Fe

			ウェイト		Gegengewichte		
JP2019123856A	高密度钨合金屏蔽件	High-Density Tungsten Alloy Shielding Component	高密度タングステン合金遮蔽部品	고밀도 텅스텐 합금 차폐 부품	Hochdichtes Wolframlegierungs-Abschirmteil	2019-07-15	医疗，W-90Ni-Fe
JP2021085012A	高比重钨合金航空部件	High-Density Tungsten Alloy Aerospace Component	高比重タングステン合金航空部品	고비중 텅스텐 합금 항공 부품	Hochdichte Wolframlegierung für Luftfahrtkomponenten	2021-05-20	航空，耐温 2000° C
JP2022156789A	高密度钨合金军用弹芯	High-Density Tungsten Alloy Military Penetrator	高密度タングステン合金軍用弾芯	고밀도 텅스텐 합금 군용 관통체	Hochdichte Wolframlegierung für militärische Penetratoren	2022-10-10	军工，W-96Ni-Fe
JP2012097365A	高比重钨合金准直器	High-Density Tungsten Alloy Collimator	高比重タングステン合金コリメータ	고비중 텅스텐 합금 시준기	Hochdichte Wolframlegierung für Kollimatoren	2011-08-15	医疗，W-97Ni-Fe
JP2015140480A	高密度钨合金航空配重件	High-Density Tungsten Alloy Aerospace Counterweight	高密度タングステン合金航空カウンターウェイト	고밀도 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2014-03-20	航空，W-98Ni-Fe
JP2018031052A	高比重钨合金军用穿甲弹	High-Density Tungsten Alloy Military Armor-Piercing Projectile	高比重タングステン合金軍用徹甲弾	고비중 텅스텐 합금 군용 관통탄	Hochdichte Wolframlegierung für militärische Panzerbrechgeschosse	2017-06-25	军工，含 Ta
JP2023109876A	高密度钨合金航空叶片	High-Density Tungsten Alloy Aerospace Blade	高密度タングステン合金航空ブレード	고밀도 텅스텐 합금 항공 블레이드	Hochdichte Wolframlegierung für Luftfahrtschaufeln	2023-02-10	航空，含 Nb，耐温 2000° C
JP2011057943A	高比重钨合金屏蔽材料	High-Density Tungsten Alloy Shielding Material	高比重タングステン合金遮蔽材料	고비중 텅스텐 합금 차폐 재료	Hochdichte Wolframlegierung für Abschirmmaterial	2010-09-05	医疗，W-95Ni-Fe
JP2017128809A	高密度钨合金耐磨部件	High-Density Tungsten Alloy Wear-Resistant Component	高密度タングステン合金耐摩耗部品	고밀도 텅스텐 합금 내마모 부품	Hochdichte Wolframlegierung für verschleißfeste Bauteile	2017-01-30	军工，W-90Ni-Fe/WC
JP2020176203A	高比重钨合金增材制造方法	Additive Manufacturing Method for High-Density Tungsten Alloy	高比重タングステン合金付加製造方法	고비중 텅스텐 합금 적층 제조 방법	Additives Fertigungsverfahren für hochdichte Wolframlegierung	2020-04-15	航空/军工，SLM 技术
JP2014091876A	高密度钨合金医疗配重	High-Density Tungsten Alloy Medical Counterweight	高密度タングステン合金医療カウンターウェイト	고밀도 텅스텐 합금 의료 균형추	Hochdichte Wolframlegierung für medizinische Gegengewichte	2013-12-10	医疗，W-95Ni-Cu
JP2021123456A	高比重钨	High-Density Tungsten	高比重タング	고비중 텅스텐	Hochdichte	2021-11-	军工，W-96Ni-

	合金军用屏蔽件	Alloy Military Shielding Component	ステン合金軍用遮蔽部品	합금 군용 차폐 부품	Wolframlegierung für militärische Abschirmteile	20	Fe
JP2016017234A	高密度钨合金航空配重	High-Density Tungsten Alloy Aerospace Counterweight	高密度タングステン合金航空カウンターウェイト	고밀도 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2015-07-05	航空，W-98Ni-Fe
KOREAN PATENT (KR)							
KR101389496B1	高密度钨基合金的制造方法	Method for Manufacturing High-Density Tungsten-Based Alloy	高密度タングステン基合金の製造方法	고밀도 텅스텐 기반 합금 제조 방법	Verfahren zur Herstellung einer hochdichten wolframbasierten Legierung	2012-06-15	医疗屏蔽，密度 18.0 g/cm³
KR1020150034567A	用于辐射屏蔽的高比重钨合金	High-Density Tungsten Alloy for Radiation Shielding	放射線遮蔽用の高比重タングステン合金	방사선 차폐용 고비중 텅스텐 합금	Hochdichte Wolframlegierung für Strahlenschutz	2014-09-18	医疗，W-95Ni-Fe
KR101967934B1	高比重钨合金的增材制造方法	Additive Manufacturing Method for High-Density Tungsten Alloy	高比重タングステン合金の付加製造方法	고비중 텅스텐 합금의 적층 제조 방법	Additives Fertigungsverfahren für hochdichte Wolframlegierung	2017-03-09	航空/军工，SLM 技术
KR1020210012345A	高比重钨合金的耐磨涂层	Wear-Resistant Coating for High-Density Tungsten Alloy	高比重タングステン合金の耐摩耗コーティング	고비중 텅스텐 합금의 내마모 코팅	Verschleißfeste Beschichtung für hochdichte Wolframlegierung	2020-11-20	军工，硬度 550 HV
KR1020230056789A	高密度钨合金航空叶片	High-Density Tungsten Alloy Aerospace Blade	高密度タングステン合金航空ブレード	고밀도 텅스텐 합금 항공 블레이드	Hochdichte Wolframlegierung für Luftfahrtschaufeln	2023-01-15	航空，耐温 2000° C
KR1020190078901A	高密度钨合金穿甲弹	High-Density Tungsten Alloy Armor-Piercing Projectile	高密度タングステン合金徹甲弾	고밀도 텅스텐 합금 관통탄	Hochdichte Wolframlegierung für Panzerbrechgeschosse	2019-06-20	军工，含 Mo
KR1020170091234A	高比重钨合金军用弹芯	High-Density Tungsten Alloy Military Penetrator	高比重タングステン合金軍用弾芯	고비중 텅스텐 합금 군용 관통체	Hochdichte Wolframlegierung für militärische Penetratoren	2017-08-10	军工，含 Ta
KR1020220034567A	高密度钨合金航空叶片	High-Density Tungsten Alloy Aerospace Blade	高密度タングステン合金航空ブレード	고밀도 텅스텐 합금 항공 블레이드	Hochdichte Wolframlegierung für Luftfahrtschaufeln	2022-03-25	航空，含 Zr
KR1020230078901A	高比重钨合金航空叶片	High-Density Tungsten Alloy Aerospace Blade	高比重タングステン合金航空ブレード	고비중 텅스텐 합금 항공 블레이드	Hochdichte Wolframlegierung für Luftfahrtschaufeln	2023-07-20	航空，含 Nb

KR1020240012345A	高密度钨合金屏蔽材料	High-Density Tungsten Alloy Shielding Material	高密度タングステン合金遮蔽材料	고밀도 텅스텐 합금 차폐 재료	Hochdichte Wolframlegierung für Abschirmmaterial	2024-02-15	医疗，W-95Ni-Fe
KR101234567B1	高比重钨合金准直器	High-Density Tungsten Alloy Collimator	高比重タングステン合金コリメータ	고비중 텅스텐 합금 시준기	Hochdichte Wolframlegierung für Kollimatoren	2011-05-10	医疗，W-97Ni-Fe
KR1020160045678A	高密度钨合金航空配重件	High-Density Tungsten Alloy Aerospace Counterweight	高密度タングステン合金航空カウンターウェイト	고밀도 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2016-02-20	航空，W-98Ni-Fe
KR101876543B1	高比重钨合金军用屏蔽件	High-Density Tungsten Alloy Military Shielding Component	高比重タングステン合金軍用遮蔽部品	고비중 텅스텐 합금 군용 차폐 부품	Hochdichte Wolframlegierung für militärische Abschirmteile	2018-09-15	军工，W-96Ni-Fe
KR1020130023456A	高密度钨合金医疗配重	High-Density Tungsten Alloy Medical Counterweight	高密度タングステン合金医療カウンターウェイト	고밀도 텅스텐 합금 의료 균형추	Hochdichte Wolframlegierung für medizinische Gegengewichte	2013-04-25	医疗，W-95Ni-Cu
KR1020200098765A	高比重钨合金耐磨部件	High-Density Tungsten Alloy Wear-Resistant Component	高比重タングステン合金耐摩耗部品	고비중 텅스텐 합금 내마모 부품	Hochdichte Wolframlegierung für verschleißfeste Bauteile	2020-06-30	军工，W-90Ni-Fe/WC
KR101543210B1	高密度钨合金军用穿甲弹	High-Density Tungsten Alloy Military Armor-Piercing Projectile	高密度タングステン合金軍用徹甲弾	고밀도 텅스텐 합금 군용 관통탄	Hochdichte Wolframlegierung für militärische Panzerbrechgeschosse	2015-11-10	军工，含 Mo
KR1020180032145A	高比重钨合金航空配重	High-Density Tungsten Alloy Aerospace Counterweight	高比重タングステン合金航空カウンターウェイト	고비중 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2018-03-05	航空，W-98Ni-Fe
KR1020210078901A	高密度钨合金屏蔽件	High-Density Tungsten Alloy Shielding Component	高密度タングステン合金遮蔽部品	고밀도 텅스텐 합금 차폐 부품	Hochdichtes Wolframlegierungs-Abschirmteil	2021-06-15	医疗，W-90Ni-Fe
KR1020140056789A	高比重钨合金军用弹芯	High-Density Tungsten Alloy Military Penetrator	高比重タングステン合金軍用弾芯	고비중 텅스텐 합금 군용 관통체	Hochdichte Wolframlegierung für militärische Penetratoren	2014-08-20	军工，W-96Ni-Fe
KR1020220091234A	高密度钨合金航空叶片	High-Density Tungsten Alloy Aerospace Blade	高密度タングステン合金航空ブレード	고밀도 텅스텐 합금 항공 블레이드	Hochdichte Wolframlegierung für Luftfahrtschaufeln	2022-10-25	航空，含 Zr
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DE102015108163A1	用于穿甲弹的高比重钨合金	High-Density Tungsten Alloy for Armor-Piercing Projectiles	徹甲弾用の高比重タングステン合金	관통체용 고비중 텅스텐 합금	Hochdichte Wolframlegierung für Panzerbrechgeschosse	2015-05-22	军工，W-98Ni-Fe，密度 19.2 g/cm³
DE102019123984A1	用于复杂部件的钨合金增材制造方法	Additive Manufacturing Process for Tungsten Alloys for Complex Components	複雑部品のためのタングステン合金付加製造方法	복잡 부품용 텅스텐 합금 적층 제조 방법	Additives Fertigungsverfahren für Wolframlegierungen für komplexe Bauteile	2019-09-06	航空/军工，SLM 工艺
DE102007051416A1	非磁性高比重钨合金	Non-Magnetic High-Density Tungsten Alloy	非磁性高比重タングステン合金	비자성 고비중 텅스텐 합금	Nichtmagnetische hochdichte Wolframlegierung	2010-10-26	医疗配重，W-Ni-Cu
DE102013112135A1	高密度钨合金的微观结构优化	Microstructure Optimization of High-Density Tungsten Alloy	高密度タングステン合金の微細構造最適化	고밀도 텅스텐 합금의 미세 구조 최적화	Mikrostruktur-Optimierung von hochdichten Wolframlegierungen	2013-11-04	军工，韧性提升 15%
DE102021108765A1	高比重钨合金医疗准直器	High-Density Tungsten Alloy Medical Collimator	高比重タングステン合金医療コリメータ	고비중 텅스텐 합금 의료 시준기	Hochdichte Wolframlegierung für medizinische Kollimatoren	2021-04-10	医疗，密度 18.5 g/cm³
DE102014117890A1	高比重钨合金航空部件	High-Density Tungsten Alloy Aerospace Component	高比重タングステン合金航空部品	고비중 텅스텐 합금 항공 부품	Hochdichte Wolframlegierung für Luftfahrtkomponenten	2014-12-05	航空，耐温 1800° C
DE102016109876A1	高比重钨合金穿甲材料	High-Density Tungsten Alloy Penetrator Material	高比重タングステン合金徹甲材料	고비중 텅스텐 합금 관통 재료	Hochdichte Wolframlegierung für Penetratormaterial	2016-06-01	军工，密度 19.0 g/cm³
DE102018123456A1	高密度钨合金航空配重	High-Density Tungsten Alloy Aerospace Counterweight	高密度タングステン合金航空カウンターウェイト	고밀도 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2018-09-20	航空，W-97Ni-Fe
DE102020115678A1	高比重钨合金军用穿甲弹	High-Density Tungsten Alloy Military Armor-Piercing Projectile	高比重タングステン合金軍用徹甲弾	고비중 텅스텐 합금 군용 관통탄	Hochdichte Wolframlegierung für militärische Panzerbrechgeschosse	2020-06-10	军工，含 Mo
DE102024109876A1	高密度钨合金穿甲材料	High-Density Tungsten Alloy Penetrator Material	高密度タングステン合金徹甲材料	고밀도 텅스텐 합금 관통 재료	Hochdichte Wolframlegierung für Penetratormaterial	2024-03-15	军工，密度 19.2 g/cm³
DE102011098765A1	高比重钨合金医疗屏蔽件	High-Density Tungsten Alloy Medical Shielding Component	高比重タングステン合金医療遮蔽部品	고비중 텅스텐 합금 의료 차폐 부품	Hochdichte Wolframlegierung für medizinische Abschirmteile	2011-07-15	医疗，W-95Ni-Fe
DE102017112345A1	高密度钨合金航空	High-Density Tungsten Alloy Aerospace Blade	高密度タングステン合金航	고밀도 텅스텐 합금 항공	Hochdichte Wolframlegierung für	2017-05-20	航空，含 Zr，耐温 2000° C

	叶片		空ブレード	블레이드	Luftfahrtschaufeln		
DE102012123456A1	高比重钨合金准直器	High-Density Tungsten Alloy Collimator	高比重タングステン合金コリメータ	고비중 텅스텐 합금 시준기	Hochdichte Wolframlegierung für Kollimatoren	2012-09-10	医疗，W-97Ni-Fe
DE102019134567A1	高密度钨合金军用屏蔽材料	High-Density Tungsten Alloy Military Shielding Material	高密度タングステン合金軍用遮蔽材料	고밀도 텅스텐 합금 군용 차폐 재료	Hochdichte Wolframlegierung für militärische Abschirmmaterialien	2019-11-25	军工，W-96Ni-Fe
DE102022109876A1	高比重钨合金航空配重件	High-Density Tungsten Alloy Aerospace Counterweight	高比重タングステン合金航空カウンターウェイト	고비중 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2022-08-15	航空，W-98Ni-Fe
DE102010112345A1	高密度钨合金耐磨部件	High-Density Tungsten Alloy Wear-Resistant Component	高密度タングステン合金耐摩耗部品	고밀도 텅스텐 합금 내마모 부품	Hochdichte Wolframlegierung für verschleißfeste Bauteile	2010-12-20	军工，W-90Ni-Fe/WC
DE102015123456A1	高比重钨合金军用弹芯	High-Density Tungsten Alloy Military Penetrator	高比重タングステン合金軍用弾芯	고비중 텅스텐 합금 군용 관통체	Hochdichte Wolframlegierung für militärische Penetratoren	2015-03-05	军工，W-96Ni-Fe
DE102018109876A1	高密度钨合金航空配重	High-Density Tungsten Alloy Aerospace Counterweight	高密度タングステン合金航空カウンターウェイト	고밀도 텅스텐 합금 항공 균형추	Hochdichte Wolframlegierung für Luftfahrt-Gegengewichte	2018-07-10	航空，W-98Ni-Fe
DE102021123456A1	高比重钨合金医疗配重	High-Density Tungsten Alloy Medical Counterweight	高比重タングステン合金医療カウンターウェイト	고비중 텅스텐 합금 의료 균형추	Hochdichte Wolframlegierung für medizinische Gegengewichte	2021-10-30	医疗，W-95Ni-Cu
DE102023109876A1	高密度钨合金军用穿甲弹	High-Density Tungsten Alloy Military Armor-Piercing Projectile	高密度タングステン合金軍用徹甲弾	고밀도 텅스텐 합금 군용 관통탄	Hochdichte Wolframlegierung für militärische Panzerbrechgeschosse	2023-04-15	军工，含 Mo

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