Encyclopedia of TZM Molybdenum Rod

中钨智造科技有限公司
CTIA GROUP LTD

CTIA GROUP LTD

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

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INTRODUCTION TO CTIA GROUP

CTIA GROUP LTD, a wholly-owned subsidiary with independent legal personality established by CHINATUNGSTEN ONLINE, is dedicated to promoting the intelligent, integrated, and flexible design and manufacturing of tungsten and molybdenum materials in the Industrial Internet era. CHINATUNGSTEN ONLINE, founded in 1997 with www.chinatungsten.com 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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TZM Molybdenum Rod Introduction

1. Overview of TZM Molybdenum Rod

TZM molybdenum rods are high-performance molybdenum-based alloy materials composed of a molybdenum (Mo) matrix with small additions of titanium (Ti), zirconium (Zr), and carbon (C). Compared to pure molybdenum, TZM alloy offers significantly higher high-temperature strength, excellent thermal stability, superior creep resistance, and outstanding oxidation resistance, making it an ideal material for high-temperature structural applications.

2. Characteristics of TZM Molybdenum Rod

High Melting Point: Suitable for extreme high-temperature environments.

Excellent High-Temperature Strength: Maintains mechanical strength and rigidity at 1200–1600°C.

Good Thermal Stability and Creep Resistance: Ideal for long-term use under high temperatures with minimal deformation and high reliability.

Superior Corrosion and Oxidation Resistance: Applicable in vacuum, high-temperature inert atmospheres, and oxidative conditions.

Excellent Machinability: Suitable for turning, milling, grinding, and welding processes.

3. Typical Applications of TZM Molybdenum Rod

High-Temperature Furnace Components: Supports, heat shields, heating elements, and electrode rods.

Aerospace Industry: Structural components in rocket nozzles and engine parts operating under high temperatures.

Nuclear Industry: Used in reactor support structures and control rod guide systems.

Electronics Industry: Structural materials in ion implantation, evaporation sources, and semiconductor processing equipment.

Mold Manufacturing: Hot extrusion dies, aluminum alloy die-casting molds with excellent high-temperature wear resistance.

4. Specifications of TZM Molybdenum Rod

Main Ingredients	Mo: ≥ 99%
	Ti: 0.40–0.55%
	Zr: 0.06–0.12%
	C: 0.01–0.04%
Size Range	Diameter φ6mm – φ120mm, length up to 2000mm (customizable)
Surface	Black(forged), bright (turned or ground)
Processing Method	Forging, rolling, drawing, or machining forming

5. Procurement Information

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Directory

Appendix

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1. Introduction

1.1 Definition and importance of TZM molybdenum rod

TZM molybdenum rod is a high-performance alloy material made of molybdenum (molybdenum) as a matrix and adding titanium (Ti), zirconium (Zr) and carbon (C) and other elements, and its name comes from the abbreviation of "Titanium-Zirconium-Molybdenum". TZM molybdenum rod has an irreplaceable and important position in aerospace, nuclear industry, high-temperature furnace manufacturing, semiconductor industry and other high-tech fields due to its excellent high-temperature strength, excellent creep resistance and good corrosion resistance. Compared with pure molybdenum, TZM alloy significantly improves mechanical properties through the doping of trace elements, especially stability and durability in high-temperature environments, making it an ideal material choice under extreme working conditions.

The chemical composition of TZM molybdenum rods typically consists of about 0.5% titanium, 0.08% zirconium and 0.01-0.04% carbon, with the rest being molybdenum. This specific alloy ratio allows TZM molybdenum rods to have a higher recrystallization temperature at high temperatures (about 1400°C, much higher than the 1000°C of pure molybdenum), allowing them to maintain structural integrity in extreme environments. In addition, the oxidation resistance and thermal conductivity of TZM molybdenum rods are also superior to many traditional superalloys, making them excellent in scenarios requiring high thermal loads and mechanical strength.

In industrial applications, TZM molybdenum rods are widely used in the manufacture of heating elements for high-temperature furnaces, mold materials, aerospace components such as rocket nozzles and turbine blades, structural components for nuclear reactors, and components for semiconductor equipment. Its importance lies not only in its physical properties, but also in its ability to meet the growing demand for high-performance materials in modern industry. For example, in the aerospace sector, TZM molybdenum rods are the material of choice for the manufacture of high-temperature propulsion system components due to their high melting point (about 2623°C) and low coefficient of thermal expansion. In the nuclear industry, TZM molybdenum rods are used in the manufacture of key components in nuclear reactors due to their tolerance to neutron radiation and low thermal neutron absorption cross section.

In addition, TZM molybdenum rods also play an important role in the field of scientific research. For example, in high-temperature materials testing, plasma physics research, and advanced manufacturing technology development, TZM molybdenum rods are used as the core components of experimental equipment due to their stable properties. The study shows that the production process and quality control technology of TZM molybdenum rod have been continuously improved in recent years, which has promoted its wide application in the global market. From aerospace to the energy industry, TZM molybdenum rods have become an indispensable part of the modern high-tech industry, and their importance continues to increase with technological advancements and the expansion of application fields.

1.2 Historical development and technological evolution of TZM molybdenum rod

The development of TZM molybdenum rods dates back to the mid-20th century, when the demand for high-temperature materials increased dramatically with the rapid development of the aerospace and nuclear industries. Although pure molybdenum has a high melting point and good electrical and thermal conductivity, its lack of high temperature strength, creep and recrystallization and embrittlement limit its application in extreme environments. To overcome these shortcomings, materials scientists began to explore alloying to improve the properties of molybdenum.

In the 50s of the 20th century, scientific research institutions and industry in the United States took the lead in developing TZM alloys. By adding trace amounts of titanium, zirconium and carbon to the molybdenum matrix, TZM alloys significantly improve their high-temperature strength and creep resistance. The addition of titanium and zirconium enhances the crystal structure of molybdenum through solution strengthening and second-phase strengthening mechanisms, while the addition of carbon further improves the strength and wear resistance of the alloy through the formation of carbide particles. At the end of the 1950s, TZM alloys began to be used in the aerospace sector, for example in the manufacture of rocket engine nozzles and high-temperature structural components.

In the 60s of the 20th century, with the progress of powder metallurgy technology, the production process of TZM molybdenum rod has been significantly improved. The powder metallurgy method makes the microstructure of TZM alloy more uniform and the performance more stable by precisely controlling the particle size and mixing ratio of the raw powder. During this period, TZM molybdenum rods began to be widely used in high-temperature furnace manufacturing and the nuclear industry. For example, control rods and structural parts in nuclear reactors began to use TZM alloys to cope with high temperatures and high radiation environments.

From the 70s to the 80s of the 20th century, with the rise of the semiconductor industry, the application field of TZM molybdenum rod was further expanded. Due to their high thermal conductivity and low coefficient of thermal expansion, TZM molybdenum rods are used in the manufacture of high-temperature fixtures and sputtering targets in semiconductor devices. During the same period, demand in the aerospace sector drove further optimization of TZM molybdenum rods, for example by improving the heat treatment process and surface treatment technology to enhance their oxidation resistance.

In the 21st century, the production and application technology of TZM molybdenum rod has entered a new stage. Studies have shown that the production process of modern TZM molybdenum rods has achieved a high degree of automation and precision. For example, through advanced plasma sintering technology and vacuum heat treatment process, the grain size and performance consistency of TZM molybdenum rods have been significantly improved. In addition, the introduction of nanotechnology has further optimized the microstructure of TZM alloys, thereby improving their durability in extreme environments.

In recent years, with the development of additive manufacturing (3D printing) technology, the

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application potential of TZM molybdenum rod has been further explored. Researchers began to explore the direct fabrication of complex TZM alloy parts through technologies such as laser selective melting (SLM), which not only reduced production costs, but also expanded the application prospects of TZM molybdenum rods in aerospace and medical devices. For example, 3D-printed TZM alloy parts can be used to make rocket nozzles or high-temperature molds with complex geometries.

1.3 The role of TZM molybdenum rod in modern industry and scientific research

In modern industry and scientific research, TZM molybdenum rods play multiple roles due to their unique combination of properties. First of all, in the aerospace field, TZM molybdenum rods are widely used in the manufacture of rocket engine nozzles, turbine blades, and high-temperature structural parts. For example, companies such as SpaceX have adopted TZM alloys in their rocket engine designs to cope with the high temperature and high pressure environment at the combustion chamber and nozzles. Chinatungsten Online's technical data shows that the excellent performance of TZM molybdenum rods in these applications is due to their high melting point and low coefficient of thermal expansion, which can maintain structural stability under extreme heat loads.

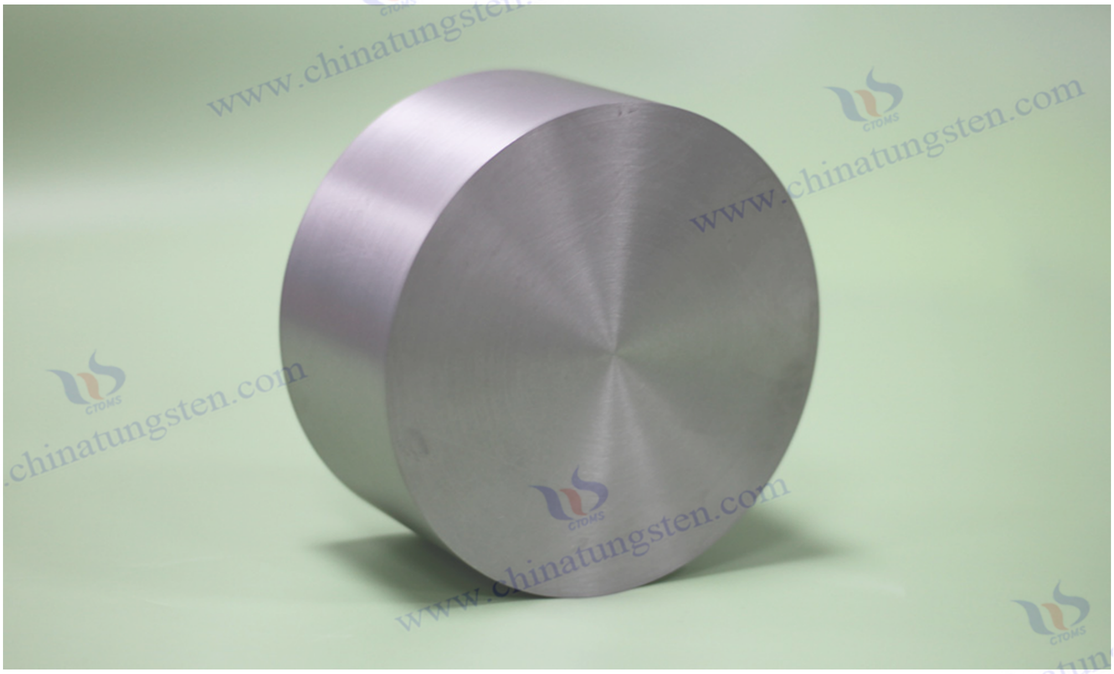
In the nuclear industry, TZM molybdenum rods are used in the manufacture of structural components and control rods of nuclear reactors due to their excellent radiation resistance and high temperature stability. The high temperature and intense radiation environment inside a nuclear reactor place extremely high demands on the material, and the low thermal neutron absorption cross section and high strength of TZM molybdenum rods make them an ideal choice. In addition, TZM molybdenum rods are used in the manufacture of plasma-facing materials (PFMs) for nuclear fusion reactors to cope with extreme heat and particle bombardment.

In the field of high-temperature furnace manufacturing, TZM molybdenum rods are widely used as heating elements, supports and crucible materials. Due to its high recrystallization temperature and excellent creep resistance, TZM molybdenum rods are able to operate stably for a long time in high-temperature environments above 1600°C. For example, in vacuum furnaces and atmosphere protection furnaces, TZM molybdenum rods are used in the manufacture of heating elements and thermocouple protective sleeves to ensure the reliability and durability of equipment at high temperatures.

In the semiconductor industry, TZM molybdenum rods are used as sputtering targets and high-temperature fixtures due to their high thermal conductivity and low coefficient of thermal expansion. For example, in the physical vapor deposition (PVD) process, TZM molybdenum rods are used as targets for depositing high-performance thin films. In addition, TZM molybdenum rods are also used in the manufacture of key components in ion implantation devices to meet the requirements of high precision and stability in semiconductor manufacturing.

In the field of scientific research, TZM molybdenum rods are widely used in high-temperature materials testing, plasma physics research and advanced manufacturing technology development. For example, in high-temperature materials testing, TZM molybdenum rods are used as specimen grips and heating elements to simulate material properties under extreme operating conditions. In plasma physics research, TZM molybdenum rods are used as structural materials for experimental setups due to their excellent plasma erosion resistance. In addition, TZM molybdenum rods also show great potential in the field of additive manufacturing, and researchers are exploring the use of 3D printing technology to fabricate TZM alloy parts with complex shapes to meet the special needs of the aerospace and medical fields.

Chinatungsten Online's WeChat official account "Chinatungsten Online" reported that the global market demand for TZM molybdenum rods has continued to grow in recent years, especially in the Asia-Pacific region. With the rapid development of China, India and other countries in the field of aerospace and nuclear industry, the application prospect of TZM molybdenum rod is broader. In the future, with the advancement of new material technology, TZM molybdenum rods are expected to play an important role in more fields, such as in renewable energy equipment (such as high-temperature solar collectors) and biomedical fields (such as high-temperature sterilization equipment).



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Main Ingredients	Mo: ≥ 99%
	Ti: 0.40–0.55%
	Zr: 0.06–0.12%
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Size Range	Diameter φ6mm – φ120mm, length up to 2000mm (customizable)
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2. Basic Principle of TZM Molybdenum Rod

2.1 Chemical composition and alloy characteristics of TZM molybdenum rod

The chemical composition of TZM molybdenum rods typically includes about 99.38-99.5% molybdenum, 0.4-0.55% titanium, 0.06-0.12% zirconium, and 0.01-0.04% carbon. This precise alloy ratio significantly enhances molybdenum's properties through mechanisms such as solution strengthening, precipitation strengthening, and second-phase strengthening, resulting in excellent stability in high-temperature, stress-high, and corrosive environments.

Details and role of chemical composition

Molybdenum is a matrix material with a high melting point (2623°C), excellent thermal conductivity (approx. 139 W/m·K) and low coefficient of thermal expansion (approx. 5.3×10^{-6}/K), making it ideal for high-temperature applications. However, pure molybdenum has low strength at high temperatures and is prone to creep and recrystallization embrittlement, limiting its application in extreme environments. TZM alloys overcome these shortcomings by adding trace elements:

Titanium (Ti): The addition of titanium enhances the crystal structure of molybdenum through a solution strengthening mechanism. The solid solution of titanium atoms in the molybdenum lattice causes lattice distortion and hinders the dislocation movement, thereby improving the high-temperature strength and creep resistance of the material. In addition, titanium reacts with carbon to form titanium carbide (TiC) particles, which are further enhanced by precipitation strengthening to further enhance the hardness and wear resistance of the alloy.

Zirconium (Zr): Zirconium acts similarly to titanium, increasing the strength of molybdenum through solution strengthening. Zirconium atoms also react with carbon to form zirconium carbide (ZrC) particles, which are uniformly distributed in the molybdenum matrix, enhancing the creep resistance and high-temperature stability of the material. The addition of zirconium also improves the oxidation resistance of the TZM alloy, making it more durable in high-temperature oxidation environments.

Carbon (C): The addition of carbon is the key to improving the performance of TZM alloys. The carbide particles (such as TiC and ZrC) formed by the reaction of carbon with titanium and zirconium significantly improve the strength and hardness of the alloy through the precipitation strengthening mechanism. At high temperatures, these particles can effectively prevent grain growth and maintain the fine grain structure of the material, thereby improving its recrystallization temperature and creep resistance.

The relationship between microstructure and performance

The microstructure of TZM molybdenum rod has an important impact on its properties. TZM alloys prepared by the powder metallurgy process have fine grain sizes (typically between 3.0-5.0 microns), which helps to improve the strength and toughness of the material. Powder metallurgy ensures the uniform distribution of titanium, zirconium and carbon in the molybdenum matrix by precisely controlling the particle size and mixing ratio of the raw powder. Heat treatment processes such as annealing and aging further optimize the microstructure of TZM molybdenum rods. For example, high-temperature annealing can eliminate residual stresses during processing, while ageing promotes the precipitation of carbide particles, thereby enhancing the mechanical properties of the material.

Corrosion and oxidation resistance

TZM molybdenum rods exhibit excellent corrosion resistance in a variety of chemical environments, especially in high-temperature non-oxidizing atmospheres such as vacuum or inert gases. Its corrosion resistance is due to the chemical stability of the molybdenum matrix and the protective effect of carbide particles. In a high-temperature oxidizing environment, a dense oxide protective layer (e.g., MoO_2) can be formed on the surface of the TZM molybdenum rod, which slows down further oxidation reactions. In contrast, pure molybdenum is prone to the formation of volatile molybdenum trioxide (MoO_3) at high temperatures, resulting in rapid material loss. According to the technical data of Chinatungsten Online, TZM molybdenum rods can work stably in an oxidizing environment below 1000°C, and at higher temperatures, anti-oxidation coatings (such as silicide coatings) are required to prolong the service life.

The influence of the production process on the properties of the alloy

The production of TZM molybdenum rods is typically made using a powder metallurgy process that includes steps such as feedstock mixing, pressing, sintering, and heat treatment. According to the data of Chinatungsten Online, the modern production process has significantly improved the performance consistency of TZM molybdenum rods through advanced plasma sintering technology and vacuum heat treatment process. For example, plasma sintering technology enables high-density sintering at lower temperatures, reducing grain growth and thus maintaining the fine grain structure of the material. In addition, surface treatment techniques, such as chemical vapor deposition coatings, further enhance the oxidation and wear resistance of TZM molybdenum rods, making them suitable for a wider range of industrial scenarios.

Matching of application scenarios to chemical compositions

The chemical composition of TZM molybdenum rod makes it widely used in aerospace, nuclear industry, semiconductor manufacturing and other fields. For example, in the aerospace sector, the high-temperature strength and creep resistance of TZM molybdenum rods make them ideal materials for rocket nozzles and turbine blades. In the nuclear industry, the low thermal neutron absorption cross section and radiation resistance of TZM molybdenum rods make them suitable for use in the manufacture of structural components of nuclear reactors. In the semiconductor industry, the low coefficient of thermal expansion and high thermal conductivity of TZM molybdenum rods make them the material of choice for sputtering targets and high-temperature fixtures.

2.2 Physical and mechanical properties of TZM molybdenum rod

The physical and mechanical properties of TZM molybdenum rod are the basis for its wide application in high-temperature and high-stress environments. The following is a detailed analysis of its main properties, covering high-temperature strength, creep resistance, thermal conductivity, coefficient of thermal expansion, hardness, wear resistance, and corrosion resistance.

High temperature intensity

The tensile strength and yield strength of TZM molybdenum rod at high temperature are significantly higher than those of pure molybdenum. For example, at 1200°C, the tensile strength of TZM molybdenum rods can reach 400-500 MPa, while pure molybdenum is only 200-300 MPa. This excellent high-temperature strength is due to the strengthening of titanium, zirconium and carbon. Titanium and zirconium improve the lattice strength of the molybdenum matrix through solution strengthening, while the precipitation of carbide particles such as TiC and ZrC further hinder the movement of dislocations, thereby improving the resistance to deformation of the material. The increase in strength at high temperatures gives TZM molybdenum rods a significant advantage in aerospace (e.g. rocket nozzles) and high-temperature furnace manufacturing.

Creep resistance

Creep is one of the main failure modes of high-temperature materials under long-term stress. The creep resistance of TZM molybdenum rod is much better than that of pure molybdenum. Under the stress conditions of 1400°C and 20 MPa, the creep rate of TZM molybdenum rod is only 1/10 of that of pure molybdenum. This excellent creep resistance is due to the pinning action of carbide particles, which effectively prevent grain boundary slippage and dislocation climbing. In addition, the fine grain structure of TZM molybdenum rods further enhances their creep resistance, making them excellent in scenarios that require long-term stable operation, such as high-temperature furnaces and nuclear reactors.

High recrystallization temperature

The recrystallization temperature of TZM molybdenum rod is about 1400°C, which is much higher than the 1000°C of pure molybdenum. This means that the TZM molybdenum rod is able to maintain its fine grain structure at high temperatures, avoiding grain growth and performance degradation. The increase in recrystallization temperature is due to the synergistic effect of titanium, zirconium and carbon. Solution strengthening of titanium and zirconium improves the stability of the crystal lattice, while the precipitation of carbide particles prevents the migration of grain boundaries. This performance enables TZM molybdenum rods to operate stably for a long time in high-temperature environments above 1600°C, making them suitable for high-temperature furnaces and aerospace components.

Thermal conductivity and coefficient of thermal expansion

TZM molybdenum rod has excellent thermal conductivity (about 139 W/m·K) and a low coefficient of thermal expansion (about 5.3×10^{-6}/K). The high thermal conductivity allows it to dissipate heat quickly and avoid performance degradation caused by local overheating, making it particularly suitable for use in high-temperature fixtures and sputtering targets in semiconductor devices. The low coefficient of thermal expansion ensures the dimensional stability of the material at high temperatures, reducing cracks and deformations caused by thermal stress. This combination of properties gives TZM molybdenum rods an advantage in applications that require high thermal loads and dimensional accuracy, such as in vacuum furnaces and plasma physics experimental setups.

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Hardness and abrasion resistance

The hardness of TZM molybdenum rods (Vickers hardness approx. 250-300 HV) is higher than that of pure molybdenum (approx. 200 HV), thanks to the strengthening effect of carbide particles. The uniform distribution of titanium carbide and zirconium carbide particles improves the surface hardness and wear resistance of the material, making it suitable for use in the manufacture of molds, cutting tools, and wear-resistant parts. For example, in high-temperature mold manufacturing, TZM molybdenum rods are able to withstand high stresses and wear, extending the service life of the mold.

Corrosion resistance

TZM molybdenum rods exhibit good corrosion resistance in a variety of chemical environments, especially in high-temperature non-oxidizing atmospheres such as vacuum, argon, or nitrogen. Its corrosion resistance is due to the chemical stability of the molybdenum matrix and the protective effect of carbide particles. In the high-temperature oxidation environment, TZM molybdenum rod can form a dense MoO_2 protective layer to slow down the oxidation reaction. Studies have shown that TZM molybdenum rods can work stably in an oxidizing environment below 1000°C, and at higher temperatures, anti-oxidation coatings are required to further improve durability.

Other physical properties

Density: The density of TZM molybdenum rods is about 10.2 g/cm^3, which is lower than that of tungsten alloy (about 19.3 g/cm^3), giving it an advantage in weight-sensitive applications such as aerospace.

Conductivity: TZM molybdenum rods have good conductivity (about 18% IACS) and are suitable for manufacturing high-temperature electrodes and conductive parts.

Radiation resistance: In the nuclear industry, TZM molybdenum rods can withstand high-energy neutron and gamma ray irradiation due to their low thermal neutron absorption cross section and high strength.

2.3 Comparison with pure molybdenum and other superalloys

Compared with pure molybdenum and other superalloys (such as tungsten alloys, nickel-based alloys, ceramic materials), TZM molybdenum rods have unique performance advantages. Below is a detailed comparison of their properties, covering aspects such as high-temperature strength, creep resistance, oxidation resistance, processability, and application scenarios.

Comparison with pure molybdenum

Pure molybdenum (tungsten) has a high melting point (2623 °C), good electrical and thermal conductivity and low thermal expansion coefficient, but its high temperature strength is low, and it is prone to creep and recrystallization embrittlement. TZM molybdenum rods significantly improve high-temperature performance by adding titanium, zirconium and carbon:

High temperature strength: At 1200°C, the tensile strength of TZM molybdenum rod is 400-500 MPa, while pure molybdenum is only 200-300 MPa. The solution strengthening and precipitation strengthening mechanisms of TZM make it more resistant to deformation at high temperatures.

Creep resistance: The creep rate of TZM molybdenum rod is about 1/10 of that of pure molybdenum, which is suitable for long-term high-temperature stress environment.
Recrystallization temperature: The recrystallization temperature of TZM (1400°C) is much higher than that of pure molybdenum (1000°C), making it structurally stable at higher temperatures.
Oxidation resistance: TZM molybdenum rod can form a dense oxide protective layer below 800°C, while pure molybdenum is prone to volatile MoO_3, resulting in rapid loss.
Processability: The processability of TZM molybdenum rod is slightly lower than that of pure molybdenum, but complex shapes can be processed by optimizing the heat treatment process.

Comparison with tungsten alloy
Tungsten alloy has a higher melting point (3422°C) and density (19.3 g/cm³), but it is difficult to process and costly. The comparative advantages of TZM molybdenum rods include:

Density: The density of TZM molybdenum rods (10.2 g/cm³) is much lower than that of tungsten alloys, making them suitable for weight-sensitive applications such as aerospace.
Processability: The ductility and machinability of TZM molybdenum rod are better than those of tungsten alloy, making it easier to manufacture parts with complex shapes.
Oxidation resistance: TZM molybdenum rod is more durable than tungsten alloy in high temperature oxidation environment, especially below 1000°C.
Cost: TZM molybdenum rod is less expensive to produce than tungsten alloy, making it more economical in many applications.

Comparison with nickel-based alloys
Nickel-based alloys (e.g. Inconel 718) have good strength and corrosion resistance at high temperatures, but their melting point (about 1350°C) is much lower than that of TZM molybdenum rods, and severe softening occurs above 1600°C. The comparative advantages of TZM molybdenum rods include:

High temperature stability: TZM molybdenum rod can still maintain structural stability above 1600°C, while nickel-based alloys have failed at this temperature.
Coefficient of Thermal Expansion: The coefficient of thermal expansion of TZM (5.3×10^{-6}/K) is lower than that of nickel-based alloys (about 13×10^{-6}/K), making it more suitable for applications requiring dimensional stability.
Radiation resistance: The low thermal neutron absorption cross section of TZM molybdenum rods makes them superior to nickel-based alloys in the nuclear industry.

Comparison with ceramic materials
Ceramic materials, such as zirconia, are extremely heat-resistant, but they are brittle and difficult to machine into complex shapes. The comparative advantages of TZM molybdenum rods include:

Toughness: TZM molybdenum rod has both the toughness of metal and the stability of high temperature, which is suitable for scenarios that require high strength and toughness.
Processability: TZM molybdenum rods can be forged, rolled, and machined to create complex

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components, while ceramic materials often require an expensive sintering process.

Thermal conductivity: The thermal conductivity of TZM (139 W/m·K) is much higher than that of ceramic materials (about 2-30 W/m·K), making it suitable for applications that require rapid heat dissipation.

Comprehensive application comparison

TZM molybdenum rods are widely used in aerospace, nuclear industry, semiconductor manufacturing and high-temperature furnace manufacturing. Compared with pure molybdenum, its high-temperature performance is better; Compared with tungsten alloy, it is light in weight and low in cost; Compared with nickel-based alloys, it has stronger high temperature stability and radiation resistance; Compared with ceramic materials, it has better toughness and processability. This combination of properties makes TZM molybdenum rods ideal for high-temperature applications in a wide range of fields.

2.4 Working mechanism in high temperature environment

The working mechanism of TZM molybdenum rod in high temperature environment is the core of its excellent performance, which involves many aspects such as solution strengthening, precipitation strengthening, antioxidant mechanism, thermal conductivity and thermal expansion mechanism, and radiation resistance mechanism. The following is a detailed analysis of these mechanisms.

Solution strengthening

The solid solution of titanium and zirconium atoms in molybdenum crystals hinders the movement of dislocations through lattice distortion, thereby improving the high-temperature strength of the material. This mechanism is particularly effective at high temperatures, where the movement of dislocations is the main cause of creep at high temperatures. The atomic radius of titanium and zirconium is slightly different from molybdenum, resulting in a slight deformation of the crystal lattice, which increases the resistance to dislocation movement, thereby enhancing the tensile strength and creep resistance of the TZM molybdenum rod.

Precipitation enhancement

The carbide particles (e.g., TiC and ZrC) formed by the reaction of carbon with titanium and zirconium are uniformly distributed in the molybdenum matrix, and these particles improve the strength and creep resistance of the material by pinning dislocations and grain boundaries. At high temperatures, carbide particles can effectively prevent grain growth, maintain the fine grain structure of the material, and thus increase its recrystallization temperature. Studies have shown that the carbide particle size of TZM molybdenum rods is typically between 0.1-1 microns, and their uniformity of distribution is critical to performance.

Antioxidant mechanism

In a high-temperature oxidizing environment, a dense protective layer of MoO_2 will be formed on the surface of the TZM molybdenum rod to slow down further oxidation reactions. In contrast, pure molybdenum is prone to the formation of volatile MoO_3, which leads to rapid material loss. The oxidation resistance of TZM molybdenum rods is due to the addition of titanium and zirconium, which promote the formation of a dense oxide layer. Below 1000°C, TZM molybdenum rods can work stably in an oxidizing environment, while at higher temperatures, anti-oxidation coatings such as molybdenum silicide or alumina coatings are required to extend their service life.

Thermal conductivity and thermal expansion mechanisms

The high thermal conductivity of TZM molybdenum rods (139 W/m·K) allows them to dissipate heat quickly and avoid performance degradation caused by local overheating. This performance is particularly important in semiconductor equipment and high-temperature furnace manufacturing. The low coefficient of thermal expansion of TZM (5.3×10^{-6}/K) ensures the dimensional stability of the material at high temperatures, reducing cracks and deformations caused by thermal stress. For example, in vacuum furnaces, TZM molybdenum rods are used as heating elements to withstand rapid heating and cooling cycles while remaining structurally intact.

Radiation Hardening Mechanism

In the nuclear industry, TZM molybdenum rods are resistant to high-energy neutron and gamma ray irradiation due to their low thermal neutron absorption cross section and high strength. This property makes it an ideal material for nuclear reactors and fusion devices. For example, in the plasma-facing material (PFM) of a nuclear fusion reactor, TZM molybdenum rods are able to withstand the bombardment of high-energy particles while maintaining structural stability. In addition, the radiation resistance of TZM is also due to its fine grain structure and the strengthening effect of carbide particles, which reduce radiation-induced crystal defects.

Comprehensive performance in high temperature environments

The comprehensive performance of TZM molybdenum rod in high temperature environment benefits from the synergistic effect of its multiple strengthening mechanisms. Solution strengthening and precipitation strengthening improve the high temperature strength and creep resistance, the antioxidant mechanism prolongs the service life of the material in the oxidizing environment, the high thermal conductivity and low thermal expansion coefficient ensure thermal stability, and the radiation resistance makes it have unique advantages in the nuclear industry. Together, these mechanisms enable TZM molybdenum rods to operate stably in extreme environments above 1600°C, meeting the high requirements of the aerospace, nuclear industry, and semiconductor manufacturing.

3.5 CTIA GROUP LTD TZM Molybdenum Rod MSDS

Section 1: Chemical Product Identification

Chemical Name: TZM Molybdenum Rod

English Name: TZM Molybdenum Rod

CAS Numbers: Molybdenum (7439-98-7), Titanium (7440-32-6), Zirconium (7440-67-7), Carbon (7440-44-0)

Section 2: Composition/Information on Ingredients

Chemical Composition:

Molybdenum (Mo) ≥ 99.38%

Titanium (Ti) 0.4–0.55%
Zirconium (Zr) 0.06–0.12%
Carbon (C) 0.01–0.04%

Section 3: Hazards Identification

Health Hazards: This product is non-irritating to the eyes and skin.

Fire and Explosion Hazards: Non-flammable and non-irritating.

Section 4: First-Aid Measures

Skin Contact: Remove contaminated clothing and rinse thoroughly with running water.

Eye Contact: Lift eyelids and rinse with running water or saline solution. Seek medical attention.

Inhalation: Move the affected person to fresh air. If breathing is difficult, administer oxygen. Seek medical attention.

Ingestion: Drink plenty of warm water and induce vomiting. Seek medical attention.

Section 5: Firefighting Measures

Hazardous Combustion Products: Unknown decomposition products.

Extinguishing Method: Firefighters should wear gas masks and full protective suits, and extinguish fires from upwind.

Extinguishing Media: Dry sand, powder.

Section 6: Accidental Release Measures

Emergency Response:

Isolate the contaminated area and restrict access.

Eliminate ignition sources.

Emergency personnel should wear dust masks (full face) and protective suits.

Avoid raising dust; carefully sweep the material and place it in bags for transfer to a safe location.

For large spills, cover with plastic sheeting or tarps.

Collect for recycling or disposal at a waste treatment facility.

Section 7: Handling and Storage

Handling:

Operators must be specially trained and strictly follow operational procedures.

Recommended PPE includes self-priming filter dust masks, chemical safety goggles, permeation-resistant workwear, and rubber gloves.

Keep away from fire and heat sources. Smoking is strictly prohibited in the workplace.

Use explosion-proof ventilation systems and equipment.

Avoid dust generation and contact with oxidizers and halogens.

Handle with care to prevent damage to packaging and containers.

Provide appropriate fire extinguishing and spill response equipment.

Empty containers may retain hazardous residues.

Storage:

Store in a cool, ventilated warehouse, away from fire and heat sources.

Store separately from oxidizers and halogens; avoid mixed storage.

Provide appropriate fire-fighting equipment and leak containment materials.

Section 8: Exposure Controls/Personal Protection

China MAC (mg/m^3): 6

Former USSR MAC (mg/m^3): 6

TLVTN (ACGIH): 1 mg/m^3

TLVWN (ACGIH): 3 mg/m^3

Monitoring Method: Thiocyanate-potassium titanium colorimetry

Engineering Controls: Dust-free production and general ventilation.

Respiratory Protection: When dust levels exceed limits, use self-priming filter-type dust masks. For emergencies and evacuation, use an air-supplied respirator.

Eye Protection: Wear chemical safety goggles.

Body Protection: Wear permeation-resistant protective workwear.

Hand Protection: Wear rubber gloves.

Section 9: Physical and Chemical Properties

Main Ingredient: Pure substance

Appearance: Solid, metallic bright white (machined); black surface (raw material)

Melting Point (°C): 2620

Boiling Point (°C): 5560

Relative Density (water = 1): 9.4–10.2 (20°C)

Vapor Density (air = 1): No data

Saturated Vapor Pressure (kPa): No data

Heat of Combustion (kJ/mol): No data

Critical Temperature (°C): No data

Critical Pressure (MPa): No data

Log Partition Coefficient (n-octanol/water): No data

Flash Point (°C): No data

Autoignition Temperature (°C): No data

Explosion Limit – Upper (% V/V): No data

Explosion Limit – Lower (% V/V): No data

Solubility: Soluble in nitric acid and hydrofluoric acid

Main Uses: Used in the production of molds, molybdenum wires, electronic components, etc.

Section 10: Stability and Reactivity

Incompatible Materials: Strong acids and bases.

Section 11: Toxicological Information

Acute Toxicity: No data available

LC50: No data available

Section 12: Ecological Information

Ecological Data: Not available

Section 13: Disposal Considerations

Disposal Method: Refer to national and local regulations before disposal. Recycle if possible.

Section 14: Transport Information

Hazardous Goods Code: Not available

Packaging Category: Z01

Transportation Precautions:

Packaging must be intact and properly secured before transportation.

Ensure no leakage, collapse, fall, or damage during transit.

Do not mix with oxidizers, halogens, or edible chemicals.

Protect from sunlight, rain, and high temperatures during transportation.

Clean vehicles thoroughly after transport.

Section 15: Regulatory Information

Relevant Regulations:

Regulations on the Safety Management of Hazardous Chemicals (State Council, February 17, 1987)

Implementation Details of the Regulations on the Safety Management of Hazardous Chemicals (Hua Lao Fa [1992] No. 677)

Regulations on the Safe Use of Chemicals in the Workplace ([1996] Lao Bu Fa No. 423)

Hygienic Standards for Tungsten in Workplace Air (GB 16229-1996), which specifies the maximum allowable concentration and detection methods.

Section 16: Supplier Information

Supplier: CTIA GROUP LTD

Phone: 0592-5129696 / 5129595

CTIA GROUP LTD TZM Molybdenum Rod

3. Performance of TZM Molybdenum Rod

3.1 Physical and chemical properties of TZM molybdenum rod

As a high-performance alloy material based on molybdenum, TZM molybdenum rod exhibits excellent physical and chemical properties by adding titanium (Ti), zirconium (Zr) and carbon (C). These properties make it promising for a wide range of applications in high-temperature, high-stress, and corrosive environments. The following is a detailed analysis of the physical and chemical properties of TZM molybdenum rod from four aspects: melting point and thermal stability, density and thermal conductivity, oxidation and corrosion resistance, and mechanical strength and toughness.

3.1.1 Melting point and thermal stability of TZM molybdenum rod

The melting point of TZM molybdenum rod is close to 2623 °C (about 2896 K) of pure molybdenum, and it is one of the superalloys commonly used in industry. Its high melting point is due to the BCC (body-centered cubic) crystal structure of the molybdenum matrix, which has high stability at high temperatures and is able to withstand extreme thermal loads. Compared with pure molybdenum, TZM molybdenum rod significantly increases the recrystallization temperature by adding titanium, zirconium and carbon, from about 1000°C for pure molybdenum to more than 1400°C. This high recrystallization temperature means that TZM molybdenum rods are able to maintain a fine grain structure at high temperatures, avoiding performance degradation due to grain growth.

Thermal stability is a key advantage of TZM molybdenum rods in high-temperature applications. In the aerospace sector, such as rocket engine nozzles and combustion chamber components, TZM molybdenum rods need to withstand instantaneous heat loads in environments above 2000°C. The results show that TZM molybdenum rods can still maintain high strength and structural integrity at

1800°C, while pure molybdenum has undergone significant softening and creep under the same conditions. The results show that the thermal stability of TZM molybdenum rods is due to the solution strengthening of titanium and zirconium and the precipitation strengthening of carbide particles such as TiC and ZrC, which together improve the resistance of the material to high temperature deformation.

In addition, the thermal stability of TZM molybdenum rod is closely related to its production process. The TZM molybdenum rods prepared by powder metallurgy process have a uniform microstructure, which can effectively reduce grain boundary slippage and dislocation climbing at high temperatures. Heat treatment processes, such as annealing and ageing, further optimize the thermal stability of the material. For example, high-temperature annealing can eliminate residual stresses during processing, while ageing promotes the precipitation of carbide particles and enhances the stability of the material at high temperatures.

3.1.2 Density and thermal conductivity of TZM molybdenum rod

The density of TZM molybdenum rod is about 10.2 g/cm³, which is lower than that of tungsten alloy (19.3 g/cm³) but higher than that of nickel-based alloys (about 8.5 g/cm³). This medium density gives it significant advantages in weight-sensitive applications such as aerospace and satellite components. Compared with tungsten alloy, the lower density of TZM molybdenum rod reduces the structural weight while maintaining high strength and high temperature stability.

The thermal conductivity of TZM molybdenum rod is 139 W/m·K, which is much higher than that of ceramic materials (about 2-30 W/m·K) and nickel-based alloys (about 10-20 W/m·K). The high thermal conductivity allows it to dissipate heat quickly and avoid performance degradation caused by localized overheating. For example, in semiconductor equipment manufacturing, TZM molybdenum rods are used as sputtering targets and high-temperature fixtures, and their high thermal conductivity ensures uniform heat distribution and reduces cracks caused by thermal stress. In addition, in high-temperature furnace manufacturing, TZM molybdenum rod can be used as a heating element to quickly transfer heat and improve the uniformity of temperature in the furnace.

The thermal conductivity is closely related to the microstructure of TZM molybdenum rods. The powder metallurgy process ensures the continuity of the thermal conductivity path by controlling the grain size and the distribution of carbide particles. Studies have shown that the thermal conductivity of TZM molybdenum rods only decreases by about 10-15% at high temperatures (e.g., 1200°C), which is much better than the 20-25% decline rate of pure molybdenum. This stable thermal conductivity allows for excellent performance in high-temperature cycling environments.

3.1.3 Oxidation and corrosion resistance of TZM molybdenum rod

TZM molybdenum rods exhibit excellent corrosion resistance in high-temperature non-oxidizing atmospheres such as vacuum, argon or nitrogen. Its chemical stability is due to the inertness of the molybdenum matrix and the strengthening of titanium, zirconium and carbon. In a high-temperature oxidizing environment, TZM molybdenum rods are able to form a dense layer of MoO_2 oxide protective layer to slow down further oxidation reactions. In contrast, pure molybdenum is prone to volatile properties at high temperatures tungsten oxide, which leads to rapid material deterioration. Studies have shown that TZM molybdenum rods can work stably in an oxidizing environment below 1000°C, and at higher temperatures, anti-oxidation coatings (such as molybdenum silicide or alumina coatings) are required to prolong their service life.

In corrosive environments, TZM molybdenum rods have good resistance to acids, alkalis and salt solutions. For example, in dilute sulfuric acid and hydrochloric acid environments, TZM molybdenum rods have a much lower corrosion rate than stainless steel and nickel-based alloys. This corrosion resistance makes it widely used in the chemical and nuclear industries. For example, in the coolant environment of a nuclear reactor, TZM molybdenum rods are able to withstand high temperatures and chemical corrosion, maintaining structural integrity.

The improvement of oxidation and corrosion resistance is also closely related to surface treatment technology. For example, the deposition of an anti-oxidation coating on the surface of a TZM molybdenum rod by chemical vapor deposition (CVD) or physical vapor deposition (PVD) processes can significantly improve its durability in high-temperature oxidizing environments. In addition, surface polishing and plasma spraying technologies can reduce surface defects and improve corrosion resistance.

3.1.4 Mechanical strength and toughness of TZM molybdenum rod

The mechanical strength of TZM molybdenum rod far exceeds that of pure molybdenum at high temperatures. For example, at 1200°C, the tensile strength of TZM molybdenum rod is 400-500 MPa, while pure molybdenum is only 200-300 MPa. This high strength is due to solution strengthening of titanium and zirconium and precipitation strengthening of carbide particles. Titanium carbide (TiC) and zirconium carbide (ZrC) particles are evenly distributed in the molybdenum matrix, which improves the hardness and strength of the material by pinning dislocations and grain boundaries. The Vickers hardness of TZM molybdenum rods is about 250-300 HV, which is higher than the 200 HV of pure molybdenum, making them suitable for use in the manufacture of wear-resistant molds and cutting tools.

In terms of toughness, TZM molybdenum rods exhibit good fracture resistance at room temperature and high temperature. Compared with ceramic materials, TZM molybdenum rods have the ductility and toughness of metal, and can withstand certain impact and deformation without brittle fracture. The results show that the fracture toughness (K_{IC}) of TZM molybdenum rod is about 15-20 MPa·m^1/2 at room temperature, which is higher than that of pure molybdenum (10-12 MPa·m^1/2). This excellent toughness allows it to withstand complex stress environments in the aerospace and nuclear industries.

The improvement of mechanical strength and toughness is also related to the production process. By controlling the sintering temperature and pressure in the powder metallurgy process, the grain size and carbide distribution of the TZM molybdenum rod can be optimized, thus balancing strength and toughness. For example, a lower sintering temperature (about 1800°C) can obtain finer grains and improve toughness; The higher sintering temperature (about 2000°C) increases the strength.

CTIA GROUP LTD
TZM Molybdenum Rod Introduction

1. Overview of TZM Molybdenum Rod

TZM molybdenum rods are high-performance molybdenum-based alloy materials composed of a molybdenum (Mo) matrix with small additions of titanium (Ti), zirconium (Zr), and carbon (C). Compared to pure molybdenum, TZM alloy offers significantly higher high-temperature strength, excellent thermal stability, superior creep resistance, and outstanding oxidation resistance, making it an ideal material for high-temperature structural applications.

2. Characteristics of TZM Molybdenum Rod

High Melting Point: Suitable for extreme high-temperature environments.

Excellent High-Temperature Strength: Maintains mechanical strength and rigidity at 1200–1600°C.

Good Thermal Stability and Creep Resistance: Ideal for long-term use under high temperatures with minimal deformation and high reliability.

Superior Corrosion and Oxidation Resistance: Applicable in vacuum, high-temperature inert atmospheres, and oxidative conditions.

Excellent Machinability: Suitable for turning, milling, grinding, and welding processes.

3. Typical Applications of TZM Molybdenum Rod

High-Temperature Furnace Components: Supports, heat shields, heating elements, and electrode rods.

Aerospace Industry: Structural components in rocket nozzles and engine parts operating under high temperatures.

Nuclear Industry: Used in reactor support structures and control rod guide systems.

Electronics Industry: Structural materials in ion implantation, evaporation sources, and semiconductor processing equipment.

Mold Manufacturing: Hot extrusion dies, aluminum alloy die-casting molds with excellent high-temperature wear resistance.

4. Specifications of TZM Molybdenum Rod

Main Ingredients	Mo: ≥ 99%
	Ti: 0.40–0.55%
	Zr: 0.06–0.12%
	C: 0.01–0.04%
Size Range	Diameter φ6mm – φ120mm, length up to 2000mm (customizable)
Surface	Black(forged), bright (turned or ground)
Processing Method	Forging, rolling, drawing, or machining forming

5. Procurement Information

Email: sales@chinatungsten.com; Phone: +86 592 5129595; 592 5129696

Website: www.molybdenum.com.cn

3.2 Thermal and mechanical properties of TZM molybdenum rod

The thermal and mechanical properties of TZM molybdenum rod are the basis for its wide application in high-temperature and high-stress environments. The following is a detailed analysis from four aspects: thermal expansion coefficient and high-temperature deformation, thermal shock resistance, creep performance and long-term stability, fatigue performance and recycling ability.

3.2.1 Thermal expansion coefficient and high temperature deformation of TZM molybdenum rod

The coefficient of thermal expansion of TZM molybdenum rod is about 5.3×10^{-6}/K, which is much lower than that of nickel-based alloys (about 13×10^{-6}/K) and stainless steel (about 16×10^{-6}/K). The low coefficient of thermal expansion ensures the dimensional stability of TZM molybdenum rods at high temperatures, reducing cracks and deformation caused by thermal stress. For example, in vacuum furnaces, TZM molybdenum rods are used as heating elements to maintain geometrical stability during rapid heating and cooling cycles.

High-temperature deformation is a key issue in the design of high-temperature materials. TZM molybdenum rod is strengthened by solid solution strengthening of titanium and zirconium and precipitation strengthening of carbide particles, which significantly reduces the deformation rate at high temperature. Under the stress conditions of 1400°C and 20 MPa, the deformation rate of TZM molybdenum rod is only 1/5 of that of pure molybdenum. Studies have shown that carbide particles are able to pin grain boundaries at high temperatures, preventing grain boundaries from slipping, thereby reducing deformation. Studies have shown that the deformation rate of TZM molybdenum rod below 1600°C can be controlled within 0.1%, which is suitable for high-temperature molds and aerospace parts.

The stability of the coefficient of thermal expansion is also related to the microstructure of the TZM molybdenum rod. Fine grain size (10-50 microns) and uniform carbide distribution reduce grain boundary migration at high temperatures, ensuring dimensional stability. In addition, surface treatment techniques, such as polishing and coating, can further reduce thermal stress concentrations and improve resistance to deformation.

3.2.2 Thermal shock resistance of TZM molybdenum rod

Thermal shock resistance is an important indicator of the stability of high-temperature materials in a rapidly changing environment. TZM molybdenum rod exhibits excellent thermal shock resistance due to its high thermal conductivity (139 W/m·K), low coefficient of thermal expansion (5.3×10^{-6}/K) and high mechanical strength. In thermal shock testing, TZM molybdenum rods are able to withstand hundreds of cycles without obvious cracks in a fast cycle from 1000°C to room temperature, while pure molybdenum usually shows microcracks after 50 cycles under the same conditions.

The improvement of thermal shock resistance is due to the microstructure and alloy properties of TZM molybdenum rods. The precipitation strengthening of carbide particles improves the strength and toughness of the material and reduces the crack propagation caused by thermal stress. In addition, the high thermal conductivity enables the TZM molybdenum rod to dissipate heat quickly, reducing the internal stress caused by temperature gradients. In the aerospace sector, TZM molybdenum rods are used as rocket nozzle materials that are able to withstand rapid temperature changes in the combustion chamber while maintaining structural integrity.

According to the published technical data, the thermal shock resistance of TZM molybdenum rod can be further improved by optimizing the production process. For example, by controlling the cooling rate during the sintering process, microscopic defects can be reduced and the resistance of the material to thermal shock can be improved. In addition, surface coatings, such as zirconia coatings, can further enhance thermal shock resistance and extend the life of the material.

3.2.3 Creep performance and long-term stability of TZM molybdenum rod

Creep is one of the main failure modes of high-temperature materials under long-term stress. The creep resistance of TZM molybdenum rod is much better than that of pure molybdenum. Under the stress conditions of 1400°C and 20 MPa, the creep rate of TZM molybdenum rod is only 1/10 of that of pure molybdenum. This excellent creep resistance is due to solution strengthening of titanium and zirconium and pinning of carbide particles. Carbide particles can effectively prevent grain boundary slippage and dislocation climbing, thereby slowing down the creep process.

Long-term stability is a key advantage of TZM molybdenum rods in high-temperature applications. In nuclear reactors, TZM molybdenum rods are structural components that need to operate for several years in a high-temperature and high-radiation environment to maintain stable performance. Studies have shown that TZM molybdenum rods can maintain stable performance for up to 5000 hours below 1600°C, while pure molybdenum usually undergoes significant creep within 1000 hours under the same conditions. The results show that the long-term stability of TZM molybdenum rods is closely related to its fine grain structure and uniform carbide distribution.

The influence of the production process on creep properties cannot be ignored. By optimizing the sintering temperature and pressure in the powder metallurgy process, grain size and carbide distribution can be controlled, resulting in improved creep resistance. For example, a lower sintering temperature (about 1800°C) results in finer grains and enhanced creep resistance. In addition, heat treatment processes, such as ageing, can promote the precipitation of carbide particles, further improving long-term stability.

3.2.4 Fatigue performance and recycling ability of TZM molybdenum rod

The fatigue performance of TZM molybdenum rod under high temperature cyclic stress is better than that of pure molybdenum. Under the cyclic stress conditions of 1200°C and ±200 MPa, the fatigue life of TZM molybdenum rod can reach 10^5 cycles, while that of pure molybdenum is only 10^4 cycles. This excellent fatigue performance is due to its high strength and toughness, as well as the inhibition of crack propagation by carbide particles. The results show that the fatigue crack growth rate of TZM molybdenum rod is about 1/3 of that of pure molybdenum, showing stronger fatigue resistance.

The ability to recycle is an important characteristic of TZM molybdenum rod in a high-temperature cycling environment. For example, in high-temperature furnaces, TZM molybdenum rods are used as heating elements to maintain stable performance during repeated heating and cooling cycles. Tests have shown that TZM molybdenum rods are able to withstand thousands of cycles in cycles from 1000°C to room temperature without significant performance degradation. This circularity makes it widely used in high-temperature furnaces and semiconductor equipment manufacturing.

The improvement in fatigue performance and recycling ability is also related to surface quality and microstructure. Surface polishing can reduce surface defects and reduce the probability of fatigue crack initiation. Heat treatment processes, such as annealing, can eliminate machining stress and increase fatigue life. In addition, the addition of an anti-oxidation coating can reduce oxidation losses during high-temperature cycling and extend cycle life.

3.3 Relationship between microstructure and properties of TZM molybdenum rod

The properties of TZM molybdenum rods are closely related to their microstructure, including grain structure and orientation, the role of titanium, zirconium and carbon, as well as surface morphology and high-temperature properties. The following is a detailed analysis from these three aspects.

3.3.1 Grain structure and orientation of TZM molybdenum rods

The grain structure of TZM molybdenum rods is usually controlled by a powder metallurgy process with a grain size between 10-50 microns. The fine grain size increases the strength and toughness of the material, reducing grain boundary slippage and creep at high temperatures. Studies have shown that TZM molybdenum rods have a smaller grain size than pure molybdenum (about 50-100 microns), thanks to the addition of titanium, zirconium and carbon, which inhibit grain growth by forming carbide particles.

Grain orientation also has an important impact on the performance of TZM molybdenum rods. During the rolling or forging process, the grains of the TZM molybdenum rod will form a certain orientation along the processing direction, showing anisotropy. The tensile strength along the rolling direction is usually about 10-15% higher than in the vertical direction. The results show that by controlling the rolling temperature and deformation, the grain orientation can be optimized and the mechanical properties of the material can be improved. For example, hot rolling (about 1400°C) can obtain a more uniform grain orientation and enhance the strength at high temperatures.

The optimization of the grain structure is also related to the heat treatment process. Annealing can relieve processing stress and adjust grain size; The aging treatment promotes the precipitation of carbide particles and enhances the grain boundary strength. Together, these processes ensure the performance stability of TZM molybdenum rods at high temperatures.

3.3.2 The role of titanium, zirconium and carbon

Titanium, zirconium and carbon are the key elements to improve the performance of TZM molybdenum rods, and their roles are mainly reflected in the following aspects:

Titanium (Ti): Titanium improves the lattice strength of molybdenum matrix through solution

strengthening. The solid solution of titanium atoms in the molybdenum lattice causes lattice distortion and hinders the movement of dislocations, thereby improving the high-temperature strength and creep resistance. In addition, titanium reacts with carbon to form titanium carbide (TiC) particles, which enhance the hardness and wear resistance of the material through precipitation strengthening.
Zirconium (Zr): Zirconium acts similarly to titanium, improving the strength and stability of the material through solution strengthening and precipitation strengthening. Zirconium reacts with carbon to form zirconium carbide (ZrC) particles, which are able to pin grain boundaries at high temperatures, preventing grain growth and increasing recrystallization temperatures. Zirconium also enhances the oxidation resistance of TZM molybdenum rods.
Carbon (C): The addition of carbon is the core of the performance improvement of TZM alloys. The carbide particles generated by the reaction of carbon with titanium and zirconium are uniformly distributed in the molybdenum matrix, and the strength, creep resistance and recrystallization temperature of the material are improved by pinning dislocations and grain boundaries. Studies have shown that the size and distribution of carbide particles reach an optimal state when the carbon content is 0.01-0.04%.

According to publicly available information, the synergistic effect of titanium, zirconium and carbon makes TZM molybdenum rods far more efficient than pure molybdenum. For example, at 1400°C, the tensile strength of TZM molybdenum rods is about 2 times higher than that of pure molybdenum, and the creep rate is reduced by about 90%.

3.3.3 Surface morphology and high temperature properties of TZM molybdenum rods

The surface morphology of TZM molybdenum rod has an important influence on its high-temperature performance. Surface defects (e.g., microcracks, porosity) can become stress concentration points, leading to crack propagation at high temperatures. Surface topography can be significantly improved through surface polishing, plasma spraying or coating techniques to improve high-temperature performance.

In the high-temperature oxidation environment, the surface morphology of TZM molybdenum rod will change to form a dense MoO_2 protective layer. The formation of this protective layer is closely related to the surface quality. Studies have shown that TZM molybdenum rods with a high surface finish can form a more uniform oxide layer, thereby improving oxidation resistance. In addition, anti-oxidation coatings, such as molybdenum silicide coatings, can further improve surface topography and extend the life of materials in high-temperature oxidizing environments.

The surface topography also affects the thermal shock resistance of TZM molybdenum rods. The smooth surface reduces thermal stress concentrations and improves thermal shock resistance. In the aerospace sector, the surface of TZM molybdenum rods often needs to be precision machined to meet the requirements of high-temperature cycling environments.

3.4 Life and reliability of TZM molybdenum rod

The longevity and reliability of TZM molybdenum rod are the key indicators for its application in high-temperature and high-stress environments. The following is a detailed analysis from three aspects: life influencing factors, failure mode analysis and reliability test.

3.4.1 Factors influencing the life of TZM molybdenum rods

The life of TZM molybdenum rods is affected by a variety of factors, including operating temperature, stress level, ambient atmosphere, production process and surface treatment, etc.:

Operating temperature: Temperature is the main factor affecting the life of TZM molybdenum rods. Below 1600°C, TZM molybdenum rod can maintain long-term stability; However, above 1800°C, the oxidation and creep rates increase significantly, shortening the lifespan.

Stress level: High stresses can accelerate creep and fatigue failure. For example, at a stress of 1400°C and 50 MPa, the life of a TZM molybdenum rod is about 1/3 that of pure molybdenum.

Ambient atmosphere: In vacuum or inert gas, the life of TZM molybdenum rod can reach thousands of hours; In an oxidizing environment, an anti-oxidation coating is required to prolong the life.

Production process: The sintering temperature, pressure, and heat treatment process in the powder metallurgy process directly affect the grain size and carbide distribution, which in turn affects the lifetime. Optimizing the process can increase the life by 20-30%.

Surface treatment: Anti-oxidation coating and surface polishing can reduce oxidation and crack initiation and prolong life. For example, a silicide molybdenum coating can extend the life of TZM molybdenum rods in an oxidizing environment at 1200°C by a factor of 2-3.

3.4.2 Failure mode analysis of TZM molybdenum rods (e.g. fracture, corrosion)

The failure modes of TZM molybdenum rod mainly include fracture, corrosion and creep failure:

Fracture: Fracture is usually caused by fatigue or thermal stress. In high-temperature cycling, surface defects can trigger crack propagation, leading to brittle or ductile fractures. The results show that the fracture toughness of TZM molybdenum rod (15-20 Mpa·m^1/2) is higher than that of pure molybdenum, but the surface quality still needs to be optimized to reduce the fracture risk.

Corrosion: In a high-temperature oxidizing environment, TZM molybdenum rods may fail due to the spalling of the oxide layer. The formation of volatile MoO_3 accelerates material loss. The anti-oxidation coating can effectively slow down corrosion.

Creep failure: Long-term high-temperature stress can lead to creep failure, which is manifested by slow deformation of the material and loss of strength. The pinning action of the carbide particles significantly reduces the creep rate, but the high stress can still lead to failure.

The failure mode analysis shows that optimizing the surface quality and coating technology is the key to improving the life of TZM molybdenum rods. For example, alumina coatings deposited by CVD can significantly reduce oxidative corrosion.

3.4.3 TZM molybdenum rod reliability test

The reliability test of TZM molybdenum rod usually includes high temperature strength test, creep test, thermal shock test and fatigue test:

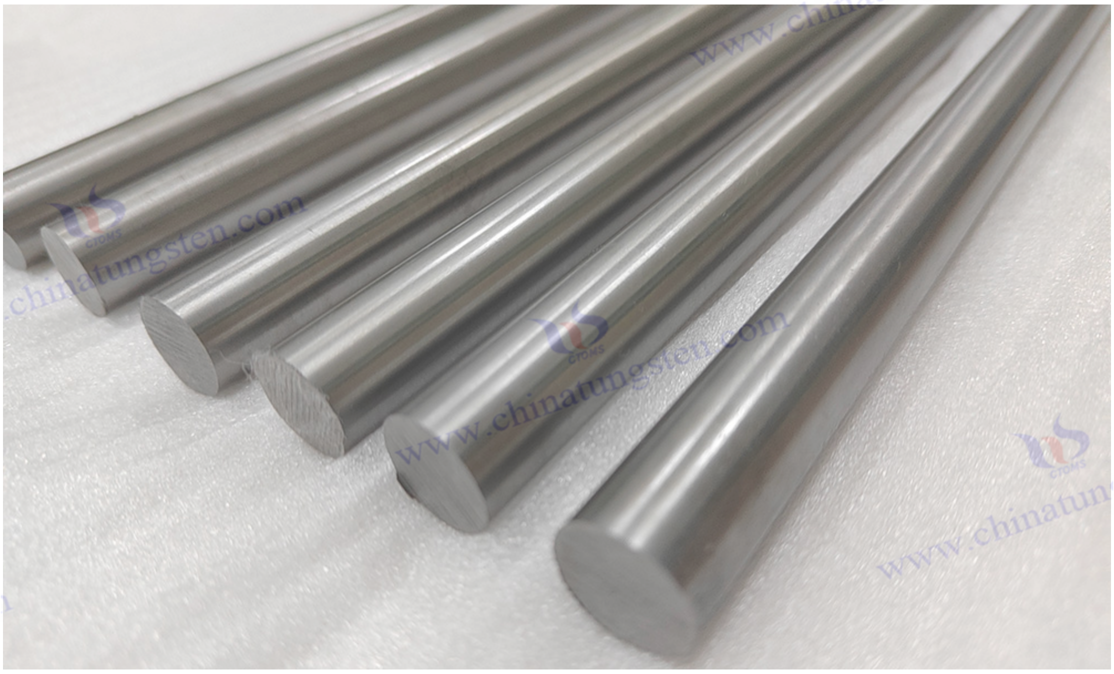
High temperature strength test: Tensile strength and yield strength are tested at 1200-1600°C by tensile testing machine to ensure that the material meets the design requirements.

Creep test: Test the creep rate at 1400°C and 20-50 Mpa stress to evaluate long-term stability. The test results show that the creep life of TZM molybdenum rods far exceeds that of pure molybdenum.

Thermal shock test: Thermal shock resistance is tested by rapid heating and cooling cycles (1000°C to room temperature). TZM molybdenum rods can usually withstand hundreds of cycles without cracking.

Fatigue test: Test the fatigue life under cyclic stress of 1200°C and ±200 Mpa to evaluate the cyclic ability.

The reliability test results show that TZM molybdenum rod has excellent reliability in high temperature and high stress environment, and is suitable for use in aerospace, nuclear industry and semiconductor manufacturing. Through strict quality control and testing, the reliability of TZM molybdenum rod can reach more than 99.9%.



CTIA GROUP LTD TZM Molybdenum Rod

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TZM Molybdenum Rod Introduction

1. Overview of TZM Molybdenum Rod

TZM molybdenum rods are high-performance molybdenum-based alloy materials composed of a molybdenum (Mo) matrix with small additions of titanium (Ti), zirconium (Zr), and carbon (C). Compared to pure molybdenum, TZM alloy offers significantly higher high-temperature strength, excellent thermal stability, superior creep resistance, and outstanding oxidation resistance, making it an ideal material for high-temperature structural applications.

2. Characteristics of TZM Molybdenum Rod

High Melting Point: Suitable for extreme high-temperature environments.

Excellent High-Temperature Strength: Maintains mechanical strength and rigidity at 1200–1600°C.

Good Thermal Stability and Creep Resistance: Ideal for long-term use under high temperatures with minimal deformation and high reliability.

Superior Corrosion and Oxidation Resistance: Applicable in vacuum, high-temperature inert atmospheres, and oxidative conditions.

Excellent Machinability: Suitable for turning, milling, grinding, and welding processes.

3. Typical Applications of TZM Molybdenum Rod

High-Temperature Furnace Components: Supports, heat shields, heating elements, and electrode rods.

Aerospace Industry: Structural components in rocket nozzles and engine parts operating under high temperatures.

Nuclear Industry: Used in reactor support structures and control rod guide systems.

Electronics Industry: Structural materials in ion implantation, evaporation sources, and semiconductor processing equipment.

Mold Manufacturing: Hot extrusion dies, aluminum alloy die-casting molds with excellent high-temperature wear resistance.

4. Specifications of TZM Molybdenum Rod

Main Ingredients	Mo: ≥ 99%
	Ti: 0.40–0.55%
	Zr: 0.06–0.12%
	C: 0.01–0.04%
Size Range	Diameter φ6mm – φ120mm, length up to 2000mm (customizable)
Surface	Black(forged), bright (turned or ground)
Processing Method	Forging, rolling, drawing, or machining forming

5. Procurement Information

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Website: www.molybdenum.com.cn

4. Preparation Process and Technology of TZM Molybdenum Rod

4.1 Selection and preparation of raw materials for TZM molybdenum rods

As a high-performance alloy material, the performance of TZM molybdenum rod is highly dependent on the quality and ratio of raw materials. The selection and preparation of raw materials is the basis for the preparation of TZM molybdenum rods, which directly affects the microstructure and properties of the final product. The following is a detailed analysis from four aspects: molybdenum powder purification, titanium zirconium carbon additive selection, alloy ratio optimization, raw material testing and quality control.

4.1.1 Purification and quality requirements of molybdenum powder

Molybdenum powder is the main raw material of TZM molybdenum rod, and its purity and quality are crucial to the alloy properties. Molybdenum powder is usually prepared by reducing ammonium paratungstate. The purification process mainly consists of the following steps:

Ore purification: Molybdenum powder is usually extracted from molybdenum concentrates such as molybdenum. Molybdenite undergoes flotation and roasting to remove impurities such as sulfur and silicon to obtain high-purity molybdenum trioxide.

Chemical reduction: Molybdenum trioxide is reduced to molybdenum powder in stages under a hydrogen atmosphere. The reduction process is divided into low-temperature reduction (400-600 °C, MoO_2) and high-temperature reduction (800-1000 °C, molybdenum metal powder). The study shows that the modern reduction process adopts a multi-stage reduction furnace to ensure that the purity of molybdenum powder reaches more than 99.95%.

Particle size control: The particle size of molybdenum powder is usually controlled at 1-5 microns, too large particle size will lead to uneven sintering, and too small particle size will increase production costs. The fine and uniform particle size helps to improve the density and mechanical properties of TZM molybdenum rods.

The quality requirements for molybdenum powder include high purity (≥99.95%), low oxygen content (≤0.005%), low impurity content (e.g., iron, silicon, aluminum, etc. ≤0.01%), and uniform particle size distribution. These requirements ensure the stability and corrosion resistance of TZM molybdenum rods at high temperatures.

4.1.2 Selection of titanium, zirconium and carbon additives

The alloying elements of TZM molybdenum rods include titanium (Ti, 0.4-0.55%), zirconium (Zr, 0.06-0.12%), and carbon (C, 0.01-0.04%), and the selection of these additives is critical to alloy properties:

Titanium (Ti): Titanium is usually added in the form of high-purity titanium powders (≥ 99.9% purity) or titanium compounds (e.g., TiH_2). The particle size of titanium powder is controlled at 1-10 microns to ensure uniform mixing with molybdenum powder. The addition of titanium improves the high-temperature strength and creep resistance of the alloy through solution strengthening and precipitation strengthening (generating TiC particles).

Zirconium (Zr): Zirconium is added in the form of high-purity zirconium powder (purity ≥ 99.9%) or zirconium compound (e.g., ZrH_2), typically with a particle size of 1-5 microns. Zirconium enhances the oxidation resistance and recrystallization temperature of the alloy through solution strengthening and the formation of ZrC particles.

Carbon (C): Carbon is usually added in the form of graphite powder or carbon black, the purity needs to reach more than 99.99%, and the particle size is controlled at 0.5-2 microns. Carbon reacts with titanium and zirconium to form carbide particles (TiC and ZrC), which are strengthened by precipitation to improve the hardness and creep resistance of the alloy.

Studies have shown that additives are selected based on their chemical activity, particle size distribution, and compatibility with molybdenum powder. For example, hydrides of titanium and zirconium decompose during the sintering process to release hydrogen, which helps to reduce oxygen content and improve alloy purity.

4.1.3 Optimization of alloy ratio

The alloy ratio of TZM molybdenum rod (Mo: 99.38-99.5%, Ti: 0.4-0.55%, Zr: 0.06-0.12%, C: 0.01-0.04%) needs to be optimized through experiments and simulations to balance strength, toughness and oxidation resistance. Key points of ratio optimization include:

Ratio of titanium and zirconium: The ratio of titanium and zirconium is typically 5:1 to 8:1 to ensure the synergistic effect of solution strengthening. Too high a titanium content can lead to increased brittleness, and too high a zirconium content can increase costs.

Carbon content control: The carbon content needs to be accurately controlled at 0.01-0.04%, too low will lead to insufficient carbide particles and reduce the strengthening effect; Too high may result in the formation of too much carbide and reduced toughness.

Homogeneity: Uniform distribution of titanium, zirconium and carbon in molybdenum powder is ensured by mechanical mixing or ball milling process to avoid local segregation affecting performance.

The results show that the optimal ratio can increase the tensile strength of TZM molybdenum rod by 10-15% and reduce the creep rate by 20-30%.

4.1.4 Testing and quality control of raw materials

The quality control of raw materials is a key part of ensuring the consistency of the performance of TZM molybdenum rods. Assays include:

Chemical composition analysis: Inductively coupled plasma emission spectroscopy (ICP-OES) or X-ray fluorescence spectroscopy (XRF) was used to detect the content of molybdenum, titanium, zirconium and carbon to ensure that the ratio requirements were met.

Particle size analysis: The particle size distribution of the powder is measured by the laser particle size analyzer to ensure the particle size uniformity.

Impurity detection: Glow discharge mass spectrometry (GDMS) is used to detect the content of impurities such as oxygen, nitrogen, and iron to ensure that it is below the standard limit.

Microstructure analysis: Scanning electron microscopy (SEM) and X-ray diffraction (XRD) are used to analyze the topography and crystal structure of powders to ensure defect-free and segregation-free.

Research shows that the world's leading producer of TZM molybdenum rods uses an ISO 9001 quality management system to ensure the quality of raw materials through multi-level testing. Quality control also includes supplier audits, batch tracking, and production process monitoring to guarantee consistency and traceability of raw materials.

4.2 TZM molybdenum rod metallurgical process

The metallurgical process of TZM molybdenum rods includes steps such as powder mixing and pressing, sintering, forging and rolling, and extrusion and drawing. These processes directly determine the microstructure and properties of TZM molybdenum rods. The following is an analysis of the details and technical points of each sub-process.

4.2.1 Powder mixing and pressing

4.2.1.1 Mechanical alloying technology

Mechanical alloying is a key step in the preparation of TZM molybdenum rods, where molybdenum powder, titanium powder, zirconium powder and toner powder are mixed evenly by high-energy ball milling. The main parameters of mechanical alloying include:

Ball mill equipment: planetary ball mill or vibrating ball mill, the grinding medium is usually tungsten carbide powder balls.

Pellet ratio: typically 10:1 to 20:1 to ensure efficient mixing and grinding.

Grinding time: 6-12 hours, too long may introduce impurities, too short will not mix evenly.

Atmosphere control: carried out under the protection of argon or nitrogen to avoid oxidation.

Mechanical alloying not only achieves uniform mixing of powders, but also enhances the solid solution effect of titanium, zirconium and molybdenum through high-energy collision induced microstructural changes. Studies have shown that mechanical alloying can increase the mixing uniformity of powders to more than 99%, significantly improving the quality of subsequent sintering.

4.2.1.2 Isostatic pressing process

Isostatic press molding (CIP) is a key process for pressing mixed powders into blanks. Isostatic pressure forming ensures a uniform density of the blank by applying uniform pressure to a liquid medium, such as water or oil. The main parameters include:

Pressure: 150-300 MPa, too high may cause cracks in the billet, too low will cause insufficient density.

Mold material: high-strength rubber or polyurethane mold, pressure resistance and good flexibility.

Billet density: 60-70% of the theoretical density, which provides the basis for subsequent sintering.

The advantage of isostatic pressing is the ability to prepare blanks with complex shapes, reducing the amount of subsequent processing. Studies have shown that the combination of cold isostatic pressing (CIP) and hot isostatic pressing (HIP) can further increase the density of the billet to more than 90% of the theoretical density.

4.2.2 Sintering process

4.2.2.1 Vacuum sintering technology

Vacuum sintering is the core process in the preparation of TZM molybdenum rods, which solidifies the blank into a high-density alloy through high-temperature sintering. The main parameters include:

Temperature: 1800-2000 °C, lower than the melting point of molybdenum (2623 °C), avoid liquid phase sintering.

Vacuum: 10^{-3}-10^{-5} Pa to reduce oxygen and nitrogen pollution.

Holding time: 2-4 hours to ensure the uniform precipitation of carbide particles.

Vacuum sintering can effectively remove the pores in the blank and increase the density to more than 98% of the theoretical density. The world's leading vacuum sintering furnace uses tungsten wire heating elements to ensure temperature uniformity.

4.2.2.2 Atmosphere sintering and temperature control

In some cases, TZM molybdenum rods are sintered in an atmosphere (e.g. hydrogen or argon atmosphere) to reduce costs. The main parameters of atmosphere sintering include:

Atmosphere: High purity hydrogen (purity≥99.999%) or argon, avoid oxidation.

Temperature control: Multi-stage heating curves (such as 1000°C pre-sintering, 1800°C main sintering) are used to avoid cracks caused by rapid temperature rise.

Cooling rate: controlled at 5-10°C/min to prevent cracks caused by thermal stress.

The advantage of atmosphere sintering is that the cost is lower, but the atmosphere purity needs to be strictly controlled to avoid contamination by impurities. Studies have shown that the density of atmosphere-sintered TZM molybdenum rods can reach 95-97% of the theoretical density.

4.2.3 Forging and rolling

4.2.3.1 Hot forging and cold forging processes

Forging is an important step in the preparation of TZM molybdenum rods to improve the density and mechanical properties of the blank. The hot forging and cold forging processes are as follows:

Hot forging: Performed at 1200-1600°C, using the ductility of molybdenum to improve the grain structure. The hot forging pressure is usually 50-100 MPa, and the deformation is controlled at 30-50%.

Cold forging: Performed at room temperature for finishing and improving surface quality. Cold forging requires higher pressures (100-200 MPa), but can significantly increase strength.

Hot forging eliminates micropores in the sintered blank and increases the density to more than 99% of the theoretical density. Cold forging further optimizes the grain orientation and enhances the anisotropy strength.

4.2.3.2 Rolling equipment and process parameters

Rolling is a key process for processing forged blanks into bars. The rolling equipment includes four-high rolling mills and multi-high rolling mills, and the main parameters include:

Rolling temperature: 1000-1400°C to ensure the ductility of the material.
Deformation: The deformation of a single rolling is controlled at 10-20% to avoid cracks.
Rolling speed: 0.5-2 m/s, balancing efficiency and quality.

The rolling process can significantly improve the surface quality and dimensional accuracy of TZM molybdenum rods. The study shows that modern rolling equipment adopts servo control system to ensure precise control of rolling parameters.

4.2.4 Extrusion and drawing

4.2.4.1 High-temperature extrusion technology

High-temperature extrusion is the process of processing rolled blanks into elongated bars, usually at 1200-1600°C. The main parameters include:

Extrusion ratio: 5:1 to 10:1 to ensure uniform deformation.
Mold material: tungsten carbide or high-temperature alloy, wear-resistant and high-temperature resistant.
Lubricant: Graphite or molybdenum disulfide to reduces friction and die wear.

High-temperature extrusion can significantly improve the density and mechanical properties of TZM molybdenum bar, which is suitable for the preparation of high-precision bars.

4.2.4.2 Drawing dies and lubricants

Drawing is the process of finishing TZM molybdenum rods to obtain high precision and smooth surfaces. The main parameters include:

Mold material: tungsten carbide or diamond mold, high hardness, wear resistance.
Drawing speed: 0.1-0.5 m/s to avoid scratches on the surface.
Lubricants: dry lubrication (e.g. graphite powder) or wet lubrication (e.g. oil-based lubricants).

The drawing process can improve the surface roughness of TZM molybdenum rod and improve the fatigue resistance.

4.3 TZM molybdenum rod processing and finishing

The machining and finishing processes of TZM molybdenum rods include turning and milling, grinding and polishing, heat treatment and annealing, and surface treatment. These processes ensure the dimensional accuracy, surface quality and performance stability of TZM molybdenum rods.

4.3.1 Turning and milling

4.3.1.1 CNC machining technology

Numerical Control Machining (CNC) is the primary method of finishing TZM molybdenum rods for the manufacture of complex-shaped components. The main parameters include:

Tool material: tungsten carbide or polycrystalline diamond (PCD), high hardness and wear resistance.

Cutting speed: 50-100 m/min, avoid overheating.

Feed: 0.05-0.2 mm/rev, balancing efficiency and surface quality.

CNC machining enables the dimensional accuracy of TZM molybdenum rods to reach ±0.05 mm, which meets the requirements of aerospace and semiconductor equipment. Studies have shown that modern CNC machining centers are capable of machining complex geometries using five-axis linkage technology.

4.3.1.2 Machining accuracy and surface roughness

The machining accuracy and surface roughness of TZM molybdenum rod have an important impact on its performance. Increasing the surface roughness (Ra) will reduce stress concentrations and crack initiation. The control of machining accuracy relies on high-precision machine tools and strict optimization of process parameters. For example, the use of low-speed cutting and coolant can reduce the heat-affected zone and improve surface quality.

4.3.2 Grinding and polishing

4.3.2.1 Mechanical polishing technology

Mechanical polishing removes tiny defects on the surface of TZM molybdenum rods through a grinding wheel or polishing cloth to improve the surface finish. The main parameters include:

Abrasive: diamond or alumina, particle size 0.5-5 microns.

Polishing speed: 1000-3000 rpm, control frictional heat.

Polishing medium: water-based or oil-based polishing slurry.

Mechanical polishing improves surface roughness and significantly improves fatigue resistance.

4.3.2.2 Chemical polishing and electropolishing

Chemical polishing and electropolishing are used to further improve the surface quality of TZM molybdenum rods:

Chemical polishing: Corrosion of surface micro-defects with acidic solutions (such as a mixture of nitric acid and sulfuric acid) with a surface roughness of up to 0.02 microns.

Electropolishing: Removal of surface material by anodic dissolution in an electrolyte, suitable for high-precision parts. The electropolishing voltage is typically 10-20 V and the current density is

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0.5-2 A/cm².

Chemical polishing and electropolishing can significantly improve the corrosion resistance and surface finish of TZM molybdenum rods.

4.3.3 Heat treatment and annealing

4.3.3.1 Annealing temperature and grain control

Annealing is a key process for relieving processing stress and optimizing grain structure. The annealing of TZM molybdenum rods is usually carried out in a vacuum or inert atmosphere at a temperature of 1000-1400°C. The main parameters include:

Annealing temperature: 1200°C to relieve most of the stress, 1400°C to adjust the grain size.
Holding time: 1-2 hours to ensure grain homogenization.
Cooling rate: 5-10°C/min to avoid thermal stress.

Annealing can control the grain size of TZM molybdenum rods to 10-30 microns, improving toughness and creep resistance.

4.3.3.2 Stress relief techniques

Stress relief techniques include low-temperature annealing (800-1000°C) and vibration stress relief. Low-temperature annealing is suitable for machined components, while vibration stress relief relieves residual stresses through mechanical vibration. These technologies can improve the fatigue life and dimensional stability of TZM molybdenum rods.

4.3.4 Surface Treatment

4.3.4.1 Antioxidant coating technology

Anti-oxidation coating is a key technology to prolong the life of TZM molybdenum rods in high-temperature oxidizing environments. Commonly used coatings include:

Molybdenum silicide ($MoSi_2$) coating: Deposition by chemical vapor deposition (CVD) or plasma spray deposition protects the material at 1500°C.

Alumina (Al_2O_3) coating: Resistant to high-temperature oxidation and corrosion by physical vapor deposition (PVD) deposition.

The anti-oxidation coating can extend the life of TZM molybdenum rods in an oxidizing environment at 1200°C by 2-3 times.

4.3.4.2 Surface carburizing and nitriding

Surface carburizing and nitriding improve surface hardness and wear resistance by introducing carbon or nitrogen atoms into the surface of TZM molybdenum rods:

Carburizing: Carried out in a carbon atmosphere of 1000-1200 °C to generate a carbide layer with a hardness of up to 500 HV.

Nitriding: Carried out in a nitrogen atmosphere of 800-1000°C to generate a nitride layer and improve corrosion resistance.

The carburizing and nitriding processes can significantly improve the wear resistance and fatigue resistance of TZM molybdenum rods.

4.4 TZM molybdenum rod production equipment and automation

The production equipment and automation technology of TZM molybdenum rod are crucial to production efficiency and product quality. The following is analyzed from three aspects: key production equipment, production line automation and intelligence, clean room and environmental control.

4.4.1 Key production equipment

4.4.1.1 Vacuum sintering furnaces

The vacuum sintering furnace is the core equipment in the production of TZM molybdenum rods, which is used to sinter powder blanks into high-density alloys. Key features include:

Heating element: Tungsten heater, high temperature resistance and uniform heat conduction.
Vacuum: 10^{-3}-10^{-5} Pa to reduce oxidative pollution.
Temperature control: the accuracy ± 5°C to ensure the uniformity of sintering.

The world's leading vacuum sintering furnace adopts PLC control system, which can achieve multi-stage heating and precise temperature control.

4.4.1.2 Forging and rolling equipment

The forging and rolling equipment includes a hydraulic forging machine and a four-high rolling mill, and the main features include:

Forging machine: pressure 500-2000 tons, suitable for hot forging and cold forging.
Rolling mill: servo control system, rolling speed 0.5-2 m/s, accuracy ± 0.05 mm.

These machines are capable of high-density and high-precision machining of TZM molybdenum rods.

4.4.1.3 CNC machining centers

The CNC machining center is used for the finishing of TZM molybdenum rods, and is equipped with a five-axis linkage system and tungsten carbide tools, which can realize the machining of complex shapes. The machining accuracy can reach ±0.01 mm, and the surface roughness Ra < 1.6 microns.

4.4.2 Automation and intelligence of production lines

The automation and intelligence of TZM molybdenum rod production line significantly improve production efficiency and quality consistency. Key technologies include:

Automatic control: PLC and SCADA systems are used to monitor sintering, forging and processing parameters in real time.

Intelligent Inspection: Real-time monitoring of blanks and finished products for defects through in-line X-ray inspection and ultrasonic inspection.

Data analytics: Leverage big data and artificial intelligence to optimize process parameters and improve product consistency.

Studies have shown that intelligent production lines can increase production efficiency by 30% and reduce the defective rate to less than 1%.

4.4.3 Cleanroom and environmental control in production

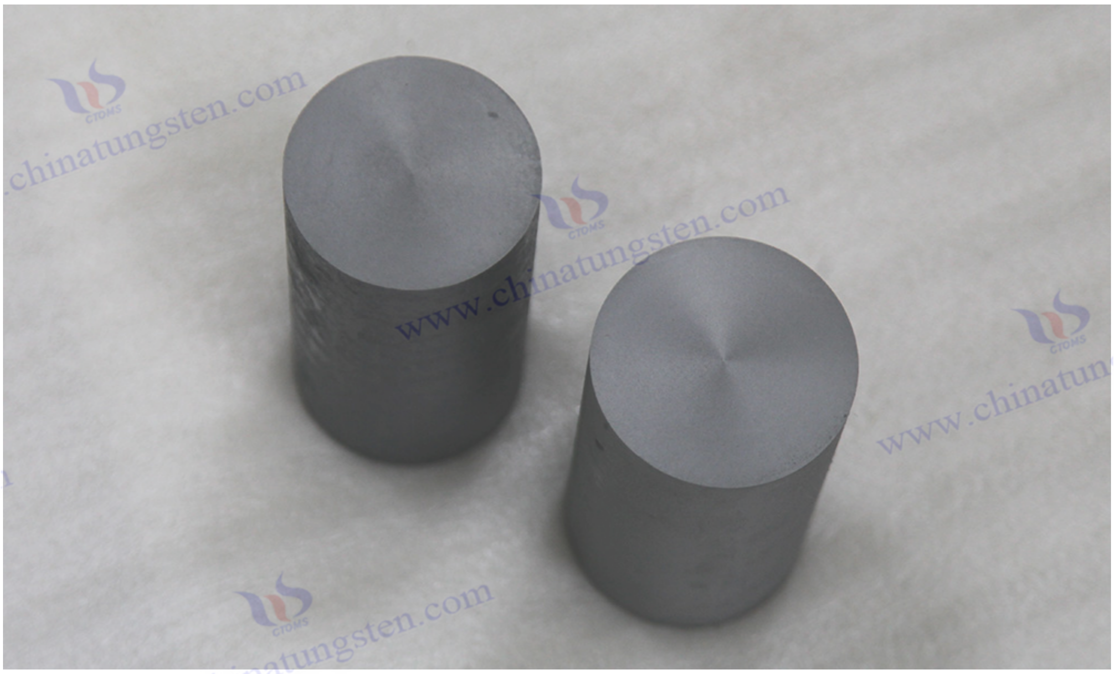
The production of TZM molybdenum rods is environmentally demanding and needs to be carried out in a clean room to avoid dust and impurity contamination. Key measures include:

Cleanliness: ISO Class 7 cleanroom, particle concentration < 10,000 particles/m³.

Environmental control: temperature 20-25°C, humidity 40-60%, avoid powder moisture absorption.

Atmosphere protection: Powder mixing and sintering are carried out under the protection of argon or hydrogen with an oxygen content of < 10 ppm.

Cleanroom and environmental controls ensure high purity and performance stability of TZM molybdenum rods, making them particularly suitable for semiconductor and aerospace applications.



CTIA GROUP LTD TZM Molybdenum Rod

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High Melting Point: Suitable for extreme high-temperature environments.

Excellent High-Temperature Strength: Maintains mechanical strength and rigidity at 1200–1600°C.

Good Thermal Stability and Creep Resistance: Ideal for long-term use under high temperatures with minimal deformation and high reliability.

Superior Corrosion and Oxidation Resistance: Applicable in vacuum, high-temperature inert atmospheres, and oxidative conditions.

Excellent Machinability: Suitable for turning, milling, grinding, and welding processes.

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High-Temperature Furnace Components: Supports, heat shields, heating elements, and electrode rods.

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5. Quality Control and Testing of TZM Molybdenum Rod

As a high-performance alloy material, the quality control and inspection of TZM molybdenum rod is the key to ensure its stable operation in high-temperature, high-stress and corrosive environments. Quality control runs through the entire production process from raw material selection to finished product inspection, involving multiple aspects such as online testing technology, performance testing and failure analysis. The following is a detailed analysis of the quality control and testing technology of TZM molybdenum rod from three sub-chapters: online testing technology, performance testing, and failure analysis and improvement.

5.1 TZM molybdenum rod on-line detection technology

In-line inspection technology is an important part of the production process of TZM molybdenum rods, which is used to monitor product quality in real time and ensure dimensional accuracy, surface quality and integrity of internal structure. The following is a detailed analysis from two aspects: dimensional and geometric accuracy inspection, and surface defect and crack detection.

5.1.1 Dimensional and geometric accuracy testing

The size and geometric accuracy of TZM molybdenum rod directly affect its application effect in aerospace, nuclear industry and semiconductor equipment. Dimensional and geometric accuracy testing mainly includes the following technologies:

Laser ranging and three-coordinate measurement: The laser rangefinder can achieve non-contact high-precision measurement with an accuracy of ±0.01 mm, which is suitable for detecting the diameter, length and roundness of TZM molybdenum rods. Coordinate measuring machines (CMMs) measure the geometry of bars with a tactile probe and are able to detect dimensional deviations in complex shapes. For example, in the aerospace industry, TZM molybdenum rods are required to have diameter tolerances within ±0.02 mm, and CMMs are able to meet this requirement.

Optical Profiler: The optical profiler measures the surface profile and geometry of TZM molybdenum rods by white light interferometry, which is suitable for detecting the cylindricity and straightness of the bars. With a resolution of up to 0.1 microns, it is suitable for high-precision applications.

On-line visual inspection system: Modern production line adopts CCD camera and image processing technology to monitor the size and geometry of TZM molybdenum rod in real time. The system uses machine learning algorithms to identify dimensional deviations, and the detection speed can reach 10 pieces per second, which significantly improves production efficiency.

Studies have shown that dimensional and geometric accuracy inspections are often combined with the ISO 1101 standard to ensure that TZM molybdenum rods meet the stringent requirements of aerospace (e.g., rocket nozzles) and semiconductor equipment (e.g., sputtering targets). The ambient temperature (20-25°C) and humidity (40-60%) should be controlled during the inspection process to avoid measurement errors caused by thermal expansion or humidity.

5.1.2 Surface defect and crack detection

Surface defects (e.g. scratches, cracks, porosity) and internal cracks can significantly reduce the mechanical properties and service life of TZM molybdenum rods. Surface defect and crack detection uses the following techniques:

Ultrasonic Testing (UT): Ultrasonic testing detects cracks, pores, and inclusions inside TZM molybdenum rods through high-frequency acoustic waves. The inspection frequency is typically 5-10 MHz, the probe diameter is 5-10 mm, and it is capable of detecting defects above 0.1 mm. Ultrasonic testing is suitable for assessing the integrity of the internal structure of bars, especially in the nuclear industry.

Eddy current testing (ET): Eddy current testing detects microscopic cracks and conductivity changes on the surface of TZM molybdenum rods by electromagnetic induction. The detection sensitivity can reach 0.05 mm, which is suitable for in-line detection. The advantage of eddy current testing is that it is fast (up to 1 m/s) and is suitable for high-volume production.

X-ray Inspection (RT): X-ray inspection is used to detect deep defects such as porosity and inclusions inside TZM molybdenum rods. Modern digital X-ray imaging systems provide high-resolution images (resolution < 0.1 mm) for the inspection of highly reliable components.

Surface visual inspection: The high-resolution CCD camera combined with artificial intelligence algorithms can detect scratches, pits, and oxide layers on the surface of TZM molybdenum rods with an accuracy of up to 0.01 mm. Studies have shown that the visual inspection system can reduce the defective rate to less than 0.5% in the production of TZM molybdenum rods.

These inspection techniques are often used in combination to achieve comprehensive inspection of surface and interior defects. For example, ultrasonic and X-ray inspection is used for internal defects, and eddy current and visual inspection is used for surface defects. Test results are subject to international standards such as ASTM E1444 (eddy current testing) and ASTM E1742 (X-ray testing).

5.2 TZM molybdenum rod performance test

Performance testing is a critical step in evaluating the performance of TZM molybdenum rods in high-temperature, high-stress, and corrosive environments. The following is a detailed analysis from three aspects: high-temperature strength and hardness test, corrosion resistance and oxidation resistance test, and thermal expansion and thermal conductivity test.

5.2.1 High temperature strength and hardness test

The high-temperature strength and hardness of TZM molybdenum rod are its core performance indicators in the aerospace and nuclear industries. Test methods include:

High-temperature tensile testing: Performed in a vacuum or inert atmosphere of 1200-1600°C, using a high-temperature tensile testing machine (such as the Instron 5980 series). The test results show that the tensile strength of TZM molybdenum rod at 1200°C is 400-500 MPa, which is much higher than that of pure molybdenum at 200-300 MPa. The test is required to comply with ASTM E21 standard to ensure temperature control accuracy ± 5°C.

High-temperature compression test: used to evaluate the compressive strength of TZM molybdenum rods at high temperatures, usually performed at 1400°C and 50 MPa. The test results show that the yield strength of TZM molybdenum rod is about 300-400 MPa, which is suitable for high-temperature mold applications.

Hardness test: Vickers hardness tester (HV) or Rockwell hardness tester (HRC) is used to test the hardness of TZM molybdenum rods. The Vickers hardness of TZM molybdenum rod at room temperature is 250-300 HV, which is higher than that of pure molybdenum at 200 HV. The high-temperature hardness test (1000°C) showed that the hardness of TZM molybdenum rod decreased by only 10-15%, showing excellent high-temperature stability.

Micro hardness test: The microscopic hardness of TZM molybdenum rod is measured by nanoindentation technology to evaluate the strengthening effect of carbide particles (such as TiC and ZrC). The test results showed that the hardness of the carbide particle area was up to 500 HV.

Studies have shown that high-temperature strength and hardness testing is combined with microstructural analysis (e.g., SEM, XRD) to evaluate the strengthening effects of titanium, zirconium and carbon.

5.2.2 Corrosion resistance and oxidation resistance test

The corrosion and oxidation resistance of TZM molybdenum rods is the key to their application in high-temperature chemical environments. Test methods include:

Antioxidant test: Carried out in an air or oxygen atmosphere of 1000-1200°C, the oxidative weight gain rate and oxide layer thickness of TZM molybdenum rod were measured. The test results show that TZM molybdenum rod can form a dense MoO_2 protective layer below 1000°C, and the oxidative weight gain rate is less than 0.1 $mg/cm^2 \cdot h$, which is much better than that of pure molybdenum (1-2 $mg/cm^2 \cdot h$). Anti-oxidation coatings, such as molybdenum silicide, can increase the service temperature up to 1500°C.

Corrosion Resistance Test: Corrosion rate test in dilute sulfuric acid, hydrochloric acid and alkaline solution. The test results show that the corrosion rate of TZM molybdenum rod in 5% sulfuric acid solution is about 0.01 mm/year, which is much lower than that of stainless steel 0.1 mm/year.

Electrochemical test: The corrosion potential and corrosion current density of TZM molybdenum rod are measured by potentiodynamic scanning method to evaluate its stability in corrosive environment. The test results show that the corrosion potential of TZM molybdenum rod is higher than that of pure molybdenum, and it shows better corrosion resistance.

Studies have shown that oxidation and corrosion resistance testing needs to be combined with real-world application environments, such as nuclear reactor coolants or semiconductor manufacturing atmospheres, to ensure the reliability of test results.

5.2.3 Thermal expansion and thermal conductivity test

Thermal expansion and thermal conductivity are the key performance parameters of TZM molybdenum rods in high-temperature applications. Test methods include:

Thermal expansion test: The coefficient of thermal expansion of TZM molybdenum rods is measured at room temperature to 1600°C using an dilatometer (e.g., NETZSCH DIL 402). The test results show that the coefficient of thermal expansion of TZM molybdenum rod is 5.3×10^{-6}/K, which is lower than that of nickel-based alloys of 13×10^{-6}/K, showing excellent dimensional stability.

Thermal conductivity test: The thermal conductivity of TZM molybdenum rods is measured by laser flash method (LFA). The test results show that the thermal conductivity of TZM molybdenum rod is 139 W/m·K, which only decreases by 10-15% at 1200°C, which is suitable for high-temperature heat dissipation applications.

Thermal diffusivity test: The thermal diffusivity of TZM molybdenum rod is calculated by combining density and specific heat data by laser flash method, and its heat conduction efficiency is evaluated. The test results show that the thermal diffusivity of TZM molybdenum rod remains stable at high temperatures.

These tests are required to comply with ASTM E228 (Thermal Expansion) and ASTM E1461 (Thermal Conductivity) standards to ensure data accuracy and repeatability. The atmosphere (e.g. argon or vacuum) needs to be controlled during the test to avoid oxidation affecting the measurement results.

5.3 Failure analysis and improvement of TZM molybdenum rod

Failure analysis is an important means to improve the quality and reliability of TZM molybdenum rods, and targeted improvement measures are proposed by analyzing the failure modes such as crack, fracture, high temperature fatigue and creep. The following is a detailed analysis from three aspects: crack and fracture analysis, high-temperature fatigue and creep analysis, and quality improvement measures.

5.3.1 Crack and fracture analysis

Crack and fracture are the main failure modes of TZM molybdenum rods in high-temperature and high-stress environments. Analytical methods include:

Fracture analysis: Observe the fracture morphology of TZM molybdenum rod by scanning electron microscope (SEM) to determine the fracture type (ductile fracture or brittle fracture). The results show that the fracture toughness of TZM molybdenum rod is 15-20 MPa·m^1/2, which is higher than that of pure molybdenum 10-12 MPa·m^1/2, but high-temperature cyclic stress may cause microcracks.

Crack Propagation Analysis: Electron Backscatter Diffraction (EBSD) is used to analyze crack propagation paths to evaluate the role of grain boundaries and carbide particles. The results show that carbide particles can effectively hinder crack propagation and improve fracture resistance.

Stress concentration analysis: The stress distribution of TZM molybdenum rod at high temperature is simulated by finite element analysis (FEA) to identify the crack initiation location. Surface defects (e.g., scratches, porosity) are major stress concentrations.

Studies have shown that cracks and fractures are often associated with surface quality and microstructural defects. For example, surface scratches during machining can trigger fatigue cracks, and pores during sintering can cause brittle fractures.

5.3.2 High temperature fatigue and creep analysis

High temperature fatigue and creep are the main failure modes of TZM molybdenum rod in long-term high temperature stress environment. Analytical methods include:

High temperature fatigue test: Fatigue test was performed under cyclic stress of 1200°C and ±200 MPa to evaluate the fatigue life of TZM molybdenum rod. The test results show that the fatigue life of TZM molybdenum rod is 10^5 cycles, which is much higher than that of pure molybdenum 10^4 cycles. Fatigue cracks usually arise from surface defects or grain boundaries, and carbide particles are able to slow crack propagation.

Creep test: The creep test was performed at 1400°C and 20 MPa to measure the creep rate and lifetime of the TZM molybdenum rod. The test results show that the creep rate of TZM molybdenum rod is about 1/10 of that of pure molybdenum, and the service life can reach 5000 hours. Creep failure is mainly caused by grain boundary slippage and dislocation climbing, and the pinning effect of carbide particles significantly reduces the creep rate.

Microstructure analysis: Transmission electron microscopy (TEM) was used to observe the dislocation and grain boundary changes of TZM molybdenum rods during high-temperature fatigue and creep processes. The results show that the solution strengthening of titanium and zirconium and the precipitation strengthening of carbide particles can effectively improve the fatigue resistance and creep resistance.

Studies have shown that high-temperature fatigue and creep analysis needs to be combined with real-world application environments, such as aerospace high-temperature cycles or long-term nuclear reactor operation, to accurately assess failure mechanisms.

5.3.3 Quality Improvement Measures

Based on the failure analysis results, the quality improvement measures of TZM molybdenum rod mainly include the following aspects:

Optimized surface quality: Mechanical, chemical, and electropolishing reduces the surface roughness to less than 1.6 microns and reduces crack initiation points. Anti-oxidation coatings (e.g. molybdenum silicide, alumina) can further improve corrosion resistance.

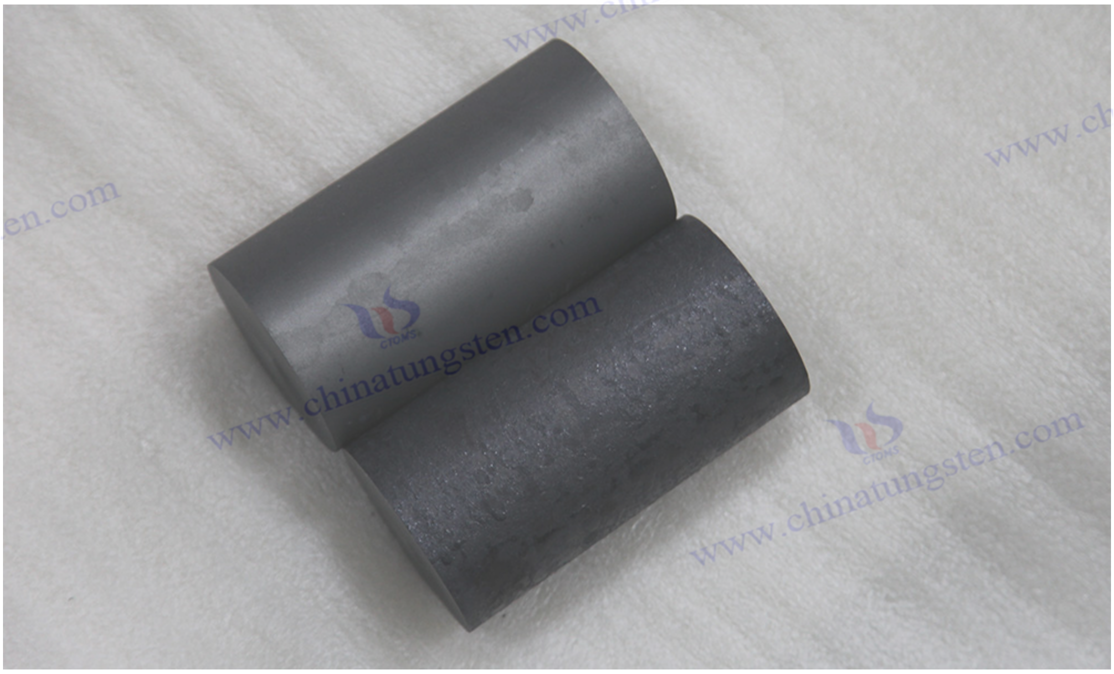
Improved microstructure: Finer grains (3.0~5.0 microns) are obtained by optimizing the powder metallurgy process (e.g., reducing the sintering temperature to 1800°C and controlling the cooling rate) to improve fatigue and creep resistance.

Enhanced production process control: Adopt online inspection technology (such as ultrasonic, X-ray) and intelligent production lines to monitor defects and performance parameters in real time to ensure product consistency.

Development of new coatings: Research on new anti-oxidation and anti-corrosion coatings (such as nanocomposite coatings) to improve the life of TZM molybdenum rods in environments above 1500°C.

Quality Management System: Implement ISO 9001 and AS9100 (Aerospace) quality management systems to ensure quality control from raw materials to finished products.

The study shows that through the above improvement measures, the defective rate of TZM molybdenum rod can be reduced to less than 0.5%, and the service life can be increased by 20-30%, which meets the high reliability requirements of aerospace, nuclear industry and semiconductor equipment.



CTIA GROUP LTD TZM Molybdenum Rod

6. Use of TZM Molybdenum Rod

As a high-performance alloy material, TZM molybdenum rod has been widely used in many high-tech fields due to its excellent high-temperature strength, creep resistance, low thermal expansion coefficient and high thermal conductivity. The addition of titanium (Ti), zirconium (Zr) and carbon (C) to TZM molybdenum rods (molybdenum) significantly improves the properties of molybdenum, making them ideal for high-temperature furnaces, aerospace, nuclear industry, electronics and semiconductor industries, and other industrial and scientific fields. The following is a detailed discussion of the use of TZM molybdenum rod from five aspects.

6.1 Applications in high-temperature furnaces

TZM molybdenum rods play a key role in the manufacture of high-temperature furnaces, due to their high melting point (about 2623°C), excellent creep resistance and oxidation resistance, and can operate stably for a long time in high-temperature environments above 1600°C. The following analyzes its application from three aspects: heating element, vacuum sintering furnace and heat treatment furnace.

CTIA GROUP LTD

TZM Molybdenum Rod Introduction

1. Overview of TZM Molybdenum Rod

TZM molybdenum rods are high-performance molybdenum-based alloy materials composed of a molybdenum (Mo) matrix with small additions of titanium (Ti), zirconium (Zr), and carbon (C). Compared to pure molybdenum, TZM alloy offers significantly higher high-temperature strength, excellent thermal stability, superior creep resistance, and outstanding oxidation resistance, making it an ideal material for high-temperature structural applications.

2. Characteristics of TZM Molybdenum Rod

High Melting Point: Suitable for extreme high-temperature environments.

Excellent High-Temperature Strength: Maintains mechanical strength and rigidity at 1200–1600°C.

Good Thermal Stability and Creep Resistance: Ideal for long-term use under high temperatures with minimal deformation and high reliability.

Superior Corrosion and Oxidation Resistance: Applicable in vacuum, high-temperature inert atmospheres, and oxidative conditions.

Excellent Machinability: Suitable for turning, milling, grinding, and welding processes.

3. Typical Applications of TZM Molybdenum Rod

High-Temperature Furnace Components: Supports, heat shields, heating elements, and electrode rods.

Aerospace Industry: Structural components in rocket nozzles and engine parts operating under high temperatures.

Nuclear Industry: Used in reactor support structures and control rod guide systems.

Electronics Industry: Structural materials in ion implantation, evaporation sources, and semiconductor processing equipment.

Mold Manufacturing: Hot extrusion dies, aluminum alloy die-casting molds with excellent high-temperature wear resistance.

4. Specifications of TZM Molybdenum Rod

Main Ingredients	Mo: ≥ 99%
	Ti: 0.40–0.55%
	Zr: 0.06–0.12%
	C: 0.01–0.04%
Size Range	Diameter φ6mm – φ120mm, length up to 2000mm (customizable)
Surface	Black(forged), bright (turned or ground)
Processing Method	Forging, rolling, drawing, or machining forming

5. Procurement Information

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6.1.1 as a heating element

TZM molybdenum rod is widely used as a heating element in high-temperature furnaces due to its high thermal conductivity (139 W/m·K) and excellent resistance to high-temperature deformation. Compared with pure molybdenum, TZM molybdenum rods have a recrystallization temperature of up to 1400°C, which can maintain a fine grain structure at high temperatures and avoid performance degradation due to grain growth. In resistance furnaces, TZM molybdenum rods are used as heating elements to withstand rapid heating and cooling cycles, maintaining long-term stability.

Specific applications include:

Vacuum furnace: TZM molybdenum rod acts as a heating element in a vacuum environment and is capable of running for thousands of hours at 1600-1800°C, suitable for the sintering of metals and ceramics. For example, in titanium alloy and zirconia sintering furnaces, TZM molybdenum rods ensure temperature uniformity and stability.

Atmosphere protection furnace: In the argon or nitrogen protective atmosphere, the oxidation resistance of TZM molybdenum rod enables it to withstand high-temperature oxidation stress and prolong the service life. According to Chinatungsten Online, the life of the heating element of TZM molybdenum rod is about 50% longer than that of pure molybdenum.

High temperature annealing furnace: TZM molybdenum rod is used to make the heating element of annealing furnace, which can provide a stable thermal field above 1400°C, which is suitable for heat treatment of high-performance alloys.

The surface of TZM molybdenum rods is usually coated with an anti-oxidation coating (e.g. molybdenum silicide, $MoSi_2$) to further improve durability in oxidizing atmospheres. The world's leading stove manufacturers use TZM molybdenum rods extensively in their high-temperature furnace designs to meet industrial and scientific needs.

6.1.2 Applications in vacuum sintering furnaces

Vacuum sintering furnace is an important equipment for the manufacture of high-performance materials (such as ceramics, metal alloys), and TZM molybdenum rods are used as supports, crucibles and heating elements for sintering furnaces due to their high strength and corrosion resistance. Key applications include:

Supports and crucibles: TZM molybdenum rods are used to make support frames and crucibles for sintering furnaces, which can withstand the gravity and thermal stress of the material at high temperatures. For example, in alumina ceramic sintering furnaces, TZM molybdenum rod supports maintain geometric stability and avoid deformation.

High Temperature Fixture: TZM molybdenum rod is processed into a fixture that is used to fix the sintered material and ensure the dimensional accuracy during the sintering process. Its low coefficient of thermal expansion (5.3×10^{-6}/K) ensures the stability of the fixture at high temperatures.

Thermocouple Protective Sleeves: TZM molybdenum rods are used in the manufacture of thermocouple protective sleeves that are able to protect thermocouples from corrosion and mechanical damage in a vacuum environment above 1800°C.

6.1.3 Applications in heat treatment furnaces

Heat treatment furnaces are used for annealing, quenching and tempering of metals and alloys, and TZM molybdenum rods are widely used in structural parts and heating elements of heat treatment furnaces because of their excellent creep resistance and high thermal conductivity. Specific applications include:

Heating element: TZM molybdenum rod is used as a heating element in the heat treatment furnace, which is able to provide a stable thermal field at 1400-1600°C, which is suitable for heat treatment of high-strength steel and titanium alloys.

Furnace internals: TZM molybdenum rods are used in the manufacture of furnace support frames, trays and partitions, which are able to withstand the weight and thermal stress of the material at high temperatures. For example, in heat treatment furnaces for aerospace components, TZM molybdenum rod supports maintain long-term stability.

Atmosphere control: In heat treatment furnaces with hydrogen or argon atmosphere, the corrosion resistance of TZM molybdenum rods enables them to withstand chemical attack and extend the life of the furnace.

The results show that the application of TZM molybdenum rod in heat treatment furnace can control the temperature uniformity in the furnace within ±5°C, and significantly improve the heat treatment quality. Global heat treatment furnace manufacturers prefer TZM molybdenum rods in their high-end equipment to meet the needs of the aerospace and automotive industries.

6.2 Aerospace field

Because of its high melting point, excellent high-temperature strength and low coefficient of thermal expansion, TZM molybdenum rod plays an irreplaceable role in the aerospace field, and is widely used in rocket nozzles, high-temperature structural parts and spacecraft thermal protection systems. The following is a detailed analysis from these three aspects.

6.2.1 Applications in rocket nozzles

Rocket nozzles are one of the most demanding applications in the aerospace industry, withstanding high temperatures of more than 2000°C and strong thermal shock. TZM molybdenum rod has become the material of choice for rocket nozzles due to its high melting point (2623°C) and excellent thermal shock resistance. Specific applications include:

Nozzle throat: TZM molybdenum rod is used to make the throat of a rocket nozzle, which is able to withstand high temperature and high pressure gas flows in the combustion chamber. For example, SpaceX's Raptor engine nozzles use TZM alloy to cope with the extreme heat load from liquid oxygen/methane combustion.

Nozzle extension: TZM molybdenum rod is used for nozzle extension, which can maintain geometric stability and reduce deformation caused by thermal stress. Its low coefficient of thermal expansion (5.3×10^{-6}/K) ensures that the nozzle does not crack during rapid temperature changes.

Anti-oxidation coating: To improve durability in oxidizing combustion environments, TZM molybdenum rod nozzles are usually coated with molybdenum silicide or zirconia coating to extend their service life.

6.2.2 Application in high-temperature structural parts

TZM molybdenum rods are widely used in aerospace high-temperature structural parts such as turbine blades, combustion chamber walls, and propulsion system components. Its excellent high-temperature strength (tensile strength 400-500 MPa at 1200°C) and creep resistance enable it to withstand complex stress environments. Specific applications include:

Turbine blades: TZM molybdenum rods are used to make the support structure of aero engine turbine blades, which can maintain strength and stability above 1400°C.

Combustion chamber wall: TZM molybdenum rod is used to make combustion chamber wall, which can withstand the scouring and thermal shock of high-temperature combustion gases. For example, NASA's X-33 space shuttle combustion chamber uses TZM alloy components.

Connectors: TZM molybdenum rods are processed into high-temperature bolts and connectors, which are suitable for high-temperature assembly of aerospace equipment.

6.2.3 Application in spacecraft thermal protection

Spacecraft are subjected to temperatures of thousands of degrees Celsius during re-entry, and TZM molybdenum rods are used in thermal protection systems (TPS) due to their high thermal conductivity and thermal shock resistance. Specific applications include:

Thermal protection plate: TZM molybdenum rod is processed into a thin plate, which is used for the thermal protection layer on the exterior of the spacecraft, which can quickly dissipate heat and protect the internal structure.

Heat shields: TZM molybdenum rods are used to make heat shields for spacecraft to prevent high temperature conduction to sensitive components. For example, some of the heat shields of the International Space Station are made of TZM alloy.

Anti-ablation coating: The surface of TZM molybdenum rods is usually coated with an anti-ablative material (such as carbon/carbon composites) to improve durability in extreme thermal environments.

6.3 Nuclear industry

TZM molybdenum rods have important applications in the nuclear industry due to their low thermal neutron absorption cross section, high-temperature strength and radiation resistance, covering nuclear reactors, nuclear fusion devices and radioactive material handling. The following is a detailed analysis from these three aspects.

6.3.1 Applications in nuclear reactors

TZM molybdenum rods are used in nuclear reactors to make control rods, structural parts and fuel cladding, and are able to withstand high temperatures and high radiation environments. Specific applications include:

Control rods: TZM molybdenum rods are used to manufacture the support structure of control rods, which are able to maintain stability at high temperatures (800-1200°C) and neutron irradiation. Its low thermal neutron absorption cross section (about 2.6 barns) makes it superior to stainless steel.

Structural parts: TZM molybdenum rods are used in the support frame and piping inside the reactor and are able to withstand the corrosion and mechanical stress of high-temperature coolants. For example, fast reactors, such as the China Experimental Fast Reactor, use TZM alloy structural parts.

Fuel cladding: TZM molybdenum rods are used to make nuclear fuel cladding, which is able to maintain tightness at high temperatures and high radiation and prevent the leakage of radioactive materials.

6.3.2 Applications in nuclear fusion devices

Nuclear fusion devices, such as tokamaks and inertial confinement fusion devices, are extremely demanding on materials, and TZM molybdenum rods are widely used due to their resistance to plasma attack and high thermal conductivity. Specific applications include:

Plasma-facing material (PFM): TZM molybdenum rods are used to fabricate deflectors and first walls of tokamak devices, which are capable of withstanding high-energy plasma bombardment and instantaneous heat loads above 2000°C. For example, the International Experimental Thermonuclear Fusion Reactor (ITER) uses TZM alloy as the deflector material.

Heat sink material: The high thermal conductivity of TZM molybdenum rod makes it a heat sink material that can quickly dissipate heat and protect the sensitive parts of fusion devices.

Structural support: TZM molybdenum rods are used to fabricate the support structure of fusion devices, which are able to maintain stability at high temperatures and strong magnetic fields.

6.3.3 Applications in the handling of radioactive materials

TZM molybdenum rods are used in the processing of radioactive materials to make containers, shielding materials and operating tools, and are resistant to high levels of radiation and chemical corrosion. Specific applications include:

Radioactive Waste Containers: TZM molybdenum rods are processed into containers for storing highly radioactive waste, which can withstand long-term radiation and corrosion.

Shielding materials: TZM molybdenum rods are used in the manufacture of radiation shielding materials, which are superior to traditional lead shielding materials due to their high density (10.2 g/cm^3) and low thermal neutron absorption cross section.

Operating tools: TZM molybdenum rods are used to manufacture high-temperature operating tools, such as manipulators and jigs, which are able to operate safely in high-radiation environments.

6.4 Electronics and semiconductor industry

TZM molybdenum rods are widely used in the electronics and semiconductor industries due to their high thermal conductivity, low coefficient of thermal expansion and corrosion resistance, including ion implantation devices, thin film deposition, and electronic device manufacturing. The following is a detailed analysis from these three aspects.

6.4.1 Applications in ion implantation devices

Ion implantation devices are used in semiconductor chip manufacturing, and TZM molybdenum rods are used as key components due to their high strength and resistance to plasma attack. Specific applications include:

Ion source components: TZM molybdenum rods are used to fabricate the electrodes and beam guiding components of the ion source, which can withstand the bombardment of high-energy ion beams. Its high thermal conductivity (139 W/m·K) ensures fast heat dissipation and avoids local overheating.

Fixtures & Targets: TZM molybdenum rods are processed into fixtures for fixing silicon wafers that are able to maintain dimensional stability in high temperature and high vacuum environments. For example, TSMC's ion implantation device uses a TZM molybdenum rod fixture.

Shielding components: TZM molybdenum rods are used in the manufacture of shielding plates in ion implantation devices, which are resistant to radiation and corrosion from high-energy particles.

6.4.2 Applications in thin film deposition

Thin film deposition (e.g., physical vapor deposition, PVD) is a key process in semiconductor and electronic device manufacturing, and TZM molybdenum rods are used as sputtering targets and fixtures due to their high thermal conductivity and corrosion resistance. Specific applications include:

Sputtering targets: TZM molybdenum rods are processed into sputtering targets for depositing high-performance thin films such as metal conductive and insulating layers. Its homogeneous microstructure ensures the homogeneity of the sputtered film.

Jigs & Supports: TZM molybdenum rods are used to make jigs and supports in PVD equipment, which can maintain stability at high temperatures and high vacuum. For example, in OLED screen manufacturing, TZM molybdenum rod fixtures are used to hold substrates.

Heating element: TZM molybdenum rod is used to make heating elements for PVD equipment, which is able to provide a stable thermal field at 800-1200°C.

6.4.3 Applications in the manufacture of electronic devices

TZM molybdenum rods are used in the manufacture of electronic devices to manufacture high-temperature fixtures, electrodes, and connectors. Specific applications include:

High-temperature fixtures: TZM molybdenum rods are used to fabricate fixtures in wafer processing and are able to maintain stability in high-temperature annealing and diffusion processes. For example, Intel's chip manufacturing equipment uses TZM molybdenum rod fixtures.

Electrodes: TZM molybdenum rods are used in the manufacture of molybdenum electrodes in electronic devices, such as electrodes in vacuum tubes and microwave devices, which can withstand high temperatures and high currents.

Connectors: TZM molybdenum rods are machined into high-temperature connectors for the assembly of electronic devices, which are able to withstand thermal cycling and mechanical stress.

6.5 Other industrial and scientific research fields

TZM molybdenum rods are also widely used in other industrial and scientific fields such as high-temperature experimental equipment, high-temperature molds and tools, and additive manufacturing. The following is a detailed analysis from these three aspects.

6.5.1 Application in high-temperature experimental equipment

TZM molybdenum rods are widely used in high-temperature experimental equipment, such as material testing furnaces, plasma physics experimental devices and high-temperature reactors, due to their high-temperature stability and corrosion resistance. Specific applications include:

Materials Testing Furnaces: TZM molybdenum rods are used to manufacture fixtures and heating elements for high-temperature tensile and compression testing furnaces, capable of providing a stable thermal field above 1600°C. For example, the ASTM E21 standard test equipment uses TZM molybdenum rod fixtures.

Plasma physics experiment: TZM molybdenum rod is used to manufacture electrodes and supports for plasma experimental devices, which can withstand the erosion of high-energy plasma. For example, the laser plasma experimental setup uses TZM alloy electrodes.

High temperature reactor: TZM molybdenum rod is used to make heating elements and support structures for chemical reactors, which can operate stably in high temperatures and corrosive atmospheres.

6.5.2 Applications in high-temperature molds and tools

TZM molybdenum rods are used in the manufacture of high-temperature molds and tools due to their high hardness (250-300 HV) and anti-wear properties. Specific applications include:

Die Casting Molds: TZM molybdenum rods are used to make die casting molds for aluminum alloys and magnesium alloys, which are able to withstand high stress and wear at 800-1000°C.

Hot forging dies: TZM molybdenum rods are used to manufacture hot forging dies for aerospace components, which are able to maintain strength and dimensional stability above 1200°C.

Cutting tools: TZM molybdenum rods are machined into high-temperature cutting tools, which are suitable for machining tungsten alloy and high-temperature alloys.

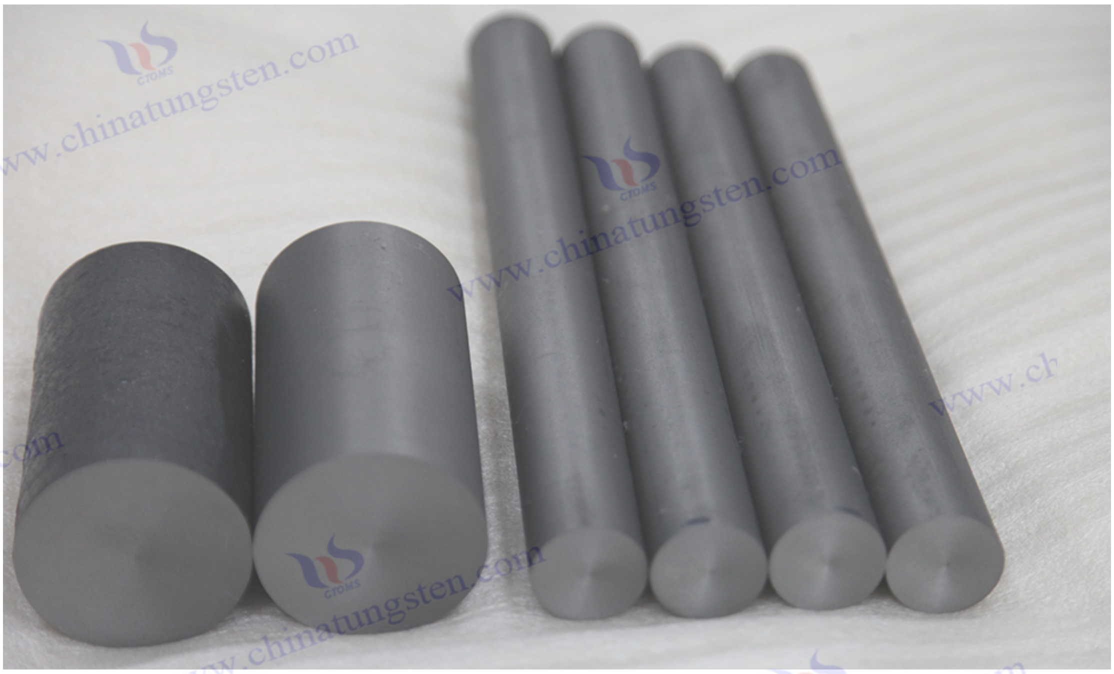
6.5.3 Applications in Additive Manufacturing

Additive manufacturing (3D printing) is an emerging application area for TZM molybdenum rods, which can fabricate TZM alloy parts with complex shapes by laser selective melting (SLM) or electron beam melting (EBM) technology. Specific applications include:

Aerospace components: TZM molybdenum rod powder is used in 3D printing rocket nozzles and turbine blades, enabling complex geometries and reducing processing costs. For example, NASA's 3D-printed TZM alloy nozzles are 30% lighter.

Medical devices: TZM molybdenum rods are used to 3D print autoclaved equipment parts that are able to maintain stability in high temperature and corrosive environments.

Scientific research model: TZM molybdenum rod powder is used in 3D printing high-temperature experimental models to meet the needs of material testing and physical experiments.



CTIA GROUP LTD TZM Molybdenum Rod

7. Technical Challenges and Future Development of TZM Molybdenum Rod

As a high-performance superalloy, TZM molybdenum rod is widely used in aerospace, nuclear industry, semiconductor manufacturing and other fields due to its excellent high-temperature strength, creep resistance and low thermal expansion coefficient. However, with the increasingly harsh application environment and the rapid development of industrial technology, the preparation and application of TZM molybdenum rod face many technical challenges, including high-temperature oxidation resistance, complex shape manufacturing and production cost control. At the same time, new materials, intelligent manufacturing and green production technologies provide new opportunities for the future development of TZM molybdenum rods. This chapter comprehensively discusses the current situation and future of TZM molybdenum rod from four aspects: technical challenges, new materials and technologies, intelligent and green manufacturing, and future development trends.

7.1 Technical Challenges

The preparation and application of TZM molybdenum rod faces many technical challenges, including the improvement of high-temperature oxidation resistance, the difficulty of manufacturing complex shapes and large sizes, and the control of production costs. These challenges have a direct impact on the performance and economics of TZM molybdenum rods in high-end applications. The following is a detailed analysis from three aspects.

7.1.1 Improvement of high temperature oxidation resistance

The oxidation resistance of TZM molybdenum rod in high temperature environment (>1000°C) is the main bottleneck of its application. Although TZM molybdenum rods improve oxidation resistance by adding titanium (Ti), zirconium (Zr) and carbon (C), they still do not perform as well as ceramics or some nickel-based alloys in oxidizing atmospheres. Specific challenges include:

Oxide volatilization: In the oxidizing environment above 1200°C, volatile molybdenum trioxide (MoO_3) will be formed on the surface of TZM molybdenum rod, resulting in rapid material loss. The results show that the oxidative weight gain rate of TZM molybdenum rod in air at 1200°C is about 0.5-1 mg/cm²·h, which is much higher than that of ceramic materials (0.01 mg/cm²·h).

Protective Layer Stability: TZM molybdenum rods can improve oxidation resistance through molybdenum silicide ($MoSi_2$) or alumina (Al_2O_3) coatings, but these coatings are prone to peeling or cracking above 1500°C or during long-term thermal cycling. For example, $MoSi_2$ coatings can achieve a peeling rate of 20-30% after 100 thermal cycles at 1600°C.

Complex environmental adaptability: In aerospace (e.g., rocket nozzles) and nuclear fusion devices, TZM molybdenum rods need to withstand high temperatures, oxidation and plasma attack at the same time, and a single anti-oxidation coating is difficult to meet multiple environmental requirements.

Improvements include:

Development of new coatings: Research on multi-layer composite coatings (such as $MoSi_2/Al_2O_3/ZrO_2$) to improve the bonding strength and thermal cycling stability of the coating and substrate through gradient structure. Recent studies have shown that nanocomposite coatings can extend the lifetime of TZM molybdenum rods by up to 50% at 1500°C.

Surface modification: Antioxidant elements (such as silicon and aluminum) are introduced into the surface of TZM molybdenum rods through laser surface treatment or ion infiltration technology to form an in-situ protective layer. For example, laser cladding silicide layers can reduce oxidative weight gain to 0.1 mg/cm²·h.

Alloy optimization: Optimize the distribution and size of carbide particles (TiC, ZrC) by adjusting the content of titanium, zirconium and carbon, and enhance the oxidation resistance of the matrix. Experiments showed that increasing the zirconium content to 0.15% could significantly reduce the oxidation rate.

7.1.2 Complex shapes and large-scale manufacturing

The complex shapes and large dimensions of TZM molybdenum rods face technical difficulties, especially in the aerospace and nuclear industries, where complex geometries (e.g., curved nozzles) or large-scale components (e.g., nuclear reactor support beams) need to be manufactured. Specific challenges include:

Limitations of powder metallurgy: TZM molybdenum rods are usually prepared by a powder metallurgy process, but this process is difficult to achieve near-net shape of complex shapes. Although isostatic pressing (CIP) can prepare complex blanks, the dimensional accuracy is only ±0.5 mm, which is difficult to meet the ± of 0.01 mm required by aerospace.

Machining difficulty: The high hardness (250-300 HV) and low toughness of TZM molybdenum rods make them prone to cracks during turning, milling and drilling. For example, the machining of complex shapes, such as internal threads or micro-holes, can lead to rapid tool wear and a 30-50% increase in machining costs.

Large-scale uniformity: The manufacture of large-size TZM molybdenum rods (diameter > 100 mm and length >1 m) needs to ensure uniformity of microstructure and properties. Temperature gradients and uneven shrinkage during the sintering process can lead to internal porosity or cracks, with a rejection rate of up to 10-15%.

Improvements include:

Additive manufacturing (3D printing): Direct printing of TZM molybdenum rod parts with complex shapes using laser selective melting (SLM) or electron beam melting (EBM) technology. SLM technology increases dimensional accuracy to ±0.05 mm and reduces scrap rates to less than 5%. The latest NASA study shows that TZM nozzles prepared by SLM are 30% lighter and 20% more performant.

Precision Forging & Rolling: Optimize the grain orientation and density of large-size TZM molybdenum rods with multi-axis forging and precision rolling equipment. For example, the four-high mill of the German SMS Group increases the density of large-format bars to 99.5% of the theoretical density.

Hot Isostatic Pressing (HIP): Hot isostatic pressing technology is used after sintering to eliminate micropores in large-sized blanks and improve uniformity. The HIP process (2000°C, 200 MPa) reduces the rejection rate to less than 2%.

7.1.3 Production cost control

The high production cost of TZM molybdenum rod limits its wide application in some fields. Cost sources include raw materials, process complexity, and quality control. Specific challenges include:

Raw material cost: The price of high-purity molybdenum powder (purity ≥ 99.95%) and titanium and zirconium additives is higher, accounting for 40-50% of the total cost. For example, the 2023 Chinatungsten Online report shows that the price of high-purity molybdenum powder is around US$50-70/kg.

Process complexity: Powder metallurgy, vacuum sintering and high-temperature machining of TZM molybdenum rods require expensive equipment (e.g., vacuum sintering furnaces, precision rolling mills) with a single equipment investment of up to millions of dollars. In addition, tool wear and scrap rates (around 10%) during machining further increase costs.

Quality control cost: In-line testing (ultrasonic, X-ray) and performance testing (high-temperature tensile and creep testing) require high-precision instruments and professionals, accounting for 20-30% of the production cost.

Improvements include:

Raw material optimization: By improving the molybdenum powder purification process (e.g., plasma reduction), the oxygen content and impurities are reduced, and the amount of additives is reduced. For example, H.C. Starck's plasma reduction technology can reduce the cost of molybdenum powder by 15%.

Process simplification: Near-net shape technology such as SLM or HIP reduces subsequent processing steps, scrap rates and processing costs. Studies have shown that near-net shape can reduce processing costs by 20-30%.

Automated production: through intelligent production lines (such as PLC control and online detection systems), improve production efficiency and reduce labor costs.

7.2 New materials and technologies

The development of new materials and technologies provides new opportunities for the improvement of the performance of TZM molybdenum rods and the expansion of application fields. The following is a detailed analysis from three aspects: modified alloy design, nanostructures and composite materials, and competition with other high-temperature materials.

7.2.1 Modified alloy design

By modifying the alloy design and optimizing the composition and microstructure of TZM molybdenum rods, its properties can be further improved. Methods include:

Add new elements: Introduce small amounts of rare earth elements (such as lanthanum, cerium) or rhenium (Re) into the TZM alloy to improve oxidation resistance and high-temperature strength. For example, the addition of 0.1% lanthanum increases the recrystallization temperature of TZM molybdenum rods to 1500°C and the tensile strength by 10-15%.

Carbide optimization: Optimize the size (0.5-2 microns) and distribution of carbide particles (TiC, ZrC) through precise control of carbon content (0.02-0.05%) and sintering process to enhance precipitation intensification. Studies have shown that uniformly distributed nanoscale carbides can reduce creep rates by up to 20%.

Solution strengthening: By increasing the solid solution content of titanium and zirconium (Ti: 0.6-0.8%, Zr: 0.15-0.2%), the lattice distortion of the molybdenum matrix is improved, and the high-temperature strength and corrosion resistance are enhanced.

7.2.2 Nanostructures and composite materials

Nanostructure and composite materials technology provide a new direction for the performance optimization of TZM molybdenum rods. Methods include:

Nanocrystalline structure: The grain size of TZM molybdenum rod is controlled at 50-100 nm through high-energy ball milling and rapid sintering technology. The nanocrystalline structure significantly improves the strength and toughness of the material. For example, the fracture toughness of nanocrystalline TZM molybdenum rods can reach 25 MPa·m^1/2, which is higher than that of conventional TZM (15-20 MPa·m^1/2).

Composites: TZM molybdenum rods are compounded with ceramics (e.g., SiC, Al_2O_3) or carbon-based materials (e.g., graphene) to form metal matrix composites (MMCs). The oxidation resistance of SiC/TZM composites is 2 times higher at 1500°C, which is suitable for deflectors of nuclear fusion devices.

Nano coatings: Nano-scale anti-oxidation coatings (e.g., Al_2O_3/ZrO_2) are deposited on the surface

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of TZM molybdenum rods by chemical vapor deposition (CVD) or physical vapor deposition (PVD) techniques. The coefficient of thermal expansion of the nano coating is more compatible with the substrate, and the peeling rate is reduced to less than 5%.

7.2.3 Competition with other high-temperature materials

TZM molybdenum rods face competition from other high-temperature materials such as tungsten alloys, nickel-based alloys, ceramics and carbon-based composites. Specific comparisons include:

Tungsten alloys: Tungsten alloys (density 19.3 g/cm³) have a higher melting point (3422°C) and strength, but a much higher density than TZM molybdenum rods (10.2 g/cm³), limiting them in weight-sensitive aerospace applications. TZM molybdenum rod can replace some tungsten alloy applications below 1600°C by optimizing oxidation resistance.

Nickel-based alloys: Nickel-based alloys (e.g., Inconel 718) have excellent oxidation resistance and toughness at 1000-1200°C, but their high-temperature strength (200-300 MPa) is lower than that of TZM molybdenum rods (400-500 MPa). TZM molybdenum rods compete at higher temperatures through nano-coating technology.

Ceramics and carbon-based composites: ceramics (e.g., SiC, ZrB_2) have excellent oxidation resistance but high brittleness; Carbon/carbon composites are lightweight but require complex coating protection in oxidizing environments. TZM molybdenum rods are designed with composites (e.g., TZM/SiC) to combine metal toughness with ceramic oxidation resistance.

Improvements include the development of TZM matrix composites, optimization of coating technology, and reduction of production costs to enhance the competitiveness of TZM molybdenum rods in the high-temperature materials market.

7.3 Intelligent and green manufacturing

Intelligent and green manufacturing technology is the development direction of TZM molybdenum rod production, which can improve production efficiency, reduce energy consumption and reduce environmental pollution. The following is a detailed analysis from three aspects: intelligent production monitoring, energy-saving and environmentally friendly production, and waste recycling.

7.3.1 Intelligent production monitoring technology

Intelligent production monitoring technology optimizes the production process of TZM molybdenum rods through real-time data collection and analysis, improving quality consistency and efficiency. Specific technologies include:

In-line inspection system: Using ultrasonic, X-ray and visual inspection technology, real-time monitoring of the size, defects and microstructure of TZM molybdenum rods. For example, X-ray imaging systems can detect internal defects of more than 0.1 mm and reduce the rejection rate to less than 0.5%.

Industrial Internet of Things (IIoT): Through sensors and PLC systems, the sintering temperature, forging pressure and processing parameters are collected in real time and transmitted to the cloud for analysis. IIoT systems can increase productivity by up to 20% and reduce equipment failure rates by 15%.

AI optimization: Uses machine learning algorithms to predict the impact of process parameters on performance, optimizing sintering temperature, rolling deformation, and coating thickness. For example, AI optimization can control the grain size of TZM molybdenum rods to 10-20 microns, improving creep resistance.

7.3.2 Energy-saving and environmentally-friendly production technology

The production process of TZM molybdenum rods (e.g. vacuum sintering, hot forging) is energy-intensive, requiring energy-saving and environmentally friendly technologies to reduce the carbon footprint. Specific measures include:

High-efficiency sintering furnace: High-efficiency vacuum sintering furnaces (e.g. tungsten heater) are used to reduce energy consumption by 15-20% by optimizing the heating curve and holding time. For example, the sintering furnace of ALD in Germany can control the energy consumption of a single sintering to less than 500 kWh.

Renewable energy: Reduce carbon emissions by switching the power source of your production equipment to solar or wind. For example, some TZM molybdenum rod producers in Europe have achieved 50% renewable energy supply.

Exhaust gas treatment: In the process of powder metallurgy and surface treatment, high-efficiency filtration systems (such as HEPA filters) are used to treat volatile oxides and acidic waste gases to ensure that the emissions meet EU RoHS standards.

Studies have shown that energy-saving and environmentally friendly technologies can reduce the carbon emissions of TZM molybdenum rod production by 30%, which is in line with the global trend of green manufacturing.

7.3.3 Efficient recycling of waste materials

Scrap (e.g. cutting chips, sintered residues) in the production of TZM molybdenum rods contains high-value molybdenum, titanium and zirconium, and efficient recycling technology reduces costs and environmental impact. Methods include:

Chemical recycling: Molybdenum, titanium and zirconium are extracted from waste materials through acid dissolution and electrochemical separation techniques. The recovery rate can reach 95% and the cost can be reduced by 20%. For example, H.C. Starck's chemical recovery process increases molybdenum recovery to 98%.

Mechanical recycling: The scrap is reprocessed into TZM molybdenum bar blanks by crushing, screening and re-sintering technology. Mechanical recycling is suitable for large-sized scrap materials with a recycling rate of about 90%.

Closed-loop recycling system: Establish a closed-loop recycling system of the production line to directly reuse waste materials into the powder metallurgy process to reduce resource waste. According to Chinatungsten Online, closed-loop recycling can reduce the scrap rate to less than 5%.

Waste recycling technology not only reduces production costs, but also meets the requirements of circular economy and promotes the sustainable development of TZM molybdenum rod industry.

7.4 Future Trends

The future development of TZM molybdenum rods will focus on high-performance design, cross-domain application expansion and extreme environment applications to meet the needs of aerospace, nuclear fusion, new energy and other fields. The following is a detailed analysis from three aspects.

7.4.1 High-performance design and optimization

The high-performance design further enhances the performance of TZM molybdenum rods through material, process and structural optimization. Specific trends include:

Multi-scale simulation: Molecular dynamics and finite element analysis are used to simulate the performance of TZM molybdenum rods in high-temperature and high-stress environments, and optimize the alloy composition and microstructure. For example, simulations show that the addition of 0.1% rhenium increases tensile strength by 15%.

Customized design: The composition, coating and shape of the TZM molybdenum rod can be customized according to the application needs (e.g. rocket nozzle or fusion deflector). For example, aerospace components can be equipped with a high titanium content (0.8%) for strength, and nuclear fusion devices can be equipped with a high zirconium content (0.2%) for enhanced oxidation resistance.

Functionally Graded Materials (FGMs): TZM-based Functional Gradient Materials are developed to improve their overall properties by forming performance gradients (e.g., surface oxidation layer, internal high-toughness matrix) within the material. FGM can extend the life of TZM molybdenum rods at 1600°C by a factor of 2.

7.4.2 Cross-domain application extension

The application field of TZM molybdenum rod is expanding from the traditional high-temperature industry to the fields of new energy, medical and national defense. Specific trends include:

New energy: TZM molybdenum rod is used to make connectors and electrodes for solid oxide fuel cells (SOFC), which can operate stably at 800-1000°C. For example, Bloom Energy's SOFC uses TZM alloy connectors.

Medical devices: TZM molybdenum rods are used in the manufacture of components for high-temperature sterilization equipment and radioisotope containers, which can withstand high temperatures and high radiation. For example, medical cobalt-60 containers have a TZM component life of up to 20 years.

Defense industry: TZM molybdenum rods are used in the manufacture of thermal protection systems and missile nozzles for hypersonic vehicles, capable of withstanding instantaneous heat loads above 3000°C.

The expansion of cross-sector applications will drive the growth of the TZM molybdenum rod market, which is expected to grow by 20% by 2030.

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TZM Molybdenum Rod Introduction

1. Overview of TZM Molybdenum Rod

TZM molybdenum rods are high-performance molybdenum-based alloy materials composed of a molybdenum (Mo) matrix with small additions of titanium (Ti), zirconium (Zr), and carbon (C). Compared to pure molybdenum, TZM alloy offers significantly higher high-temperature strength, excellent thermal stability, superior creep resistance, and outstanding oxidation resistance, making it an ideal material for high-temperature structural applications.

2. Characteristics of TZM Molybdenum Rod

High Melting Point: Suitable for extreme high-temperature environments.

Excellent High-Temperature Strength: Maintains mechanical strength and rigidity at 1200–1600°C.

Good Thermal Stability and Creep Resistance: Ideal for long-term use under high temperatures with minimal deformation and high reliability.

Superior Corrosion and Oxidation Resistance: Applicable in vacuum, high-temperature inert atmospheres, and oxidative conditions.

Excellent Machinability: Suitable for turning, milling, grinding, and welding processes.

3. Typical Applications of TZM Molybdenum Rod

High-Temperature Furnace Components: Supports, heat shields, heating elements, and electrode rods.

Aerospace Industry: Structural components in rocket nozzles and engine parts operating under high temperatures.

Nuclear Industry: Used in reactor support structures and control rod guide systems.

Electronics Industry: Structural materials in ion implantation, evaporation sources, and semiconductor processing equipment.

Mold Manufacturing: Hot extrusion dies, aluminum alloy die-casting molds with excellent high-temperature wear resistance.

4. Specifications of TZM Molybdenum Rod

Main Ingredients	Mo: ≥ 99%
	Ti: 0.40–0.55%
	Zr: 0.06–0.12%
	C: 0.01–0.04%
Size Range	Diameter φ6mm – φ120mm, length up to 2000mm (customizable)
Surface	Black(forged), bright (turned or ground)
Processing Method	Forging, rolling, drawing, or machining forming

5. Procurement Information

Email: sales@chinatungsten.com; Phone: +86 592 5129595; 592 5129696

Website: www.molybdenum.com.cn

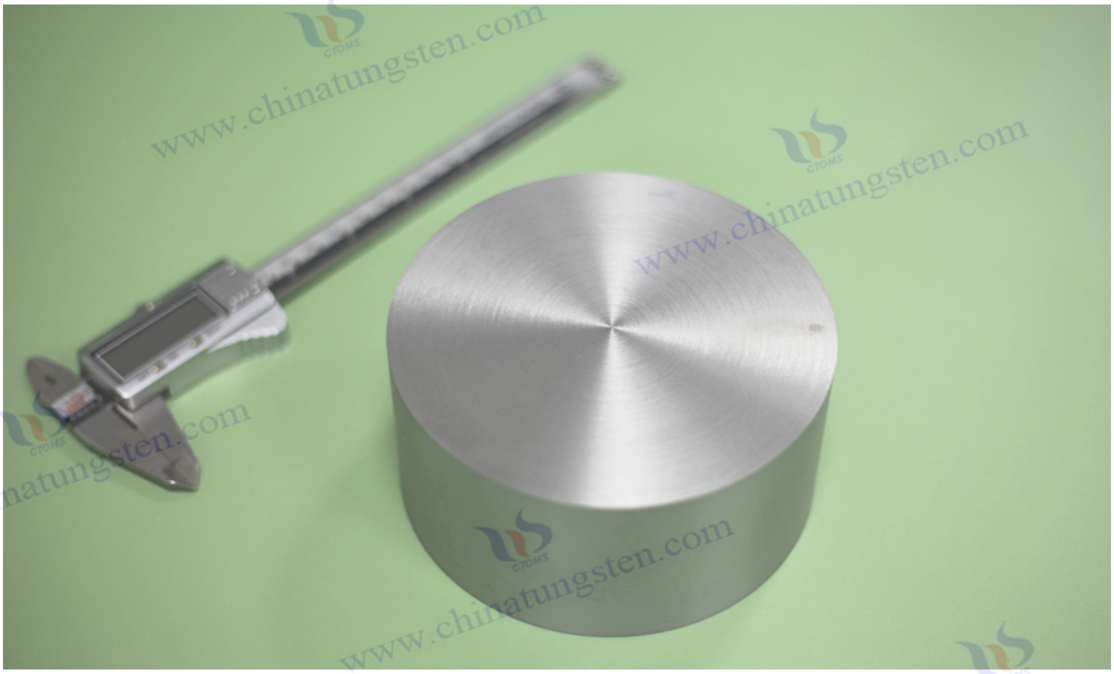
7.4.3 Applications in Extreme Environments

The application of TZM molybdenum rod in extreme environments (such as ultra-high temperature, strong radiation, and strong corrosion) is the focus of future development. Specific trends include:

Ultra-high temperature environments: Through the development of new anti-oxidation coatings and composite materials, TZM molybdenum rods can be applied to ultra-high temperature environments above 2000°C, such as next-generation rocket engines and plasma thrusters.

Strong radiation environment: In nuclear fusion and space exploration, TZM molybdenum rods need to be exposed to high-energy neutron and gamma ray irradiation. The addition of rare earth elements and the optimization of the microstructure can improve the radiation resistance to meet the needs of ITER and lunar bases.

Highly corrosive environments: In the offshore and chemical industries, TZM molybdenum rods need to be resistant to acid gases and salt spray. Surface nitriding and composite coating technology reduces the corrosion rate to 0.005 mm/year.



CTIA GROUP LTD TZM Molybdenum Rod

8. TZM Molybdenum Rod Standards and Specifications

As a high-performance superalloy, TZM molybdenum rod is widely used in aerospace, nuclear industry, semiconductor manufacturing and other fields, and its production, testing and application need to follow strict standards and specifications. These standards cover material composition, performance testing, production process, quality control and environmental management to ensure the quality consistency, safety and international market competitiveness of TZM molybdenum rods. This chapter comprehensively discusses the standards and specifications related to TZM molybdenum rod from five aspects: national standards (national standards), international standards (ISO), American standards (American standards), other international and industry standards, and standard implementation and certification.

8.1 National Standards (GB)

As the world's largest producer of molybdenum resources and a manufacturer of TZM molybdenum rods, China has formulated a series of national standards (GB/T) to regulate the production and application of TZM molybdenum rods. These standards cover material properties, test methods and equipment processes, and provide a unified basis for domestic enterprises and international trade. The following is a detailed analysis from three aspects.

8.1.1 GB/T Molybdenum and Molybdenum Alloy Material Standards

The Chinese National Standards (GB/T) specify in detail the chemical composition, physical properties and processing requirements of molybdenum and molybdenum alloys (such as TZM), and the main standards include:

GB/T 3462-2017 Molybdenum and molybdenum alloy bars: This standard specifies the chemical composition of TZM molybdenum rods (Mo≥99.38%, Ti: 0.4-0.55%, Zr: 0.06-0.12%, C: 0.01-0.04%), dimensional tolerance (diameter±0.02 mm, length±1 mm), surface quality (Ra≤3.2 microns) and mechanical properties (tensile strength≥ 400 MPa, 1200°C). The standard requires TZM molybdenum rods to be prepared by vacuum sintering or atmosphere sintering to ensure that the density reaches more than 98% of the theoretical density.

GB/T 4194-2015 Chemical analysis methods for molybdenum and molybdenum alloys: This standard specifies in detail the methods for the analysis of molybdenum, titanium, zirconium, carbon and impurity elements in TZM molybdenum rods, including inductively coupled plasma emission spectroscopy (ICP-OES) and X-ray fluorescence spectroscopy (XRF). For example, the oxygen content should be controlled at ≤0.005%, and impurities such as iron and silicon should ≤ 0.01%.

GB/T 17792-2014 General technical conditions for molybdenum and molybdenum alloy bars: This standard covers the microstructure requirements, surface defect detection and packaging and transportation requirements of TZM molybdenum rods. The standard emphasizes that there must be no scale, scratches or porosity on the surface of the bar.

8.1.2 Testing and evaluation standards for superalloys

The superalloy testing and evaluation standard is used to evaluate the mechanical properties, oxidation resistance and creep resistance of TZM molybdenum rods in a high-temperature environment. Key criteria include:

GB/T 4338-2015 High temperature tensile test method for metal materials: This standard specifies the tensile test method for TZM molybdenum rod at 1000-1600 °C, which requires the use of vacuum or inert atmosphere (such as argon) to test the environment, and the temperature control accuracy is ± 5 °C. The test results show that the tensile strength of TZM molybdenum rod at 1200°C is 400-500 MPa and the elongation is 5-10%.

GB/T 2039-2012 Creep and endurance strength test methods for metal materials: This standard is used to test the creep performance of TZM molybdenum rods at 1400°C and 20 MPa, requiring a creep rate of less than 10^{-6}/s and a life of ≥ 5000 hours. Testing requires a high-temperature creep tester (e.g., Instron 5980 series).

GB/T 16878-1997 Test method for high temperature hardness of metal materials: This standard

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specifies the Vickers hardness (HV) test method for TZM molybdenum rod at 1000 °C, and the hardness is required to be maintained at 200-250 HV. The test results show that the high-temperature hardness of TZM molybdenum rod is better than that of pure molybdenum (150-200 HV).

These standards ensure the reliability of TZM molybdenum rods in high-temperature applications such as rocket nozzles, nuclear reactor components. According to the technical report of Chinatungsten Online, the implementation of GB/T 4338 and GB/T 2039 has significantly improved the application quality of TZM molybdenum rods in the aerospace field.

8.1.3 Execution equipment and process specifications

The equipment and process specifications ensure the standardization and safety of the TZM molybdenum rod production process. Key criteria include:

GB/T 15067-2016 Technical conditions for molybdenum and molybdenum alloy processing equipment: This standard specifies the performance requirements for vacuum sintering furnaces, forging machines and rolling equipment. For example, the vacuum sintering furnace needs to reach a vacuum degree of 10^{-3}-10^{-5} Pa and a temperature uniformity of ±5°C; The pressure range of the forging machine is 500-2000 tons.

GB 50828-2012 Safety specification for the production of superalloys: This standard requires that the TZM molybdenum rod production workshop be equipped with explosion-proof devices, exhaust gas treatment systems (such as HEPA filters) and clean rooms (ISO class 7, particle concentration< 10,000 particles/m³). The standard also specifies measures to prevent dust and oxidation in powder metallurgy processes.

GB/T 29490-2013 Requirements for enterprise energy management systems: This standard guides TZM molybdenum rod manufacturers to optimize energy consumption, such as using high-efficiency sintering furnaces (energy consumption < 500 kWh/time) and renewable energy power supply.

These specifications ensure the safety, efficiency and environmental friendliness of TZM molybdenum rod production. For example, a Chinese manufacturer of TZM molybdenum rods has increased production efficiency by 20% and reduced scrap rate to less than 5% by implementing GB/T 15067.

8.2 International Standards (ISO)

The International Organization for Standardization (ISO) standard provides a uniform specification for the global production and application of TZM molybdenum rods, covering materials testing, environmental management, and non-destructive testing. The following is a detailed analysis from three aspects.

8.2.1 ISO 6892 Tensile Testing of Metallic Materials

The ISO 6892 series of standards, including ISO 6892-1:2019 and ISO 6892-2:2018, specifies the tensile test method for TZM molybdenum rods at room temperature and high temperatures:

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ISO 6892-1:2019 (Tensile at Room Temperature): Requires testing of tensile strength (600-700 MPa), yield strength (500-600 MPa), and elongation (10-15%) of TZM molybdenum rods using a universal testing machine (e.g., Instron 5982). The test is performed at a constant strain rate (10^{-3}/s) with a surface roughness of Ra ≤0.4 microns.

ISO 6892-2:2018 (High Temperature Tensile): Specifies a tensile test method at 1000-1600°C, requiring the use of a vacuum or an inert atmosphere (e.g. argon, purity ≥ 99.999%) and a temperature control accuracy of ±5°C. The test results show that the tensile strength of TZM molybdenum rod at 1200°C is 400-500 MPa, which is better than that of pure molybdenum at 200-300 MPa.

8.2.2 ISO 14001 Environmental Management System

ISO 14001:2015 is a globally accepted standard for environmental management systems that guides TZM molybdenum rod manufacturers to reduce their environmental impact. Specific requirements include:

Energy management: It is necessary to optimize the energy consumption of sintering furnaces and processing equipment, such as the use of high-efficiency heating elements (Tungsten heaters) and renewable energy sources. The energy consumption of TZM molybdenum rod manufacturers should be controlled below 500 kWh/ton.

Waste management: Waste materials generated during powder metallurgy and surface treatment (e.g. molybdenum dust, acid waste) are required to be sorted and recycled. For example, chemical recycling can increase molybdenum recovery to 98%.

Emission control: Requires the installation of high-efficiency exhaust gas treatment systems (e.g., HEPA filters) to ensure that volatile oxides (MoO_3) and acid gas emissions comply with local regulations (e.g., EU RoHS standards).

The world's leading producers of TZM molybdenum rods, such as Plansee, are ISO 14001 certified, reducing carbon emissions by 30%, in line with the green manufacturing trend.

8.2.3 ISO 3452 Standard for Non-Destructive Testing

The ISO 3452 series of standards, including ISO 3452-1:2021, specifies a penetrant testing method for TZM molybdenum rods for the detection of surface cracks and defects. Specific requirements include:

Penetrant Testing (PT): Detects cracks, pores, and scratches on the surface of TZM molybdenum rods using fluorescent or visible dye permeate. Detection sensitivity of up to 0.05 mm for aerospace components such as rocket nozzles.

Inspection process: including surface cleaning, permeate application, developer application, and defect observation. The standard requires an ambient illuminance of 500-1000 lx and a temperature of 20-25°C.

Acceptance criteria: surface crack length ≤ 0.1 mm, pore diameter ≤ 0.05 mm. TZM molybdenum rods are required to pass 100% penetrant testing for aerospace applications.

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TZM Molybdenum Rod Introduction

1. Overview of TZM Molybdenum Rod

TZM molybdenum rods are high-performance molybdenum-based alloy materials composed of a molybdenum (Mo) matrix with small additions of titanium (Ti), zirconium (Zr), and carbon (C). Compared to pure molybdenum, TZM alloy offers significantly higher high-temperature strength, excellent thermal stability, superior creep resistance, and outstanding oxidation resistance, making it an ideal material for high-temperature structural applications.

2. Characteristics of TZM Molybdenum Rod

High Melting Point: Suitable for extreme high-temperature environments.

Excellent High-Temperature Strength: Maintains mechanical strength and rigidity at 1200–1600°C.

Good Thermal Stability and Creep Resistance: Ideal for long-term use under high temperatures with minimal deformation and high reliability.

Superior Corrosion and Oxidation Resistance: Applicable in vacuum, high-temperature inert atmospheres, and oxidative conditions.

Excellent Machinability: Suitable for turning, milling, grinding, and welding processes.

3. Typical Applications of TZM Molybdenum Rod

High-Temperature Furnace Components: Supports, heat shields, heating elements, and electrode rods.

Aerospace Industry: Structural components in rocket nozzles and engine parts operating under high temperatures.

Nuclear Industry: Used in reactor support structures and control rod guide systems.

Electronics Industry: Structural materials in ion implantation, evaporation sources, and semiconductor processing equipment.

Mold Manufacturing: Hot extrusion dies, aluminum alloy die-casting molds with excellent high-temperature wear resistance.

4. Specifications of TZM Molybdenum Rod

Main Ingredients	Mo: ≥ 99%
	Ti: 0.40–0.55%
	Zr: 0.06–0.12%
	C: 0.01–0.04%
Size Range	Diameter φ6mm – φ120mm, length up to 2000mm (customizable)
Surface	Black(forged), bright (turned or ground)
Processing Method	Forging, rolling, drawing, or machining forming

5. Procurement Information

Email: sales@chinatungsten.com; Phone: +86 592 5129595; 592 5129696

Website: www.molybdenum.com.cn

8.3 American Standards (US Standard)

American standards (ASTM, ASME) have an important influence on the global application of TZM molybdenum rods, especially in the aerospace and nuclear industries. The following is a detailed analysis from three aspects.

8.3.1 ASTM B387 Standard for Molybdenum and Molybdenum Alloy Bars

ASTM B387-18 is the core standard for TZM molybdenum rods, specifying material composition, properties, and processing requirements:

Chemical Composition: Mo≥99.38%, Ti: 0.4-0.55%, Zr: 0.06-0.12%, C: 0.01-0.04%, impurities (such as Fe, Si)⩽0.01%.

Mechanical properties: tensile strength 600-700 MPa at room temperature, elongation 10-15%; Tensile strength at 1200°C 400-500 MPa. The standard requires testing in accordance with ASTM E8 (room temperature tensile) and ASTM E21 (high temperature tensile).

Dimensions & Surface: Diameter tolerance ± 0.02 mm, surface roughness Ra≤0.4 microns, no cracks, oxide scale or porosity.

Microstructure: Grain size 10-30 microns, density ≥ 98% theoretical density.

8.3.2 ASTM E384 Microhardness Test

ASTM E384-17 specifies a microhardness test method for TZM molybdenum rods to evaluate material hardness and microstructure uniformity:

Test method: Vickers hardness tester (HV) is used, the loading force is 0.5-1 kg, and the indentation time is 10-15 seconds. The test results show that the hardness of TZM molybdenum rod is 250-300 HV, and the carbide particle area can reach 500 HV.

High temperature hardness: tested at 1000°C, the hardness is maintained at 200-250 HV, which is better than the 150-200 HV of pure molybdenum.

Microstructure analysis: Scanning electron microscopy (SEM) was used to observe the microstructure around the indentation to evaluate the distribution and intensification effect of carbide particles.

ASTM E384 ensures the reliability of TZM molybdenum rods in high-temperature molds and aerospace components. For example, Boeing uses ASTM E384 to test the hardness of TZM molybdenum rods to ensure the performance of turbine blade supports.

8.3.3 ASME Standard for the Manufacture of High Temperature Equipment

The ASME (American Society of Mechanical Engineers) standard regulates the manufacture and application of TZM molybdenum rods in high-temperature equipment such as nuclear reactors, aero engines. Key criteria include:

ASME BPVC Section II: Specifies material properties and certification requirements for TZM molybdenum rods, such as tensile strength, creep properties, and oxidation resistance. The standard requires a creep rate of less than 10^{-6}/s for TZM molybdenum rods at 1400°C.

ASME BPVC Section VIII: Specifies manufacturing processes such as welding, heat treatment, and non-destructive testing of TZM molybdenum rods in high-temperature pressure vessels. The standard requires 100% ultrasonic testing (UT) and X-ray testing (RT).

ASME Y14.5 Dimensions & Tolerances: Specifies the geometric tolerances (e.g., roundness, straightness) of TZM molybdenum rods to ensure installation accuracy in high-temperature equipment.

8.4 Other international and industry standards

In addition to Chinese and American standards, standards from Japan (JIS), Germany (DIN) and Russia (GOST) also provide specifications for the production and application of TZM molybdenum rods. The following is a detailed analysis from three aspects.

8.4.1 JIS G 0571 Test Standard for Molybdenum Materials

JIS G 0571:2012 is a Japanese industrial standard that specifies methods for testing the chemical composition and properties of molybdenum and molybdenum alloys (including TZM):

Chemical composition: Mo≥ 99.38%, Ti: 0.4-0.55%, Zr: 0.06-0.12%, impurities (such as O, N) ≤ 0.005% of TZM molybdenum rod.

Mechanical property test: including room temperature tensile (tensile strength 600-700 MPa), high temperature tensile (1200°C, 400-500 MPa) and hardness test (HV 250-300).

Surface quality: The surface roughness is required to be Ra≤3.2 microns, without cracks and oxide scale. The standard also specifies a method for penetrant testing of surface defects.

JIS G 0571 is widely used in the semiconductor and high-temperature furnace manufacturing industries in Japan. For example, Japan's Toshiba Corporation uses JIS G 0571 to test TZM molybdenum rods for use in ion implantation devices.

8.4.2 DIN EN 10228 non-destructive testing standard

The DIN EN 10228 series of standards, including DIN EN 10228-3:2016, specifies non-destructive testing methods for TZM molybdenum rods, with a focus on ultrasonic testing (UT):

Ultrasonic testing: Uses a 5-10 MHz probe to detect cracks, pores, and inclusions inside TZM molybdenum rods. With a detection sensitivity of up to 0.1 mm, it is suitable for components in the aerospace and nuclear industries.

Acceptance criteria: internal defect size ≤ 0.1 mm, surface crack length ≤ 0.05 mm. The standard requires 100% inspection of high-reliability components (e.g. nuclear reactor control rods).

Testing equipment: The use of high-precision ultrasonic detectors (such as Krautkramer, Germany) is required to ensure the repeatability of test results.

8.4.3 GOST 17431 Molybdenum Alloy Standard

GOST 17431-72 is a Russian standard for molybdenum alloys, which is suitable for the production and testing of TZM molybdenum rods:

Chemical Composition: Mo≥99.38%, Ti: 0.4-0.55%, Zr: 0.06-0.12%, C: 0.01-0.04%, Impurities≤0.01%.

Mechanical properties: tensile strength 600-700 MPa at room temperature, tensile strength 400-500 MPa at 1200°C, creep life ≥ 5000 hours (1400°C, 20 MPa).

Processing requirements: It is required to be prepared by vacuum sintering or atmosphere sintering, with a density of ≥ 98% theoretical density and a surface roughness of Ra≤0.8 microns.

GOST 17431 is widely used in the Russian nuclear industry and aerospace sectors, for example, the Russian company Rosatom uses this standard to produce TZM molybdenum rods for nuclear reactors.

8.5 Standard Implementation and Certification

Standard implementation and certification is a key part of ensuring the quality and competitiveness of TZM molybdenum rods in the international market, involving production testing, quality management system and export compliance. The following is a detailed analysis from three aspects.

8.5.1 Standard applications in production and testing

The production and testing of TZM molybdenum rods must strictly follow the above-mentioned national, international and industry standards. Specific implementations include:

Raw material control: According to GB/T 4194 and ASTM B387, the composition of molybdenum powder, titanium powder and zirconium powder was analyzed using ICP-OES and XRF to ensure that the impurity content was ≤ 0.01%.

Process control: sintering, forging and machining processes according to GB/T 15067 and ASME BPVC Section VIII. For example, vacuum sintering furnaces need to maintain a vacuum level of 10^{-3}-10^{-5} Pa and a temperature uniformity of ±5°C.

Performance test: Test the tensile strength, creep properties and hardness of TZM molybdenum rods according to ISO 6892, GB/T 4338 and ASTM E384. For example, a high-temperature tensile test is performed at 1200°C with a tensile strength of ≥ 400 MPa.

Non-destructive testing: 100% inspection of TZM molybdenum rods for the aerospace and nuclear industry according to ISO 3452 and DIN EN 10228 using penetrant testing and ultrasonic testing to ensure that there are no cracks and pores.

8.5.2 Quality management system certification (e.g. ISO 9001)

ISO 9001:2015 is a globally accepted quality management system standard that guides quality control and continuous improvement in TZM molybdenum rod manufacturers. Specific requirements include:

Process management: It is required to record and trace the whole process of raw material procurement, production process, testing and packaging of TZM molybdenum rod. For example, a batch management system needs to be established to ensure that each batch of TZM molybdenum rods can be traced back to the raw material.

Customer satisfaction: Continuous improvement of the performance and production efficiency of TZM molybdenum rod is required through customer feedback and quality audit. For example, aerospace customers require TZM molybdenum rods with dimensional tolerances of ≤± 0.01 mm.

Continuous improvement: Reduce rejects and production costs through data analysis and process optimization. For example, Plansee is ISO 9001 certified, reducing the production cost of TZM molybdenum rods by 15%.

In addition, TZM molybdenum rod manufacturers in the aerospace sector are required to be AS9100 certified to ensure that they meet the special requirements of the aerospace industry, such as 100% non-destructive testing and supply chain transparency.

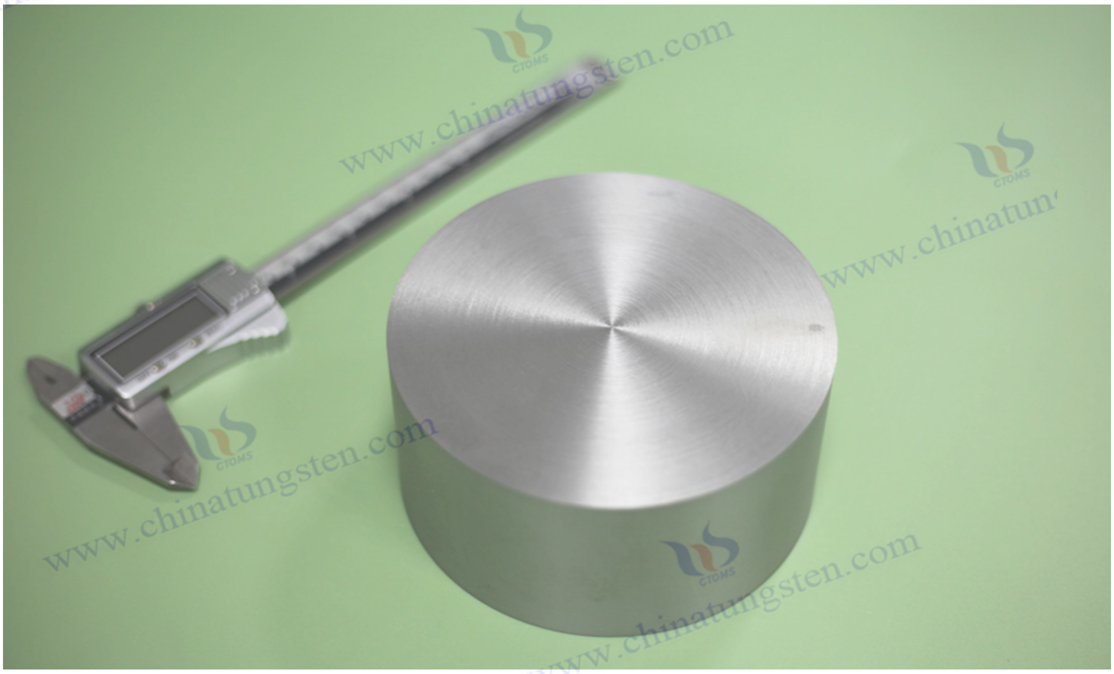
8.5.3 Export and International Standard Compliance

The export of TZM molybdenum rods is subject to the standards and regulations of the target market, involving the harmonization and certification of multinational standards. Specific requirements include:

Harmonization of standards: TZM molybdenum rods are required to comply with ASTM B387 and ASME standards for export to the United States, DIN EN 10228 and ISO 14001 for export to Europe, and JIS G 0571 for export to Japan.

Certification requirements: Export products need to obtain certification for the target market, such as CE certification in the European Union, UL certification in the United States or GOST-R certification in Russia. The certification process includes material testing, process audits, and environmental compliance checks.

Compliance management: It is required to establish a compliance management system and accept third-party audits on a regular basis. For example, SGS and TÜV are common certification bodies for the export of TZM molybdenum rods, ensuring that products comply with international regulations (e.g. RoHS, REACH).



CTIA GROUP LTD TZM Molybdenum Rod

Appendix

A. Glossary

1. Related Terms

TZM Alloy

Definition: A superalloy with molybdenum (Mo) as the matrix, adding titanium (Ti, 0.4-0.55%), zirconium (Zr, 0.06-0.12%) and carbon (C, 0.01-0.04%), with excellent high-temperature strength, creep resistance and low coefficient of thermal expansion.

Molybdenum-Based Alloy

Definition: An alloy with molybdenum as the main component and other elements (such as titanium, zirconium, rhenium) added to improve properties. TZM is a typical representative of molybdenum-based alloys.

High-Temperature Alloy

Definition: Metal materials that can withstand mechanical stress and chemical corrosion for a long time in a high-temperature environment above 600°C, including nickel-based alloys, tungsten-based alloys and molybdenum-based alloys.

Anti-Oxidation Coating

Definition: A protective layer (e.g., molybdenum silicide, Al_2O_3) applied to the surface of TZM molybdenum rod to reduce high-temperature oxidation and material loss.

Coefficient of Thermal Expansion (CTE)

Definition: The expansion rate per unit length of the material under temperature change, the thermal expansion coefficient of TZM molybdenum rod is 5.3×10^{-6}/K.

Creep Resistance

Definition: The ability of a material to resist slow deformation at high temperatures and under constant stress. The creep rate of TZM molybdenum rod at 1400°C is about 1/10 of that of pure molybdenum.

Fracture Toughness

Definition: The ability of the material to resist crack propagation, the fracture toughness of TZM molybdenum rod is 15-20 MPa·m^1/2, which is higher than that of pure molybdenum 10-12 MPa·m^1/2.

2. Preparation and Processing Terminology

Powder Metallurgy

Definition: A method for preparing metal materials by mixing metal powders, pressing molding, and high-temperature sintering. TZM molybdenum rod is usually made of powder metallurgy process, and the sintering temperature is 1800-2000°C.

Vacuum Sintering

Definition: The process of heating a blank of metal powder in a vacuum (10^{-3}-10^{-5} Pa) to combine it into a dense material. Vacuum sintering of TZM molybdenum rods can increase the density to more than 98% of the theoretical density.

Hot Isostatic Pressing

Definition: Isotropic compression of materials at high temperatures (1800-2000°C) and high pressures (100-200 MPa) to eliminate internal porosity and defects.

Cold Isostatic Pressing

Definition: Isotropic pressure is applied to a powder by a liquid medium at room temperature to form a high-density billet. The CIP pressure of TZM molybdenum rod is usually 200-300 MPa.

Precision Forging

Definition: Plastic deformation of TZM molybdenum rod by high-temperature (1200-1400°C) multi-axis forging equipment to improve density and mechanical properties.

Machining

Definition: Shape machining of TZM molybdenum rods by turning, milling, drilling and other processes with tolerances up to ±0.01 mm.

Surface Polishing

Definition: Reduction of the surface roughness of TZM molybdenum rod (Ra≤0.05 microns) by mechanical, chemical or electrochemical methods to reduce crack initiation points.

Non-Destructive Testing

Definition: Inspection of internal and surface defects of TZM molybdenum rods by ultrasonic, X-ray or penetrant testing methods with a sensitivity of up to 0.05 mm.

Near-Net-Shape Forming

Definition: Optimization of preparation processes (e.g. SLM or HIP) to directly form parts close to the final shape, reducing post-processing.

3. High Temperature Application Terminology

High-Temperature Strength

Definition: The ability of a material to resist tensile, compression, or shear deformation at high temperatures (>1000°C). The tensile strength of TZM molybdenum rod at 1200°C is 400-500 MPa.

Thermal Shock Resistance

Definition: The ability of a material to resist cracks or fractures under rapid temperature changes. TZM molybdenum rod has excellent thermal shock resistance due to its low coefficient of thermal expansion (5.3×10^{-6}/K).

Thermal Conductivity

Definition: The ability of the material to conduct heat, the thermal conductivity of TZM molybdenum rod is 139 W/m·K, which only decreases by 10-15% at 1200°C.

Oxidation Resistance

Definition: The ability of a material to resist oxide formation and loss in a high-temperature oxidizing environment. TZM molybdenum rods formed a protective layer of MoO_2 at 1000°C, and the oxidative weight gain rate was < 0.1 mg/cm²·h.

Plasma Erosion

Definition: The phenomenon of surface loss of a material under bombardment with high-energy plasma. TZM molybdenum rods can withstand 10^6 plasma impacts, which is better than pure molybdenum.

Thermal Protection System

Definition: A system used to protect a spacecraft from thermal damage at high temperatures, such as re-entry. TZM molybdenum rods are used in the manufacture of thermal shields and heat shields.

High-Temperature Fatigue

Definition: The ability of a material to resist crack initiation and propagation under high-temperature cyclic stress. The fatigue life of TZM molybdenum rod at 1200°C is 10^5 cycles.

Thermal Cycling Stability

Definition: The ability of a material to maintain its properties and structure during repeated heating and cooling. TZM molybdenum rods can withstand 1000 thermal cycles (room temperature - 1600°C).

4. Materials Science and Metallurgical Terminology

Solid Solution Strengthening

Definition: By dissolving titanium and zirconium atoms into the molybdenum matrix, the lattice distortion is caused to improve the strength and hardness of the material.

Precipitation Strengthening

Definition: By forming carbide particles (e.g., TiC, ZrC) in the molybdenum matrix, dislocation movement is hindered, and high-temperature strength and creep resistance are improved.

Grain Size

Definition: The average size of the crystals in the material, the grain size of TZM molybdenum rods is usually 10-30 microns, which affects the strength and toughness.

Recrystallization Temperature

Definition: The temperature at which the grains of a material rearrange to form new grains at high temperatures. The recrystallization temperature of TZM molybdenum rod is 1400-1500°C, which is higher than that of pure molybdenum at 1100°C.

Dislocation
Definition: A linear defect inside a crystal that affects the plastic deformation and strength of a material. TZM molybdenum rods are pinned to dislocations by carbide particles to improve creep resistance.

Grain Boundary
Definition: The interface between grains that affects the strength, toughness, and corrosion properties of a material. The grain boundaries of TZM molybdenum rods are strengthened with zirconium to reduce high-temperature slippage.

Scanning Electron Microscope
Definition: A microscope for observing the surface topography and fracture characteristics of TZM molybdenum rods with a resolution of up to 1 nanometer.

Transmission Electron Microscope
Definition: A microscope for observing the internal microstructure (e.g., dislocations, carbide particles) of TZM molybdenum rods with a resolution of up to 0.1 nm.

X-Ray Diffraction
Definition: X-ray analysis of the crystal structure, phase composition and stress state of TZM molybdenum rods.

Finite Element Analysis
Definition: Predict stress distribution and failure risk by computer simulation of the performance of TZM molybdenum rod under high temperature and high stress.

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