What Are Tungsten Alloy Rivet Top Bars

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

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

INTRODUCTION TO CTIA GROUP

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

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

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

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

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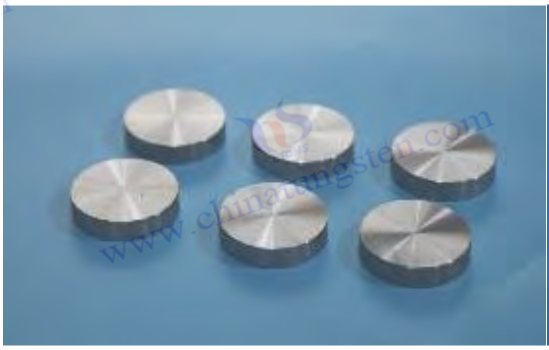
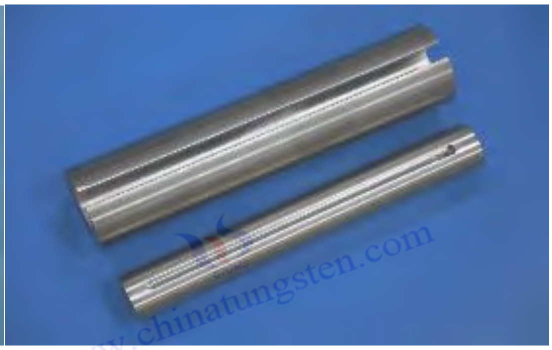

Chapter 1 Overview of Tungsten Alloy Rivet Tops

1.1 Definition of Tungsten Alloy Rivet Top Rod

Tungsten alloy rivet mandrels are alloy products with tungsten as the main component. They are typically manufactured using powder metallurgy and machined into specific rod- shaped tools, primarily used for support and shaping during the riveting process. These mandrels are placed at the rivet tail during installation, acting as a reverse support to withstand hammering or pressure, allowing the rivet head to deform smoothly and form a secure connection. Tungsten alloy is chosen for its high density and hardness, enabling it to maintain shape stability under repeated impacts while possessing a certain degree of toughness to prevent brittle fracture. The diameter and length of the mandrel are designed according to the rivet specifications, and its surface is often precision ground to ensure a good fit with the rivet tail.

Tungsten alloy mandrels commonly use tungsten -nickel-iron or tungsten-nickel-copper alloys. The binder phase provides the necessary plasticity, making the mandrel less prone to cracking during processing and use. The preparation process includes powder mixing, pressing, sintering, and thermomechanical processing, with final heat treatment to adjust the microstructure. The working surface of the mandrel needs to be smooth and flat to reduce friction and damage during rivet deformation. The emergence of tungsten alloy mandrels has solved the problem of insufficient durability of traditional steel mandrels in high-strength rivet applications, especially in applications requiring multiple uses, where their lifespan is more stable.

From a functional perspective, tungsten alloy rivet setters not only provide mechanical support but also, through their high density, help concentrate energy transmission, resulting in more uniform rivet deformation. The setter's end face shape is diverse, such as flat, concave , or convex , to accommodate different rivet types. In use, the setter is fixed to a pneumatic or manual riveting gun, and the operator controls the force to achieve the connection. Maintenance of tungsten alloy setters is relatively simple; regular inspection of surface wear and polishing are sufficient. In conclusion, as an important component of riveting tools, tungsten alloy rivet setters , with their material advantages, improve the efficiency and quality of the connection process and are gradually gaining recognition in the industrial assembly field.

1.1.1 Structural features of tungsten alloy rivet top bars

Tungsten alloy rivet mandrels are mainly reflected in their rod-shaped shape and internal two-phase microstructure. The external design emphasizes functional adaptability, while the internal microstructure determines durability. The mandrel is cylindrical in shape, with one end serving as the working surface for direct contact with the rivet tail, and the other end as a gripping or fixing end for easy installation in riveting equipment. The working surface is typically flat or has shallow grooves to better accommodate rivet tail deformation, and the smooth sides reduce operating resistance. The length and diameter ratio is matched to the rivet size to ensure stable support without interfering with surrounding components.

The internal structure exhibits typical tungsten alloy dual-phase characteristics, with tungsten particles forming a continuous skeleton as the hard phase, and binder phases such as nickel-iron or nickel-copper filling the gaps, providing connectivity and toughness. This microstructure is formed through a sintering process, with nearly spherical tungsten particles and a uniformly distributed binder phase to prevent stress concentration. After hot working, the microstructure displays a fibrous texture, aligned axially to enhance longitudinal strength. The surface is finely ground, resulting in low roughness and reduced rivet adhesion.

Structural features also include end face design; concave top bars help the rivet form a mushroom head, and flat surfaces provide temporary support for large-area rivets. The fixed end often has threads or slots for quick connection to the rivet gun . Tungsten alloy top bars are compact, moderately heavy, and easy to operate manually or automatically. After heat treatment, internal stress is released, and the structure is stabilized to resist impact fatigue.

From a usage perspective, this structural feature makes energy transfer in the mandrel more efficient and deformation zone control better during riveting. The structural design of the tungsten alloy mandrel reflects practical considerations in tool engineering, optimizing its support function through the coordination of its shape and structure , and playing a stabilizing role in assembly lines and maintenance work. With the development of riveting technology, the mandrel structure is also gradually becoming more refined to adapt to more connection needs.

1.1.2 Basic characteristics of tungsten alloy rivet top bars

Tungsten alloy rivet mandrels lie primarily in the combination of their material properties and functional design. This tool acts as a support during riveting, needing to withstand repeated impacts and pressures while maintaining shape stability. The high density of tungsten alloy is one of its most significant features. This property allows the mandrel to have a greater mass for the same volume, providing stronger inertial support and helping to concentrate energy transfer during rivet tail deformation, resulting in a more uniform connection. High hardness is another important characteristic. The tungsten phase acts as a hard skeleton to resist wear, while the binder phase provides a certain degree of toughness, preventing chipping or denting during high-frequency use. Heat resistance is also outstanding. Tungsten alloy has a low tendency to soften under the localized high temperatures generated during riveting, and rivet material does not easily adhere to the surface, keeping the working surface smooth.

The machinability of tungsten alloy mandrels allows for precision forming; the mandrel diameter and end face shape can be customized according to the rivet type. The low coefficient of friction after surface polishing reduces resistance during rivet deformation. Chemical stability makes the mandrel resistant to corrosion from oil or coolant in the workshop environment, and it is not prone to rusting during long-term storage. Its moderate weight makes it easy for operators to hold or for equipment installation without adding excessive burden. These characteristics of tungsten alloy mandrels stem from the dual-phase structure formed by powder metallurgy, where tungsten particles are uniformly distributed and a binder phase fills the gaps, resulting in balanced mechanical properties.

In practical use, these characteristics manifest as a long service life, allowing the same mandrel to support multiple riveting operations without frequent replacements, and the ability to be restored to a worn working surface through simple polishing. Tungsten alloy mandrels also offer excellent acoustic response, producing a crisp sound upon impact, making it easy for operators to judge the quality of the riveting. They feature diverse end-face designs; flat-head designs are suitable for standard rivets, while concave-head designs help create specific head shapes. These fundamental characteristics make tungsten alloy mandrels excellent for assembly lines and maintenance work, gradually becoming a commonly used tool for high-strength riveting. With advancements in material processing, these characteristics are continuously being refined to adapt to more diverse connection needs.

1.1.3 The Position of Tungsten Alloy Rivet Tops in Materials Science

Tungsten alloy rivet mandrels fall under the category of high-density refractory alloy tool materials. This positioning stems from the application of tungsten alloys in the composite design of hard and tough phases, filling the gaps in high impact durability of traditional tool steels. In materials science, tungsten alloys are considered representative of powder metallurgy composite materials, where tungsten particles are bonded to the binder phase through liquid-phase sintering or melt infiltration processes, forming pseudo-alloy or true alloy structures. Rivet mandrels, as a specific product of this material, embody the engineering extension of refractory metals into the field of functional tools.

The Position of tungsten alloy mandrels also highlights their role in the impact tool material spectrum . Compared to tungsten carbide cemented carbide, tungsten alloys emphasize a better balance of toughness, while compared to high-speed steel, they prioritize density and heat resistance. In materials science research, these mandrels are often used as case studies to analyze the mechanical behavior of dual-phase microstructures, where tungsten particles provide hardness support, and the binder phase coordinates deformation and absorbs energy. Positioned as a precision assembly tool material, tungsten alloy mandrels support the development of high-strength riveting, especially in applications requiring repeated use. In a broader classification of materials, tungsten alloy mandrels fall under the category of functional structural materials, providing both mechanical support and optimizing energy transfer through density characteristics. Advances in materials science have led to the evolution of these mandrels from traditional steel replacements to composite optimizations, with surface treatments or microalloying further enhancing their performance. The role of tungsten alloy mandrels reflects the transformation path of refractory alloys from basic research to tool applications, providing reliable support in assembly engineering. With advancements in joining technologies, the role of this material is also expanding, incorporating more intelligent or environmentally friendly elements.

1.2 Main elemental analysis of tungsten alloy rivet top bars

Tungsten alloy rivet mandrels focuses on the synergistic effect of tungsten as the main component with other auxiliary metals. This analysis helps to understand the source of the material's performance in impact bracing. Tungsten provides the basis for high density and hardness, while auxiliary elements such as nickel, iron, or copper improve the balance between workability and toughness. The elemental proportions are designed based on phase diagrams and sintering behavior, with a higher tungsten content to maintain density, and appropriate addition of auxiliary elements to promote uniform microstructure.

Tungsten alloy mandrels considers functional requirements: high density to support impact energy transmission, hardness to resist wear, and toughness to prevent brittle fracture. Tungsten's refractory properties manifest as high-temperature stability in the mandrel, while auxiliary elements lower the brittle transition temperature, allowing the material to be processed at room temperature. Element integration is achieved through powder metallurgy, with homogeneous mixing followed by sintering to form a two-phase structure. Analysis also extends to impurity control; residual oxygen or carbon can induce defects, requiring purification management. Elemental analysis of tungsten alloy mandrels provides a basis for process optimization, supporting the stable performance of the tool in riveting assemblies. With advancements in materials research, elemental analysis is becoming increasingly refined to adapt to more joining scenarios.

1.2.1 The role of tungsten in tungsten alloy rivet mandrels

The primary role of tungsten in tungsten alloy rivet mandrels is to provide high-density and hardness support. This ensures the mandrel maintains its shape stability and effectively transmits energy under riveting impacts. As the main element, tungsten has a large atomic mass and a compact crystal structure, forming a hard phase framework in the mandrel that resists wear and dents on the working surface. During riveting, the mandrel endures repeated hammering; tungsten's high hardness reduces surface deformation, maintains precise contact with the rivet tail, and helps the rivet head to form uniformly. Tungsten's heat resistance also plays a role in the use of mandrels . During localized frictional heating, the tungsten phase has a low tendency to soften, resulting in minimal overall dimensional changes in the mandrel and preventing thermal fatigue damage. The high density of tungsten concentrates the mass of the mandrel , leading to greater inertia for the same volume, more efficient transfer of impact energy to the rivet, and a more stable connection strength. During the sintering process, the spherical distribution of tungsten particles reduces surface energy, promoting densification, resulting in fewer internal pores and consistent strength within the mandrel .

Tungsten's role is also reflected in its chemical stability. When the mandrel is exposed to the workshop environment, the tungsten phase exhibits strong oxidation resistance, preventing the formation of a porous layer on its surface and maintaining a smooth finish. Even after the addition of auxiliary elements, the tungsten phase still dominates the performance, resulting in slow wear of the mandrel during long-term use. The role of tungsten in tungsten alloy rivet mandrels demonstrates the fundamental contribution of refractory metals to tool materials, supporting reliable riveting processes through density and hardness, and gaining practical value in the assembly field.

1.2.2 Integration of Auxiliary Metal Elements in Tungsten Alloy Rivet Top Rods

The integration of auxiliary metal elements in tungsten alloy rivet mandrels is primarily achieved through a binder phase. These elements, such as nickel, iron, or copper, combine with tungsten particles to form a two-phase structure, improving overall toughness and processing adaptability. The integration process is completed during the powder mixing and sintering stages. The auxiliary element powder is uniformly distributed between the tungsten powder particles, melting and wetting the tungsten particles during liquid-phase sintering, filling the gaps and establishing connections. Chemically, the auxiliary elements have low miscibility with tungsten, maintaining clear phase boundaries , while the binder phase provides deformation coordination and reduces mandrel brittleness .

The role of integration is to balance the high hardness of tungsten, and the auxiliary elements lower the room temperature brittle transition temperature, allowing the mandrel to absorb energy under impact loads and avoid sudden fracture. Nickel is commonly used as a major auxiliary element; its high ductility improves the cold working performance of the mandrel after integration , facilitating precision grinding of the end face. The addition of iron or copper further adjusts the density or thermal conductivity, and the integration ratio is adjusted according to the mandrel specifications . Post-sintering heat treatment promotes element diffusion, improves interfacial bonding strength, and enhances the fatigue resistance of the mandrel .

The integration of auxiliary elements also affects surface properties; the exposed binder phase enhances corrosion resistance, and the mandrel is more stable in humid environments. The uniformity of integration is controlled through powder ball milling or spray drying to avoid performance fluctuations caused by localized agglomeration. The integration of auxiliary metal elements in tungsten alloy mandrels embodies the synergistic design of composite materials, optimizing the overall performance of the tool through the bridging effect of the binder phase and providing a reliable foundation in riveting supports.

1.2.2.1 Effect of Nickel Addition on Tungsten Alloy Rivet Top Rods

Addition of nickel to tungsten alloy rivet mandrels primarily improves toughness and machinability. This effect allows the mandrel to absorb more energy under impact conditions, reducing the risk of brittle fracture. As a key binder element, nickel forms a face-centered cubic solid solution during sintering, encapsulating tungsten particles and providing continuous deformation channels. Chemically, nickel exhibits good wettability to tungsten, resulting in uniform flow in the liquid phase, promoting particle rearrangement and densification, and leading to a denser internal structure in the mandrel .

With the addition of nickel, the room temperature plasticity of the ejector bar improves, making it less prone to cracking during cold working such as grinding or turning, and making it easier to achieve the required surface finish. In impact applications, nickel helps to balance the stress distribution of tungsten particles, reducing the tendency for the ejector bar's working surface to dent or chip, resulting in a more stable service life. The corrosion resistance of nickel is also transferred to the ejector bar surface, resisting oil and moisture in the workshop and maintaining cleanliness.

The proportion of nickel added affects the balance of effects; an appropriate amount significantly improves toughness, while excessive amounts slightly decrease density. After heat treatment, the nickel phase becomes more homogeneous, interfacial bonding is enhanced, and the fatigue resistance of the mandrel is improved. The effect of nickel addition on tungsten alloy rivet mandrels reflects the toughening effect of a binder element, supporting the durability of the tool during riveting through interphase coordination, and contributing practical value in assembly applications.

1.2.2.2 Effect of Iron Addition on Tungsten Alloy Rivet Top Rods

The addition of iron in tungsten alloy rivet mandrels primarily forms a binder phase system with nickel , creating a nickel-iron solid solution. This addition significantly impacts the mandrel 's mechanical properties and processing characteristics. Iron is infinitely miscible with nickel, lowering the liquidus appearance temperature during sintering, promoting tungsten particle rearrangement and densification, and simultaneously adjusting the stacking fault energy of the binder phase, making it more prone to cross-slip and twinning deformation. The addition of iron enhances the pinning effect of the binder phase on dislocations, improving the overall yield strength and fatigue resistance of the mandrel. In the repeated impact riveting environment, the working surface of the mandrel is less prone to microcracks or dents.

The addition of iron enhances the magnetic properties of the mandrel , a characteristic that can be used for magnetic clamping or positioning in certain assembly applications, facilitating automated operation. Iron also improves the oxidation resistance of the binder phase, forming a denser protective layer on the surface, making the mandrel less prone to localized corrosion in humid or oily environments. Adjusting the iron -nickel ratio affects the strength of the effect; a moderate iron content provides a good balance between toughness and strength, reducing the likelihood of edge chipping during cold working processes such as turning or grinding. During heat treatment, iron promotes the uniform distribution of precipitated phases, further strengthening the microstructure. The addition of iron also contributes to the thermal stability of the mandrel ; during high-temperature annealing, iron inhibits excessive coarsening of the binder phase, maintaining a fine grain structure, resulting in minimal dimensional changes during localized frictional heating. The economic efficiency of iron makes the tungsten-nickel-iron system a common choice, with readily available raw materials and relatively controllable production costs. The effect of iron addition is also reflected in the acoustic response; the sound upon impact is more muffled, helping operators judge the riveting force. The addition of iron to tungsten alloy rivet mandrels demonstrates the reinforcing effect of auxiliary elements in the binder phase. Through synergy with nickel , it optimizes the overall performance of the mandrel and provides practical value in the field of riveting tools.

1.2.2.3 Mechanism of copper doping in tungsten alloy rivet mandrels

The mechanism of copper doping in tungsten alloy rivet mandrels mainly manifests in the formation of a non-magnetic binder phase and the improvement of thermal conductivity. This mechanism is suitable for riveting applications that require avoiding magnetic interference or rapid heat dissipation. Copper and nickel are infinitely miscible, forming a face-centered cubic solid solution in the tungsten-nickel-copper system. During sintering, the liquid phase flows and wets the tungsten particles, promoting rearrangement and densification. At the same time, the high thermal conductivity of copper makes the temperature gradient of the mandrel more gradual during impact heating, reducing thermal stress concentration.

The core of copper doping lies in its contribution to microstructure uniformity. The copper phase fills the gaps in the tungsten framework, forming a continuous network. Chemically, copper has a small wetting angle with tungsten, resulting in a clean interface and more uniform energy dispersion during impact testing . Copper's high ductility improves the room temperature plasticity of the ejector pin , enhancing its cold working performance and facilitating the precision molding of complex end faces. Copper doping also introduces a non-magnetic effect, preventing interference when the ejector pin is used near magnetic clamping equipment , making it suitable for electronic assembly lines.

Copper also modulates thermal expansion behavior in the mechanism, reduces internal stress by matching with tungsten, and minimizes the tendency for cracking under thermal cycling of the mandrel . In terms of surface properties, the exposed copper phase enhances corrosion resistance, and the mandrel is resistant to oil and cleaning agents. The copper doping ratio affects the mechanism's performance; at an appropriate level, thermal conductivity and toughness are balanced. After heat treatment , the copper phase becomes more homogeneous, enhancing the fatigue resistance of the mandrel . The copper doping mechanism embodies the functional integration of the conductive phase in the composite material, optimizing the thermomechanical behavior of the mandrel through network filling , and playing a stabilizing role in riveting supports.

1.2.2.4 Mechanism of doping other elements in tungsten alloy rivet mandrels

The doping of other elements in tungsten alloy rivet mandrels is mainly achieved through microalloying or dispersion strengthening. These elements, such as cobalt, molybdenum , or rare earth compounds, are added in small amounts to refine the microstructure or improve specific properties. Cobalt doping enhances the strength of the binder phase; chemically, cobalt reduces stacking fault energy and promotes twinning deformation, thus improving the impact toughness of the mandrel . Molybdenum partially replaces tungsten, regulating thermal expansion and recrystallization temperature, resulting in better high-temperature dimensional stability of the mandrel .

Rare earth elements such as lanthanum or yttrium are dispersed in oxide form, pinning grain boundaries to hinder migration and increasing recrystallization temperature . This results in fine grains in the mandrels after hot working, enhancing their strength and durability. The addition of small amounts of carbides, such as titanium carbide, forms a third phase for reinforcement, further increasing the surface hardness of the mandrels and resisting rivet wear. Mechanistically, these elements segregate at interfaces or grain boundaries during sintering, altering surface energy and diffusion paths, leading to a denser and more uniform microstructure.

The doping mechanism also includes a purification effect, where rare earth elements capture oxygen and sulfur impurities to form stable compounds and reduce brittle inclusions. Cobalt-molybdenum composite doping synergistically strengthens the material, resulting in a balanced overall performance of the mandrel . Strict control of the doping amount is maintained to avoid introducing excessive new phases that could damage toughness. Heat treatment activates the material, and solution treatment and aging precipitate fine particles. The doping mechanisms of other elements demonstrate the material optimization through microalloying; targeted improvements in the performance of tungsten alloy mandrels are achieved through small additions , contributing practical improvements to riveting tools.

1.3 Microstructure of tungsten alloy rivet top bar

The microstructure of tungsten alloy rivet mandrels is characterized by a two-phase composite structure. Tungsten particles, acting as the hard phase, are encapsulated by a binder phase , forming a cermet-like microstructure. This structure originates from powder metallurgy and has further evolved after sintering and hot working. The tungsten particles are mostly nearly spherical or polyhedral, and their size distribution affects the balance between strength and toughness. The binder phase fills the interparticle gaps, providing continuous deformation channels. The interface layer is crucial to the structure; the transition zone formed by element diffusion enhances the bonding. Defects such as porosity or segregation within the structure must be controlled to maintain the mandrel's impact resistance.

Microstructural observation commonly utilizes scanning electron microscopy (SEM) and transmission electron microscopy (TEM) to reveal the degree of particle spheroidization and phase distribution uniformity. Rolling introduces fibrous texture, aligning it axially to enhance longitudinal strength. Heat treatment adjusts grain size and precipitated phases, optimizing performance. The microstructure of tungsten alloy mandrels embodies the engineering practice of refractory alloy composite design, supporting stable tool performance in riveting through interphase coordination and providing reliable support in assembly applications.

1.3.1 Influence of Crystal Structure on the Performance of Tungsten Alloy Rivet Studs

Influence of crystal structure on the performance of tungsten alloy rivet mandrels is mainly reflected in the interaction between the body-centered cubic lattice of the tungsten phase and the face-centered cubic lattice of the binder phase. This influence determines the mandrel's hardness, toughness, and fatigue resistance. Tungsten particles maintain a body-centered cubic structure, with limited slip systems but high hardness, providing rigid support under impact loads and resisting deformation of the working surface. The binder phase, with its abundant face-centered cubic lattice slip systems, exhibits strong deformation coordination ability, absorbs impact energy, and prevents brittle fracture of the mandrel . Crystal orientation forms texture during processing, with grain elongation along the rolling direction, increasing axial strength.

The influence of crystal structure is also reflected in interface matching. Lattice mismatch between tungsten and the binder phase generates a stress field, which is released by heat treatment, resulting in a more stable bond. Annealing induces recrystallization, and grain refinement improves the balance between strength and toughness. Impurities segregate at grain boundaries, altering structural stability;

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purification processes reduce these effects. Crystal defects such as dislocations multiply under impact, and the binder phase recovers quickly, resulting in better fatigue resistance of the mandrel .

During thermal cycling, the difference in thermal expansion of the crystal structure generates micro-stress, but the binder phase buffers this stress, ensuring the stability of the mandrel dimensions . Exposed surface crystals affect wear; polishing reduces friction by creating a smooth crystal surface. The influence of crystal structure on the performance of tungsten alloy rivet mandrels reflects the materials science principle of phase-lattice synergy. Structural optimization supports the tool's durability, contributing practical value in riveting practices.

1.3.2 Observation of Phase Separation Phenomenon in Tungsten Alloy Rivet Top Rods

The observation of phase separation in tungsten alloy rivet mandrels mainly involves the distribution characteristics of the tungsten phase and the binder phase. This phenomenon originates from the liquid phase flow and cooling precipitation during sintering, manifesting as the spheroidization and separation of tungsten particles and the network filling of the binder phase. Scanning electron microscopy (SEM) in backscatter mode is commonly used for observation; the tungsten phase , with its higher atomic number, appears brighter, while the binder phase appears darker, creating a striking contrast. The tungsten particles are nearly spherically separated, with the spacing determined by the volume of the binder phase; this uniform separation promotes stress dispersion.

Phase separation observation also revealed an interfacial transition layer where element diffusion forms a gradient region, enhancing bonding and preventing delamination. Insufficient sintering results in incomplete separation and residual pores; over-sintering leads to coarsening of particles, excessive separation, and decreased toughness. After hot working, the phase separation elongates along the deformation direction, forming a fibrous structure, and cross-section observation shows a layered distribution. Annealing promotes homogenization of phase separation, resulting in fine and dispersed precipitates.

Cooling rate affects the separation phenomenon; rapid cooling locks in fine separation, while slow cooling results in slight particle growth. Impurities agglomerate at phase boundaries as dark spots; purification reduces this phenomenon. Observation of phase separation in tungsten alloy rivet mandrels reveals the formation process of composite structures. Microscopic analysis guides process adjustments, supports the stability of mandrel performance , and enables it to play a role in riveting tools.

1.4 Theoretical Basis of Tungsten Alloy Rivet Top Rods

Tungsten alloy rivet mandrels is primarily based on alloy phase diagram analysis and thermodynamic principles. These foundations help explain the material's behavioral changes during preparation and use. Phase diagrams provide a guiding framework for inter-element interactions, revealing the solubility and phase equilibrium of tungsten with auxiliary metals, while thermodynamics analyzes the feasibility and stability of the process from an energy perspective. The application of this theoretical basis makes mandrel design more scientific; from composition selection to process parameters, everything is based on phase diagram data and energy calculations, avoiding blind adjustments.

Phase diagram theory in mandrels is reflected in the prediction of the liquid phase region of tungsten-nickel-iron or tungsten-nickel-copper systems. The sintering temperature is set with reference to the phase diagram to ensure an appropriate amount of liquid phase is present, promoting particle rearrangement. Thermodynamic principles involve changes in Gibbs free energy, driving the dissolution-re- precipitation mechanism; the densification of the mandrel microstructure depends on a negative free energy process. The theoretical foundation also includes the concept of interfacial energy; the reduction of tungsten particle surface energy promotes spheroidization, from which the impact resistance of the mandrel benefits.

Thermodynamic equilibrium guides stress release during annealing, and residual stress in the mandrel minimizes energy through diffusion. The combination of phase diagrams and thermodynamics analyzes the high-temperature stability of the mandrel , and element diffusion rate calculations help optimize holding time. The theoretical basis of tungsten alloy mandrels embodies the multidisciplinary nature of materials science, supporting tool performance prediction through phase diagrams and energy principles, and providing theoretical support for riveting applications.

1.4.1 Application of Alloy Phase Diagrams in Tungsten Alloy Rivet Rods

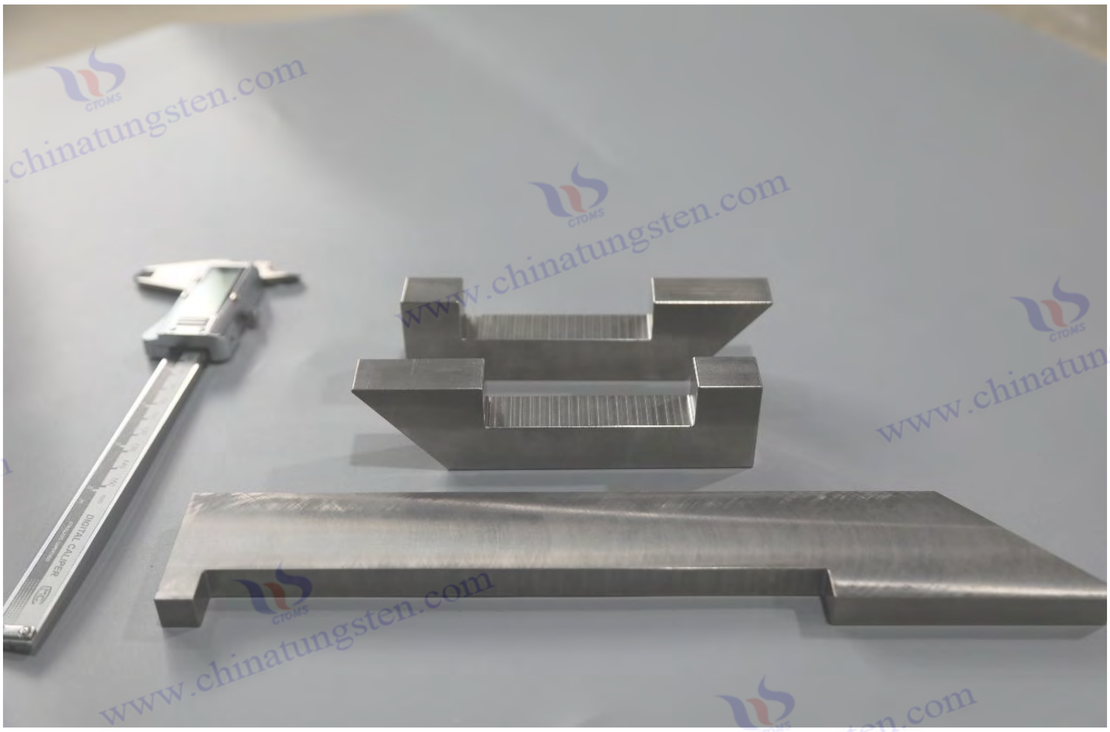
The application of alloy phase diagrams in tungsten alloy rivet mandrels primarily guides composition design and process parameter selection. This application helps predict inter-element phase equilibrium and temperature-dependent behavior, ensuring stable mandrel microstructure and consistent performance. The phase diagram depicts the miscible regions of tungsten with auxiliary metals such as nickel and iron . The mandrel composition is set within the solid solution limit to avoid the formation of harmful phases. The liquid phase region is used in the sintering process; heating the mandrel to the temperature shown in the phase diagram promotes the melting and wetting of the binder phase and tungsten particles, achieving rearrangement and densification.

Phase diagrams are also applied in the heat treatment stage. Recrystallization temperature is estimated from the phase diagram, and mandrel annealing avoids excessively high temperatures that could lead to coarsening. The tungsten-nickel binary phase diagram shows low-temperature separation; during mandrel cooling , the phase diagram guides precipitation control, maintaining a fine distribution and improving toughness. The tungsten-iron phase diagram is used to adjust magnetism; in non- magnetic environments , the mandrel reduces iron content to match the non-magnetic region of the phase diagram. For multi-element extensions of the phase diagram, such as the tungsten-nickel-iron ternary phase, mandrel ratio optimization references the liquidus line, balancing wetting and strength. In these applications, phase diagram simulation software assists in prediction, and mandrel experiments verify the phase diagram data. The application of phase diagrams in mandrels demonstrates the guidance of theory for practice, supporting the reliability of material preparation through equilibrium analysis and contributing practical value in the field of riveting tools.

1.4.2 Influence of Thermodynamic Principles on Tungsten Alloy Rivet Top Rods

The thermodynamic principles affecting tungsten alloy rivet mandrels primarily manifest in guiding the feasibility and stability of the process through energy changes. This influence persists from sintering to use, aiding in the analysis of the mandrel's behavioral mechanism. The Gibbs free energy principle drives liquid phase formation during sintering, negative values promote particle rearrangement, and mandrel densification depends on the energy-minimizing path. Endhalpy changes influence the heating process; as the mandrel temperature rises, it absorbs heat, and the melting of the binder phase provides the flow energy.

The principle of entropy increase is manifested in diffusion; during the heat treatment of the mandrel , the random distribution of elements increases the entropy value, resulting in a more stable interface bonding. Phase equilibrium thermodynamics guides composition adjustment, and the mandrel's auxiliary element ratio is based on the free energy curve to avoid the formation of high-energy phases. Thermodynamic effects also include stress release; during mandrel annealing , residual energy is reduced through diffusion, restoring performance. In impact applications, thermodynamic analysis of energy transfer helps concentrate kinetic energy, and the deformation process follows the law of energy conservation. Oxidation thermodynamics predicts surface behavior, and the free energy calculation of the mandrel in air guides coating protection. The influence of thermodynamic principles on tungsten alloy rivet mandrels reflects an energy-based understanding of materials, and the application of these principles supports tool performance optimization, playing a guiding role in riveting practice.



CTIA GROUP LTD Tungsten Alloy Rivet Top Rod

Chapter 2 Classification and Related Analysis of Tungsten Alloy Rivet Tops

2.1 Classification of Tungsten Alloy Rivet Tops Based on Composition

Tungsten alloy rivet mandrels are classified primarily based on the different binder phase elements, reflecting the systematic differences in density, toughness, processability, and cost. Common categories include tungsten -nickel-iron (TNI) systems, tungsten-nickel-copper (TNC) systems, and other variant systems . Tungsten is the dominant element with a high proportion, and the proportion of binder phase elements is adjusted to balance performance. TNI systems emphasize mechanical strength and magnetic properties, while TNC systems emphasize non-magnetic properties and thermal conductivity. High-density categories aim to maximize tungsten content.

The classification is based on phase diagrams and sintering behavior. Nickel, as a basic binder element, is mutually soluble with other metals to form solid solutions. The addition of iron or copper alters phase properties. In production, compositional classification guides powder formulation and process routes. Tungsten-nickel-iron systems have higher liquid-phase sintering temperatures, while tungsten-nickel-copper systems are easier to cold work. The classification also considers application adaptability; magnetic push rods are suitable for specific clamping applications, while non-magnetic push rods are used for electronic assembly. Impurity control is universal in the classification, with low oxygen and carbon content to avoid embrittlement.

Composition-based classification provides a framework for mandrel selection. Engineers match categories based on rivet material and operating conditions; tungsten -nickel-iron systems offer high impact resistance , while tungsten-nickel-copper systems provide surface stability. The classification system expands with materials research, with rare earth or cobalt doping forming new branches.

2.1.1 High-density tungsten alloy rivet top bar

High-density tungsten alloy rivet mandrels are characterized by their high tungsten content. These mandrels utilize the advantage of concentrated mass in riveting support, providing stronger inertial reaction force and energy transfer efficiency, resulting in more uniform and complete rivet deformation. The high-density design is achieved by reducing the proportion of the binder phase, with tungsten particles dominating the composition. After sintering, the microstructure is dense with fewer pores, resulting in a larger overall mass for the same volume and more stable reaction force upon impact.

The high-density mandrel's structure is primarily composed of a tungsten skeleton, with a thin layer of binder encapsulating the particles, resulting in a tight interfacial bond . The mandrel's working surface has high hardness, resisting repeated indentation at the rivet tail. During processing, the high-density billet is hot-rolled and shaped; cold working requires auxiliary annealing to release stress and prevent cracking. After surface grinding, the surface is smooth, reducing rivet adhesion. The mandrel exhibits low vibration and stable operation when used in high-speed riveting equipment.

High-density tungsten alloy rivet mandrels are suitable for supporting large or high-strength rivets. The high density of tungsten concentrates energy into the rivet, resulting in consistent connection strength. They exhibit good thermal stability, with minimal shape change during localized heating, leading to a longer mandrel lifespan . They also possess strong chemical stability, exhibiting slow corrosion in workshop environments and requiring minimal maintenance. High-density varieties also include tungsten -nickel-iron variants for magnetically assisted positioning and tungsten-nickel-copper variants for non- magnetic applications in electronic assembly.

In production, fine tungsten powder is used to enhance density in high-density rivet tops , and prolonged sintering and holding promote rearrangement. Heat treatment adjusts the microstructure, and annealing refines the grains to balance toughness. These properties of high-density rivet tops stem from the material advantages of tungsten , providing reliable support in riveting tools and gradually becoming a common choice for heavy-duty applications. With the diversification of assembly requirements, the application range of high-density tungsten alloy rivet tops is also expanding, contributing practical improvements to connection processes.

2.1.2 Low-density tungsten alloy rivet top bar

Low-density tungsten alloy rivet mandrels are a variant category that reduces overall density by adjusting the composition ratio or introducing lightweight elements. These mandrels maintain a balance between the basic hardness and toughness of the tungsten alloy while reducing weight, facilitating operator and equipment load management. Low-density designs typically reduce tungsten content or partially replace tungsten with molybdenum , resulting in a correspondingly increased proportion of the binder phase. The post-sintering microstructure remains a two-phase composite, but the tungsten particle skeleton is relatively sparse, while the copper or nickel network is more continuous. Although the working surface hardness of the mandrel is slightly lower than that of the high-density type, it is sufficient to withstand typical riveting impacts, and surface wear is uniform.

low-density tungsten alloy mandrels are dominated by a binder phase, with deformation coordination as the primary feature. Tungsten particles provide necessary support, resulting in gentler energy absorption during impact and reduced equipment backlash. Improved machinability allows for easier cold and hot rolling to achieve thin-walled or long bar shapes, and flexible end-face forming. Thermal stability still depends on the tungsten or molybdenum phase, with minimal shape change during localized heating. Good chemical stability makes the surface easy to plate or polish, resisting corrosion from the workshop environment.

These mandrels are suitable for light riveting equipment or manual operation. Their light weight reduces operator fatigue, and their moderate inertia supports precision rivet forming. The molybdenum -copper variant offers better thermal conductivity, resulting in rapid heat dissipation and low temperature rise during continuous operation. The low-density category also includes tungsten-copper pseudo- alloys, where the copper phase continuously enhances conductivity, and the mandrels exhibit no magnetic interference in electronic assembly. In production, low-density mandrel powder is easier to mix evenly, has a wider sintering temperature window, and simplifies process control.

low-density tungsten alloy rivet mandrels has expanded to portable tools or light-duty workstations in automated lines, where their lightweight nature facilitates management when frequent mandrel changes are required. A variety of surface treatments are available, with chemical plating enhancing appearance and corrosion resistance. These characteristics of low-density mandrels stem from material optimization through compositional adjustments, providing a lightweight option for riveting supports and gradually becoming a practical tool for specific applications. With the trend towards lightweight assembly, the application scope of this category is also expanding, contributing flexible value to connection processes.

2.1.3 Rare Earth Doped Tungsten Alloy Rivet Top Rod

Rare earth-doped tungsten alloy rivet mandrels are a special category optimized by adding trace amounts of rare earth elements such as lanthanum , yttrium , or cerium . These mandrels refine the microstructure of traditional tungsten alloys, improving high-temperature stability and fatigue resistance. Rare earth doping is typically added to the powder in the form of oxides and dispersed in the binder phase or interface during sintering. Chemically, rare earths capture oxygen and sulfur impurities , forming stable compounds and purifying grain boundaries to reduce brittleness sources.

rare-earth -doped mandrels are mainly grain refinement and interface strengthening. Rare earth pinning at grain boundaries hinders migration, increases recrystallization temperature, and maintains a fine microstructure after hot working, resulting in high strength and durability. Tungsten particles are more fully spheroidized, and the binder phase is uniformly encapsulated, leading to a more balanced stress distribution during impact . Surface properties are improved, with rare earth agglomeration forming a thin protective layer, enhancing the mandrel's oxidation resistance.

This type of mandrel is suitable for high-temperature or long-term riveting applications. It does not coarsen during localized frictional heating, and its hardness decays slowly. Rare earth doping also improves fatigue resistance; microcrack propagation is slow under repeated impacts, resulting in a more stable mandrel lifespan . During processing, the doped mandrel exhibits slightly better cold workability and is less prone to edge chipping. It also possesses strong chemical stability, with rare earth elements inhibiting corrosion initiation.

rare-earth-doped tungsten alloy rivet mandrels requires controlling the uniformity of doping levels, with powder ball milling or spray drying aiding in distribution. Heat treatment activates the doping mechanism, and aging precipitation further enhances the rare-earth phase. These properties of rare-earth-doped mandrels stem from the materials science principle of microalloying, providing performance enhancements in riveting tools and gradually becoming the choice for demanding applications. As research progresses, this doping category is becoming more refined, contributing to the potential expansion of mandrel functionality .

2.2 Application-based classification of tungsten alloy rivet top bars

Tungsten alloy rivet mandrels are classified primarily according to their application and working conditions, reflecting the varying adaptability of mandrels in different riveting environments. In machining, impact resistance and lifespan are emphasized, while in precision instruments, accuracy and stability are prioritized. The classification is based on the mandrel's hardness, density, and surface properties. Machining mandrels have a high tungsten content to resist wear, while precision instrument mandrels have a uniform microstructure to prevent micro-deformation.

The classification also considers rivet material and equipment type; aluminum alloy rivets are paired with low-hardness mandrels, while steel rivets require high-strength mandrels. In production, the classification guides end-face design and working surface treatment; in mechanical applications, concave surfaces accommodate deformation, while in precision applications, planar surfaces provide temporary support. The classification system evolves with assembly technology, incorporating automation-compatible elements. The application-based classification of tungsten alloy mandrels provides a practical framework for selection, supports the optimization of riveting processes through domain matching, and plays a role in industrial assembly.

2.2.1 Tungsten alloy rivet setters used in machining

In the machining industry, tungsten alloy rivet mandrels are tools specifically designed for high-strength riveting. These mandrels act as a reverse support in machine tools or hand riveting guns , withstanding heavy load impacts and helping rivets form a strong connection on sheet metal. The mandrel has a large diameter and a flat or shallowly concave working surface to accommodate the expansion of the rivet tail, while its smooth sides reduce equipment friction. The high hardness of tungsten alloy allows the mandrel to resist repeated indentations from steel or aluminum rivets, and its surface wear is slow, making it suitable for mass production environments.

In machining, these ejector pins are commonly used for riveting automotive bodies, ship components, or building steel structures. The tungsten particle skeleton provides rigidity, while the bonding phase absorbs vibration energy, preventing edge chipping . The end face design is adjusted according to the rivet type: a flat-head type supports blind riveting, while a concave- head type assists in self-piercing riveting . The ejector pin is fixed to a pneumatic riveting gun; under high operating pressure, the inertial reaction force is concentrated, resulting in uniform rivet deformation. It exhibits strong chemical stability, resisting coolant or oil contamination, and can be cleaned to restore its smoothness.

In the machining field , adjustable-length mandrels are used ; short mandrels are used manually, while longer mandrels are used on automated lines. After heat treatment, the microstructure becomes fibrous, resulting in high axial strength and resistance to bending under lateral forces. A brushed surface treatment increases grip friction and facilitates replacement. The application of tungsten alloy mandrels in this field improves riveting efficiency, reduces downtime for maintenance, and ensures consistent connection quality. High-density tungsten -nickel-iron systems are commonly used in production, with magnetic-assisted positioning. These adaptability features stem from the combination of materials and processes, providing reliable support in mechanical assembly. Maintenance of these mandrels includes periodic inspection of working surface dents and polishing to restore smoothness. The fatigue resistance of tungsten alloys ensures stable performance in high-frequency riveting, resulting in aesthetically pleasing rivet heads. Applications extend to heavy machinery maintenance, where mandrels withstand the impact of large-diameter rivets without deformation. The positioning of tungsten alloy rivet mandrels in the machining field reflects the engineering value of tool durability, optimizing connection processes through impact support and contributing practical improvements to industrial production.

2.2.2 Tungsten alloy rivet top bars for use in precision instruments

In the field of precision instruments, tungsten alloy rivet mandrels are specialized tools for miniature or high-precision riveting. These mandrels have a small diameter and a mirror-smooth working surface, serving as a support to ensure precise and damage-free deformation of the rivet on small parts. The mandrel body is short and precise, with a flat end face to avoid scratching precision surfaces, and polished sides to reduce operating resistance. The uniform structure of the tungsten alloy ensures consistent density in the mandrel , stable reaction force upon impact, and symmetrical rivet head shaping.

In precision instruments, these mandrels are used for riveting electronic devices, medical devices, or optical instruments. The finely distributed tungsten particles ensure consistent bonding and minimal deformation, preventing pitting on the working surface . The end face design emphasizes flatness, ensuring even pressure distribution when supporting micro-rivets. Highly chemically inert, the mandrel is resistant to cleanroom environments, preventing particle shedding and contamination of components. Mounted on manual or electric precision riveting guns, they require low operating force, and their moderate inertia allows for precise control of deformation. The field of precision instruments , the length of the mandrel is crucial, and shorter mandrels facilitate operation in confined spaces. Heat treatment refines the grain size, making the mandrel resistant to micro- fatigue and maintaining its shape over long-term use. Surface electroplating or passivation improves compatibility, ensuring the mandrel does not react with the instrument materials. The application of tungsten alloy mandrels in this field guarantees riveting precision, prevents loosening of connections, and ensures stable instrument function. During production, the tungsten-nickel-copper system is non-magnetic, making it suitable for electronic assembly. The low thermal expansion of tungsten alloy ensures dimensional stability under temperature changes, guaranteeing accurate rivet positioning. Applications extend to aerospace instruments and laboratory equipment, with the miniature design of the mandrel adapting to space constraints. The positioning of tungsten alloy rivet mandrels in precision instruments reflects the tool value of material refinement, optimizing small connections through precision support and playing a role in high-tech assembly.

2.2.3 Tungsten alloy rivet top bar for high-temperature environments

High-temperature environment-specific tungsten alloy rivet mandrels are a type of tool optimized for hot working or high-temperature riveting conditions. These mandrels must withstand localized high temperatures and thermal cycling during riveting while maintaining shape stability and support accuracy. The mandrel's design prioritizes thermal stability, featuring a high tungsten content to enhance melting point support. A heat-resistant binder phase is selected, resulting in a dense microstructure after sintering and reducing the tendency for thermal softening. The working surface is flat or shallowly concave , and undergoes special heat treatment to form a high-temperature resistant layer that resists frictional heat generation.

In high-temperature riveting, this type of mandrel is used for hot riveting or hot metal connections. The tungsten particle skeleton maintains rigidity at high temperatures, while the copper or nickel phases coordinate thermal expansion, preventing deformation or cracking. The end face design considers heat conduction, enabling rapid heat dissipation and reducing heat accumulation, resulting in low temperature rise during continuous use. It exhibits strong chemical stability; the surface of the mandrel forms a natural or artificially passivated anti-oxidation layer, resisting corrosion from high-temperature gases. Its moderate length facilitates operation with high-temperature equipment, and the fixed end is compatible with heat-resistant materials.

of mandrels for high-temperature environments includes high-temperature annealing, which refines the grains to improve resistance to thermal fatigue . The mandrels exhibit slow microcrack propagation under repeated thermal shock. Surface coatings or dispersion strengthening further improve heat resistance, ensuring the mandrels remain stable in high-temperature oil or gas media. The application of tungsten alloy mandrels in this field supports the reliability of hot-working connections, resulting in uniform rivet formation and consistent connection quality.

of these rivet mandrels focuses on inspecting for surface oxidation after cooling and polishing to restore a smooth finish. The high-density variant exhibits strong inertia, ensuring efficient energy transfer during hot riveting. The high-temperature-specific category of tungsten alloy rivet mandrels reflects the engineering adaptability of the material's heat-resistant design, providing stable support during hot assembly and gradually becoming a practical choice for high-temperature riveting. With advancements in hot working technology, the application of these mandrels is expanding, contributing temperature-resistant value to the joining process.

2.2.4 Tungsten alloy rivet top bar for wear environments

Tungsten alloy rivet mandrels for abrasive environments are reinforced tools designed for high-friction or abrasive impact conditions. These mandrels resist surface wear and maintain a smooth working surface and support accuracy when riveting hard materials or performing high-frequency operations. The mandrel body has high hardness, reinforced with dispersed tungsten particles or surface-hardened, and the binder phase maintains a toughness balance to prevent chipping. The working surface is mirror-polished or micro-textured to reduce rivet adhesion and abrasive embedding. In abrasive environments, these mandrels are used for riveting stainless steel, titanium alloys, or composite materials. The tungsten phase resists abrasive scratches, and surface pitting buildup is slow. The flat end face design supports large-area rivets, and the wear-resistant coating on the sides reduces equipment friction. With good chemical stability, the mandrel is resistant to coolant abrasion and the surface is less prone to wear grooves. The length is adjustable according to the equipment, and the fixed end is reinforced to prevent loosening.

Of mandrels specifically designed for abrasive environments includes surface ion implantation or carbide coating, resulting in enhanced wear resistance through a hardness gradient, and longer service life in high-frequency riveting. Heat treatment refines the grain size, further improving fatigue and wear resistance. The application of tungsten alloy mandrels in this field enhances durability, and the consistent rivet head shape reduces replacement frequency.

Of these rivet jacks includes regular inspection of surface roughness, polishing, or touch-up coating. The tungsten -nickel-iron system offers high hardness, making it suitable for heavy wear applications. The wear-specific category of tungsten alloy rivet jacks reflects engineering optimization of the material's wear-resistant design, providing reliable support under harsh friction conditions and gradually becoming a common tool for high-durability riveting.

2.3 Performance Difference Analysis of Tungsten Alloy Rivet Top Rod Types

Tungsten alloy rivet mandrel types are mainly based on a comparison of composition, application, and structural variations. This analysis helps to understand the performance emphasis of different categories in riveting supports. High-density types have high density and strong inertial reaction force, making them suitable for heavy-duty impacts. Their energy transfer is concentrated, and rivet deformation is uniform. Low-density types are lightweight, flexible in operation, suitable for light equipment, and exhibit low vibration and good precision control.

Rare earth doped types exhibit refined microstructure, improved fatigue resistance and heat resistance, resulting in less micro-damage to the ejector pin during thermal cycling or long-term use. Machining-specific types offer high hardness, wear resistance, and a long working surface life for the ejector pin. Precision instrument-specific types exhibit good uniformity, minimal micro-deformation, and high ejector pin support accuracy. High-temperature-specific types have high softening temperatures, stable shapes, and stable performance under thermal shock. Wear-specific types feature surface strengthening, strong scratch resistance, and durability in frictional environments.

Performance differences are also reflected in machinability and maintenance; high-density types require heat assistance for processing, while low-density types are easier to cold work. Rare-earth-doped types have good annealing response and require more specialized mechanical surface treatments. This difference analysis guides selection: high-density types are for heavy-duty applications, low-density types are for lightweight applications, and rare-earth types are for high-temperature applications and harsh wear environments. The performance difference analysis of tungsten alloy mandrel types reflects the materials science significance of classification design, supporting targeted tool applications and providing diverse choices in riveting practice.

2.3.1 Effect of Composition Variation on Physical Properties of Tungsten Alloy Rivet Top Rods

Compositional changes on the physical properties of tungsten alloy rivet mandrels is mainly reflected in the adjustment of density, thermal stability, and surface characteristics, providing diverse performance options for different applications. Increasing the tungsten content increases the overall density of the mandrel , resulting in a more concentrated mass distribution. This provides a more stable inertial reaction force during riveting impact, leading to more uniform deformation at the rivet tail. Adjusting the proportion of the bonding phase alters thermal expansion behavior. When the nickel-iron system dominates, the mandrel exhibits excellent dimensional stability under varying temperature conditions. Switching to a nickel-copper system improves thermal conductivity, allowing for faster dissipation of localized frictional heat and reducing temperature rise at the working surface.

Compositional changes also affect surface wettability and chemical stability. Increased copper content makes it easier for a uniform protective layer to form on the mandrel surface , resisting corrosion from workshop oils or cleaning agents, while the addition of iron helps form a dense oxide film, improving resistance to atmospheric corrosion. Trace doping with rare earth elements purifies the grain boundaries of the mandrel , improving its structural stability under thermal cycling and reducing the likelihood of microcracks on the surface. Compositional adjustments also affect the distribution of residual stress after processing; an appropriate nickel-copper ratio can reduce internal stress, allowing the mandrel to maintain its shape more stably during repeated use. In actual production, compositional variations are achieved through powder proportioning and sintering parameters. The matching of tungsten powder particle size with the binder phase powder further refines the impact on performance. Under the same riveting conditions, mandrels with different compositions exhibit more concentrated energy transfer in higher-density types, better temperature rise control in types with better thermal conductivity, and longer maintenance cycles in types with strong corrosion resistance. The influence of compositional variations on the physical properties of tungsten alloy rivet mandrels provides flexibility in tool selection. Appropriate proportioning meets various requirements such as machining, precision assembly, and high-temperature environments, demonstrating significant adaptability in riveting practice.

2.3.2 Application-oriented design reflected in tungsten alloy rivet mandrels

Application-oriented design in tungsten alloy rivet mandrels is primarily reflected in the targeted optimization of their dimensions, working surface shape, and surface treatment. This design philosophy allows the mandrel to better adapt to specific riveting conditions, improving operational efficiency and connection quality. Mandrels used in machining often feature larger diameters and concave working ends to accommodate the large deformation of the high-strength rivet tail. The mandrel's length is moderate for easy fixation with a pneumatic riveting gun , while anti-slip textures on the sides facilitate manual adjustment. In the precision instrument field, a slender mandrel and flat working surface are preferred to ensure precise support of miniature rivets, with a mirror-polished surface to avoid scratching sensitive components.High-temperature environment -specific mandrels are designed with heat dissipation in mind. Shallow grooves on the working surface promote airflow, the mandrel body is made of a heat-resistant bonding phase, and the ends are coated with a heat-insulating layer to reduce heat transfer to equipment . Abrasive environment- specific mandrels feature a hardened or micro-textured working surface to increase the wear-resistant layer thickness, and reinforced fixed ends to withstand higher frequency impacts. Application-guided design extends to the fixing method; some mandrels have quick-lock or threaded interfaces for seamless integration with automated equipment. Surface treatment also reflects application orientation. Machining mandrels often use oil-resistant coatings, while precision instrument mandrels choose bright coatings that prevent particle shedding. High-temperature mandrels are further coated with an anti-oxidation coating. The length-to-diameter ratio is matched according to the rivet specifications; short and thick types are suitable for heavy loads, while long and thin types are beneficial for operation in confined spaces. This application-oriented design in tungsten alloy rivet mandrels transforms the tool from a general-purpose tool to a specialized one. Through the coordination of structure and treatment, the adaptability of riveting processes is improved, playing a practical role in various industrial scenarios.

2.3.3 The effect of microstructural differences on the mechanical properties of tungsten alloy rivet mandrels

The microstructural differences in tungsten alloy rivet mandrels primarily influence their mechanical properties through tungsten particle size, binder phase distribution, and interfacial bonding. This microstructural control determines the mandrel 's strength, toughness, and fatigue resistance under impact loads. High-density mandrels feature finer, more uniformly distributed tungsten particles, with a thin layer of binder phase forming a dense skeleton. This results in more thorough stress dispersion during impact, reducing the likelihood of surface dents or microcracks. Conversely, low- density mandrels have larger tungsten particle spacing, a more continuous binder phase network, and enhanced deformation coordination, leading to more gentle energy absorption under light loads or vibration environments.

rare-earth -doped mandrels is characterized by grain boundary purification and dispersed phase reinforcement. Rare-earth compounds pin grain boundaries, hindering slip, thus improving the mandrel's resistance to high-temperature fatigue and resulting in slower strength decay after thermal cycling. Machining- specific mandrels utilize surface hardening to form a gradient structure, with enriched tungsten particles on the surface enhancing wear resistance, while the core binder phase maintains toughness and prevents brittle edge chipping. Precision instrument- specific mandrels exhibit high particle spheroidization, clean interfaces free of impurity agglomeration, minimal stress concentration under minor impacts, and outstanding shape stability. The fiber texture induced by hot working is also a control method. Grain elongation in the rolling direction enhances axial strength, resulting in a lower bending tendency of the mandrel under lateral forces. Annealing refines the recrystallized grains, balancing hardness and plasticity, and the mandrel exhibits good performance recovery after repeated use. The microstructural differences in the control of the mechanical properties of tungsten alloy rivet mandrels provide performance gradients for different applications. Microstructural optimization achieves a reasonable balance between strength and toughness, exhibiting a stable mechanical response in riveting supports. With advancements in observation technology, this control method is continuously being improved, opening up more possibilities for enhancing mandrel performance.

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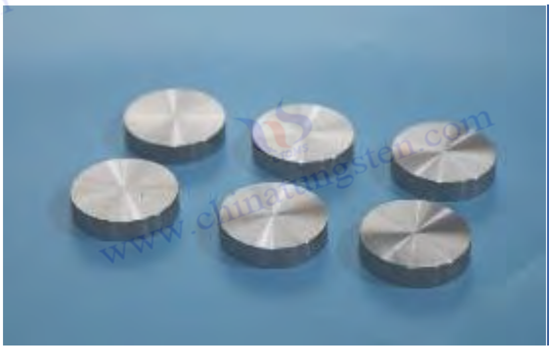
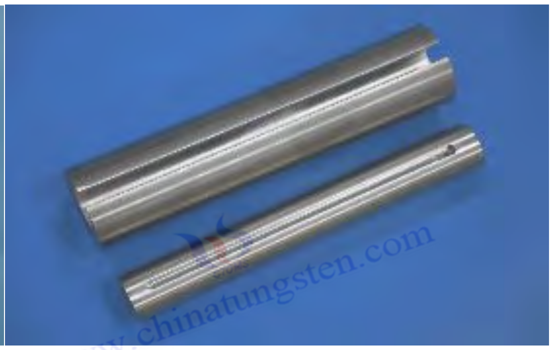



Chapter 3 Fabrication Process of Tungsten Alloy Rivet Rods

3.1 Metallurgy Method for Tungsten Alloy Rivet Rods

Tungsten alloy rivet mandrels is a complete process chain from powder raw materials to finished tools. This method achieves the composite of tungsten and auxiliary elements through mixing, forming, sintering, and post-treatment to form rod-shaped products suitable for riveting support. Powder selection is fundamental to the method. High-purity tungsten powder and binder phase powders such as nickel-iron or nickel-copper are mixed in a specific ratio. The fine particle size of the tungsten powder enhances density, while the high activity of the binder phase powder promotes wetting. In the mixing stage, mechanical ball milling or a V-mill is used for uniform distribution. Chemically, surfactants are used to prevent agglomeration and ensure macroscopic uniformity of elements.

The forming process involves pressing mixed powders into rod-shaped blanks. Cold isostatic pressing is commonly used for large-sized top rod blanks . The liquid medium transmits pressure is isotropically , resulting in uniform blank density and avoiding stress gradients. Compression molding is suitable for small batches, using a steel mold with unidirectional pressure and lubricant to reduce friction. After forming, the strength of the green blank is enhanced by a temporary binder, facilitating handling.

Sintering is the core of the process. Heating under vacuum or hydrogen atmosphere causes the binder phase to melt and wet the tungsten particles when a liquid phase appears, leading to rearrangement and densification. Controlling the temperature window allows for appropriate liquid phase flow, preventing collapse or segregation. The holding period involves a dissolution-re-precipitation mechanism to spheroidize the particles, resulting in clean interfacial bonding. Slow cooling locks in the microstructure, preventing thermal stress cracking. Hot isostatic pressing assists sintering to close pores and increase the billet density.

Hot working deforms the sintered billet , drawing or rolling to reduce its diameter, multi-directional forging to create a uniform microstructure, and intermediate annealing to release hardening and restore plasticity. The mandrel end face is machined and ground to a smooth surface. Heat treatment solution-aging precipitates phases, strengthening the mandrel to achieve a balance of strength and toughness.

Surface treatment involves chemical cleaning to remove oxidation, polishing to improve smoothness, and coating to enhance corrosion resistance. Finishing involves shearing to a fixed length and inspecting dimensional density. The flexibility of the powder metallurgy method allows for parameter adjustments based on mandrel specifications ; high-density types extend sintering holding time, while low-density types increase the proportion of the binder phase. The method is economical, and waste powder can be recycled.

The application of powder metallurgy in tungsten alloy rivet mandrels embodies materials engineering from microscopic composite to macroscopic forming. Chain optimization enhances tool durability and provides a stable foundation for riveting support. With technological advancements, this method is also incorporating automation elements, contributing efficiency value to mandrel production .

3.1.1 Raw material preparation steps in the preparation of tungsten alloy rivet mandrels

The raw material preparation step in the fabrication of tungsten alloy rivet mandrels is the starting point of the powder metallurgy process. This step, through tungsten powder purification, particle size control, and alloy element mixing, ensures the uniformity of microstructure and consistency of performance in subsequent forming and sintering. Raw material preparation emphasizes the matching of chemical purity and physical properties. Tungsten powder, as the main component, needs to be highly pure to avoid defects induced by impurities, while alloy element powders with high activity promote wetting. The process begins with the reduction of ammonium tungstate, progressing to powder sieving and mixing. Chemically, the reduction reaction removes oxygen, and mixing promotes random element distribution.

The preparation process includes tungsten powder preparation, auxiliary powder selection, and homogenization. Tungsten powder particle size is controlled through hydrogen reduction grading, while alloy powders such as nickel, iron, and copper are prepared using carbonyl or atomization methods. Before mixing, the powder is dried to prevent moisture absorption, and chemical cleaning removes surface contaminants. The systematic nature of the preparation steps ensures controllable composition of the mandrel , resulting in a stable foundation for density and hardness. Raw material quality directly affects the impact resistance of the mandrel , and purification reduces sources of brittleness. The flexibility of raw material preparation allows for adjustments based on mandrel type ; high-density types use fine, pure tungsten powder, while low-density types incorporate a binder phase. The powder is stored in a dry environment to prevent oxidation and agglomeration. The raw material preparation steps in the production of tungsten alloy rivet mandrels embody the engineering management of basic materials , supporting the smooth operation of the process chain through purification and mixing, and laying a reliable material foundation for mandrel production . With technological advancements, this preparation is also incorporating automated weighing and testing, improving efficiency and consistency.

3.1.1.1 Purification and Particle Size Control of Tungsten Powder

core aspects of preparing raw materials for tungsten alloy rivet mandrels . This control achieves high purity and suitable distribution of tungsten powder through multi-stage reduction and sieving, ensuring dense sintering and uniform microstructure of the mandrel . Purification begins with recrystallization of ammonium tungstate to remove alkali metals and phosphorus and sulfur impurities. After calcination into oxides, hydrogen reduction occurs, where hydrogen reacts with the oxides to generate water, which is then discharged. Dew point control ensures timely removal of moisture, preventing re-oxidation of the tungsten powder. Staged reduction at low temperatures removes water of crystallization, while high temperatures form metallic tungsten. This process is repeated to improve purity.

Particle size control is reflected in the reduction parameters. High temperature and fast boat speed produce coarse powder, while low temperature and slow speed produce fine powder. Chemically, reduction kinetics affect crystal nucleus growth, and moisture concentration adjustment inhibits abnormal coarsening. Distribution is monitored using a laser particle size analyzer or Fisher's method. Fine powder enhances sintering activity, while coarse powder provides strength support. Abnormal particles are removed by sieving or air classifying. High-density top rods require uniform fine powder, while low-density top rods allow for a slightly wider distribution.

The combination of purification and control results in a clean tungsten powder surface, low oxygen and carbon content, reduced brittle inclusions, and improved impact toughness of the mandrel . Chemical cleaning and acid washing remove residues, followed by drying and inert gas-sealed storage. The purification and particle size control of the tungsten powder reflect the refinement of raw material engineering, and reduction sieving supports the reliable formation of the mandrel structure , contributing fundamental value in rivet tool production. With advancements in testing technology, this control is continuously refined, enabling the optimization of material properties.

3.1.1.2 Homogeneity of alloying elements

The uniformity of alloying elements is a crucial step in the preparation of tungsten alloy rivet mandrel raw materials . This uniformity is achieved through mechanical mixing or ball milling to ensure random element distribution and prevent sintering segregation from affecting the consistency of mandrel performance . Before mixing, alloy powders such as nickel, iron, and copper undergo pretreatment to remove the oxide layer through reduction and to chemically enhance surface activity and promote bonding. A V-type or double-cone mixer is used at low speed to prevent separation, and extended mixing time ensures macroscopic uniformity.

Ball milling refines the powder through high-energy impact mixing and pre-alloying, inducing diffusion through chemical and mechanical forces, resulting in initial interfacial bonding. A spray-drying variant atomizes the suspension into spherical composite powder, improving flowability and uniformity. After mixing, samples are taken for chemical analysis or electron microscopy to verify the distribution; low elemental deviation is considered acceptable. Mixing uniformity affects the density distribution of the mandrel . Uniform mixing ensures smooth sintering rearrangement, reduces localized binder phase, and balances the mandrel's strength and toughness. Chemical additives aid dispersion, and the mixture is wet-mixed with alcohol followed by drying. Controlling mixing uniformity ensures stress dispersion during impact and consistent wear on the working surface. The uniformity of alloy element mixing in tungsten alloy rivet mandrels reflects the pursuit of uniformity in batching engineering, supporting macroscopic consistency of the microstructure through physicochemical interactions and laying the performance foundation in tool manufacturing. With advancements in mixing equipment, this uniformity continues to improve, contributing practical improvements to mandrel reliability.

3.1.2 Effect of sintering process on the density of tungsten alloy rivet mandrels

The sintering process's influence on the density of tungsten alloy rivet mandrels is mainly reflected in the control of temperature, atmosphere, and holding time. This influence determines the degree of transformation of the mandrel from a porous blank to a dense product, thus affecting its support stability and durability during riveting impacts . In the initial solid-phase diffusion stage of sintering, the particle necks bond, and the density increases slowly. After entering the liquid phase stage, the binder phase melts and wets the tungsten particles, and the rearrangement mechanism makes the particles tightly packed, significantly increasing the density. Higher temperatures increase the amount of liquid phase, resulting in more thorough flow and filling of pores; however, excessively high temperatures lead to over-flow, causing blank deformation or segregation, and uneven density distribution.

Atmosphere selection affects density; hydrogen reduction removes oxide inclusions, maintains interface cleanliness, and promotes wetting and densification; a vacuum environment removes volatile impurities and reduces closed-cell residue. Extended holding time allows for sufficient rearrangement and dissolution-reprecipitation, reducing the spheroidization surface energy of tungsten particles and increasing pore shrinkage density; however, excessive holding time may lead to particle coarsening and the introduction of new pores. Slow heating rates prevent premature local liquidation, which can create density gradients. Controlled cooling prevents thermal stress cracking, which can affect the final density consistency.

The effects of the sintering process extend to the mandrel dimensions. When the length-to-diameter ratio of the rod-shaped billet is large, the end density tends to be low, requiring support fixtures to aid in uniformity. Auxiliary processes such as hot isostatic pressing apply pressure after sintering to close the pores, further increasing density. With high tungsten content, sintering density relies more heavily on liquid phase optimization; less binder phase necessitates longer holding times. The impact of the sintering process on the density of tungsten alloy rivet mandrels reflects the densification principle of high-temperature metallurgy, supporting the volumetric properties of the mandrel through parameter coordination , thus laying the mechanical foundation for riveting tools. With advancements in process monitoring, the control of this effect is becoming more refined, providing a reliable guarantee for the consistency of mandrel density.

3.1.3 Optimization of Press Forming Technology in Tungsten Alloy Rivet Top Rods

The optimization of pressing technology in tungsten alloy rivet mandrels mainly focuses on improving pressure distribution, die design, and powder flowability. This optimization ensures uniform green density and complete shape, providing a high-quality foundation for subsequent sintering. Cold isostatic pressing optimization utilizes the isotropic pressure transmission of the liquid medium , resulting in a small density gradient in the rod-shaped billet . Optimized parameters include a slow pressurization rate and extended holding time to avoid cracking caused by elastic rebound. The selection of a flexible die material matches the hardness of the tungsten powder, reducing frictional damage.

The molding optimization employs bidirectional pressurization, a floating mold structure to balance the density of the upper and lower parts, and press tonnage matched to powder volume, with a gradual pressing speed to prevent delamination. Powder flowability optimization includes the addition of lubricant, and chemically, zinc stearate reduces interparticle friction, resulting in denser filling.

Optimization also includes pre-pressurization and venting to reduce residual enclosed gases. The rod-shaped preform optimization involves controlling the length-to-diameter ratio and using a supporting mandrel to help prevent bending.

Optimization of press forming technology affects the consistency of ejector pins ; high-density green blanks result in less sintering shrinkage and better dimensional accuracy. Fine tungsten powder optimizes compaction, while coarser powder requires higher pressure. Optimized testing involves multi-point measurement of green blank density to guide parameter iteration. Chemical purity management ensures low lubricant residue, preventing sintering contamination. The optimization of press forming technology in tungsten alloy rivet ejector pins demonstrates pressure coordination in the forming process, supporting reliable blank preparation through mold and parameter improvements, contributing practical value to tool production. With the development of press precision, this optimization is expanding, providing more possibilities for ejector pin forming.

3.1.4 The effect of liquid phase sintering on densification of tungsten alloy rivet mandrels

of liquid-phase sintering on tungsten alloy rivet mandrels is mainly achieved through the wetting, rearrangement, and dissolution-re-precipitation mechanisms following the melting of the binder phase. This process transforms the mandrel from a porous state of a pressed billet into a high-density product, enhancing its mechanical support capabilities. When the liquid phase appears, the binder phase flows and encapsulates the tungsten particles, reducing surface tension and driving particle rearrangement to fill large pores, resulting in a rapid increase in density. A small wetting angle promotes capillary action, and chemically, a decrease in interfacial energy accelerates the process.

The dissolution-reprecipitation mechanism takes effect during the holding period. Small tungsten particles dissolve into the liquid phase, while larger particles precipitate on their surface. Particle spheroidization reduces stress at sharp corners, and pore shrinkage further densifies the structure. The mechanism works best when the liquid phase volume is moderate; excessive flow leads to deformation, while insufficient volume results in inadequate rearrangement. Temperature window controls the liquid phase ratio, and holding time allows the mechanism to fully develop. A protective atmosphere prevents oxidation from interfering with wetting, and hydrogen reduction ensures a clean interface.

The role of liquid-phase sintering is also reflected in the uniformity of the rod-shaped mandrels . Long billets, aided by supporting fixtures, facilitate liquid phase distribution, avoiding low density at the ends. When tungsten content is high, the effect depends on optimizing the binder phase; in copper systems, the liquid phase temperature is low and easily controlled . Subsequent repressurization replenishes residual pores in the liquid phase. The densification effect of liquid-phase sintering on tungsten alloy rivet mandrels embodies the metallurgical principle of high-temperature flow, supporting the volume stability of the mandrel through a synergistic mechanism , laying a durable foundation for riveting tools. With advancements in sintering equipment, the control of this effect is becoming more refined, providing a reliable path for mandrel densification.

3.2 Machining Technology of Tungsten Alloy Rivet Tops

Machining technology for tungsten alloy rivet mandrels is an important component of powder metallurgy post-processing. This technology transforms sintered billets into precision rod-shaped tools through turning, grinding, drawing, and hot forging, optimizing dimensional accuracy, surface quality, and microstructure. Machining compensates for the shape limitations and surface roughness of sintered billets. The high hardness of tungsten alloys necessitates the use of hard cutting tools and appropriate cooling during machining. The technology includes forming and plastic deformation; forming achieves a refined shape, while plastic deformation refines the microstructure and improves strength.

The machining technology emphasizes tool wear resistance and matching cutting parameters. The hard phase of tungsten particles facilitates tool sharpening, while the bonding phase ensures smooth cutting. The coolant provides chemical stability and corrosion protection, and dry cutting or minimal lubrication reduces thermal damage. The machining sequence progresses from roughing to finishing, first turning to form the shape, then grinding for a smooth finish. Hot working is combined with cold working, with hot forging for initial blanking followed by cold grinding for finishing. Defect control focuses on cracks and surface scratches, which are alleviated through stress release during annealing. The machining technology of tungsten alloy rivet mandrels reflects the forming challenges of refractory alloys. Precision tooling is achieved through tool and process optimization, providing a dimensionally stable foundation for riveting supports. With the application of CNC equipment, the precision of this technology is also improving, contributing practical value to the diversification of mandrel functions .

3.2.1 Application of forming in tungsten alloy rivet mandrels

The application of forming in tungsten alloy rivet mandrels is mainly achieved through turning, milling, and grinding. This process shapes the sintered billet into a precise rod shape with functional end faces, ensuring a good fit between the mandrel and the rivet tail and providing stable support. The forming process begins with the sintered billet, followed by turning to remove the outer skin and determine the diameter. Carbide or diamond cutting tools are used to resist the hardness of tungsten , and the cutting speed is moderate to avoid heat accumulation. Chemical coolant is used for lubrication and heat dissipation to prevent surface burns or microcracks.

In forming applications, the end face design is diverse: flat-headed shapes are machined for a smooth finish, while concave -headed shapes are milled to accommodate rivet deformation. Grinding the sides of the bar improves roundness, and low surface roughness reduces friction. Forming precision is achieved through CNC lathes, with strict dimensional tolerance control supporting automated riveting. Heat treatment after forming avoids stress concentration, and annealing softens the surface to improve machinability.

Forming also includes machining the fixed end , such as threading or slotting, to facilitate equipment installation. Chemical cleaning removes chips, and polishing restores a smooth finish. The application of forming in tungsten alloy rivet mandrels demonstrates the dimensional control of precision machining, achieving reliable tool profile finishing through toolpath optimization, and providing practical support in riveting practices. With advancements in machining centers, this application is expanding, offering more possibilities for mandrel customization.

3.2.2 Application of Plastic Deformation in Tungsten Alloy Rivet Tops

The application of plastic deformation in tungsten alloy rivet mandrels is mainly achieved through forging, drawing, and rolling. This application refines the sintered microstructure and improves the strength, toughness, and density uniformity of the mandrel . Plastic deformation begins with hot forging, where the binder phase softens at high temperatures to coordinate the deformation of tungsten particles, multi-directional forging uniforms stress, chemical diffusion promotes particle bonding, and microstructural fibrosis enhances axial properties.

In deformation applications, drawing reduces the diameter, elongates the grains of the rod, and improves bending resistance. Rolling involves multiple passes of reduction, intermediate annealing releases hardening and restores plasticity, and cold rolling finishes a smooth surface. The plastic deformation mechanism involves dislocation multiplication and strengthening, while the binder phase absorbs energy to prevent brittle fracture. The deformation is controlled gradually, with a large initial reduction for shaping and a smaller reduction for finishing in the later stages.

Plastic deformation also improves internal porosity and increases the density of closed residual defects. Dynamic recovery from hot deformation is active, reducing dislocation rearrangement and accumulation. Chemical atmosphere protection prevents oxidation, and the deformed surface is easy to clean. The application of plastic deformation in tungsten alloy mandrels embodies the engineering practice of high-temperature, low-speed deformation, supporting the tool's mechanical properties through microstructure optimization and providing a durable foundation for riveting impacts. With the increasing precision of deformation equipment, this application is becoming more refined, contributing practical improvements to mandrel strength.

3.2.3 Optimization of the Microstructure of Tungsten Alloy Rivet Top Rods by Heat Treatment

Tungsten alloy rivet mandrels through heat treatment is mainly achieved through steps such as annealing, solution treatment, and aging. This optimization adjusts grain size, phase distribution, and defect state, improving the balance of strength and toughness and fatigue resistance of the mandrel . Heat treatment is performed before and after machining. After sintering, annealing releases residual stress, and chemical diffusion drives dislocation migration and annihilation, reducing internal stress in the mandrel and preventing the propagation of microcracks during use. Vacuum or hydrogen atmosphere protection prevents oxidation, and the temperature is controlled within the recrystallization range of the binder phase. During the holding period, grain boundary migration refines the grains.

The optimization process also includes solution treatment, where high-temperature dissolution of alloying elements forms a supersaturated solid solution, followed by rapid cooling to lock in the state, and the binder phase strengthens and improves the hardness of the mandrel. Aging treatment precipitates fine phases, pinning dislocations and hindering slip, thus improving the impact toughness of the mandrel . Heat treatment optimizes interface bonding, and element diffusion forms a gradient zone, enhancing the wear resistance of the mandrel's working surface . Further spheroidization of tungsten particles is achieved during optimization, reducing surface energy and minimizing stress at sharp corners.

Heat treatment optimizes the microstructure, significantly impacting the overall performance of the mandrel . Refined grains result in high strength without sacrificing toughness, and coordinated deformation during repeated riveting. Optimization parameters are adjusted based on the alloy system; higher temperatures promote recovery in tungsten-nickel-iron alloys, while tungsten-nickel-copper alloys offer better thermal conductivity and faster heat dissipation. Chemical purity management minimizes impurities and prevents the precipitation of abnormal phases. Heat treatment- optimized the mandrel's microstructure reflects material control over thermal diffusion, supporting tool performance stability through cyclic treatment and providing a reliable foundation for riveting supports. With advancements in furnace control technology , this optimization is becoming increasingly refined, contributing practical value to mandrel durability .

3.2.4 Application of precision grinding technology in surface machining of tungsten alloy rivet setters

Machining of tungsten alloy rivet mandrels primarily to achieve high surface finish and precise dimensions. This application involves gradually removing material using a grinding wheel or belt to achieve a smooth working surface and control the roundness of the mandrel. The grinding process is divided into rough grinding and fine grinding. Rough grinding removes machining allowances and surface defects, while fine grinding improves the surface finish. Chemically, diamond or boron carbide grinding wheels resist the hardness of tungsten , and coolant lubrication dissipates heat and prevents thermal damage.

In applications, mirror grinding of the ejector pin's working surface reduces rivet adhesion, resulting in a low coefficient of friction and uniform forming. Centerless or centered grinding of the outer cylindrical portion of the pin ensures stable support and high roundness. Strict parallelism control during end face grinding ensures good fit between the ejector pin and the rivet. Precision grinding processes are adapted to the length-to-diameter ratio of the rod-shaped ejector pin , and the clamping method avoids bending vibration. Frequent wheel dressing maintains sharpness, and grinding parameters (speed and pressure) are matched to the characteristics of tungsten alloys.

Precision grinding applications also include special shapes, concave surfaces, or grooves achieved using forming wheels, and the ejector pin better accommodates rivet deformation. Chemical cleaning removes grinding debris, and polishing assists in restoring shine. The precision grinding process of tungsten alloy ejector pins embodies the refinement of surface engineering, supporting high-quality tool surfaces through step-by-step removal, and contributing practical improvements to riveting practices. With the development of CNC grinding machines, the precision of this application is also improving, providing more possibilities for the surface functions of ejector pins.

3.2.5 Realization of Complex Shapes for Tungsten Alloy Rivet Rods via Electrical Discharge Machining

Electrical discharge machining (EDM) is used to achieve complex shapes for tungsten alloy rivet mandrels primarily by removing material through electrical discharge. This application is suitable for precision forming of grooves, irregular shapes, or internal features on the mandrel end face , overcoming the limitations of traditional machining. EDM utilizes pulsed discharge between the tool electrode and the mandrel ; the chemically heated spark melts and vaporizes the localized material, and the medium washes away the removed material . Tungsten alloys have good electrical conductivity, resulting in stable discharge, and the machining process avoids deformation as no mechanical force is used.

The process tool electrode is formed into a negative shape using copper or graphite. The ejector pin is fixed in the working fluid, and the etching rate is controlled by the pulse width current parameter . Complex shapes, such as multi-level concave surfaces or side holes, are shaped by CNC wire cutting through electrode trajectory programming. The ejector pin is cooled and chipped using kerosene or deionized water as a chemical medium to prevent excessive heat-affected zone. Surface roughness is adjusted by precision discharge and restored by polishing after surface finishing.

The advantages of electrical discharge machining (EDM) lie in its non-contact nature. For tungsten alloys with high hardness, traditional cutting methods are difficult, while EDM removes material evenly . Small features of the mandrel, such as micro-concavities or textures, are easily achieved, improving rivet containment. Chemical cleaning removes the white layer, and heat treatment releases residual stress. EDM of tungsten alloy mandrels enables flexible forming of complex shapes, supports diverse tool designs through the discharge mechanism, and provides customized support in specialized riveting applications.

3.3 Characterization and Quality Control of Tungsten Alloy Rivet Top Rods

Tungsten alloy rivet mandrels are crucial aspects of the manufacturing process. This control involves verifying the consistency of material microstructure, composition, and properties through microscopic analysis, spectroscopic methods, and physical testing, ensuring the reliable performance of the mandrel in riveting support. Characterization focuses on microstructure and elemental distribution, while quality control covers density uniformity, hardness distribution, and surface defects. Microscopic observation of particle spheroidization and phase interfaces, spectroscopic identification of component purity, and physical testing evaluate mechanical properties.

Control is implemented throughout production, from raw material powder to finished mandrels, with multi-point sampling and testing to avoid batch deviations. Chemical analysis limits impurities, microscopic porosity checks, and mechanical testing of impact toughness are conducted.

Characterization data is used to provide feedback for process adjustments, and sintering parameters are optimized to reduce defects. Quality control standards reference industry specifications, and mandrel density and hardness ranges are matched to application requirements. Clean laboratory operations are conducted to prevent contamination from interfering with results.

tungsten alloy rivet mandrels embody the closed-loop inspection system of materials engineering, and support the performance stability of the tool through multi-method collaboration, providing reliable assurance in riveting practice.

3.3.1 Application of Microscopic Analysis in Tungsten Alloy Rivet Top Rods

Microscopic analysis in tungsten alloy rivet mandrels is primarily achieved using optical microscopes, scanning electron microscopes (SEM), and transmission electron microscopes (TEM). This helps observe microstructural features, particle distribution, and defect morphology, guiding process optimization and quality assessment. Optical microscopes are used for preliminary metallographic observation; after polishing and etching the sample cross-section, the tungsten particles and the binder phase are clearly contrasted, allowing for the assessment of spheroidization and phase distribution uniformity. Chemical etching selectively dissolves the binder phase, highlighting the tungsten framework outline.

Scanning electron microscopy (SEM) provides higher resolution and backscattered imaging, revealing high brightness in the tungsten phase , darker binder phase, and clear visibility of particle spacing and interfaces in the top rod cross-section . Energy dispersive spectroscopy (EDS) assists in elemental mapping, revealing localized segregation or impurities. Transmission electron microscopy (TEM) observation of thin-section samples reveals dislocations, grain boundaries, and precipitated phases after ion thinning, allowing for analysis of the top rod impact damage mechanism.

Microscopic analysis is applied in production control. After sintering, samples are inspected for residual porosity; after hot working, fiber texture is observed; and after surface wear, the damaged layer is assessed. Analytical results guide annealing temperatures, refining grains and improving toughness. Analysis of the longitudinal section of the mandrel ensures axial uniformity, and end faces are used to inspect for defects on the working surface. Chemical preparation and corrosion are applied appropriately to avoid excessive dissolution that masks key features. The use of microscopic analysis in tungsten alloy rivet mandrels demonstrates the material science tool of microscopic characterization. Through multi-scale observation, it supports a related understanding of microstructure properties, plays a key role in quality control, and provides visual evidence for improving mandrel durability.

3.3.2 Identification of the composition of tungsten alloy rivet mandrels using spectroscopic methods

Spectroscopic methods for identifying the composition of tungsten alloy rivet mandrels primarily employ X-ray fluorescence, optical emission, and atomic absorption spectroscopy. These methods provide information on elemental content and distribution, ensuring that the mandrel composition meets design requirements and preventing impurities from affecting performance. X-ray fluorescence spectroscopy provides non-destructive analysis of surface composition; the intensity of characteristic fluorescence excitation reflects the proportion of tungsten, nickel, iron, or copper. Multi-point scanning of the mandrel body assesses uniformity.

Photoemission spectroscopy involves dissolving the sample, followed by plasma excitation, and using spectral lines to identify the type and content of elements, suitable for detecting trace impurities such as oxygen and carbon . Atomic absorption spectroscopy uses characteristic light absorbed by the nebulized solution to sensitively determine low-content auxiliary elements. The application of spectroscopic methods is evident in raw material acceptance and finished product inspection, including powder batch purity identification and top rod cross-section analysis of segregation.

Sample preparation is crucial in the identification process; surface cleaning avoids contamination, and the dissolving acid exhibits high selectivity. Spectroscopic methods for identifying the composition of tungsten alloy rivet mandrels support quality traceability, allowing for adjustments to the mix ratio when deviations occur. Chemical standard samples calibrate the instrument, and repeated measurements ensure consistency. Identification results guide heat treatment, as elemental distribution influences precipitation behavior.

The comprehensive use of spectroscopic methods covers the macroscopic to microscopic scale, enabling rapid fluorescence screening and precise emission quantification. The composition of the mandrel remains stable during riveting applications, and spectroscopic identification provides long-term evidence. The identification of the composition of tungsten alloy rivet mandrels using spectroscopic methods demonstrates the material support of analytical chemistry, optimizes production control through elemental information, and contributes reliable data to tool quality.

3.3.3 The Importance of Density Testing in Quality Assessment of Tungsten Alloy Rivet Master Rods

density testing in the quality assessment of tungsten alloy rivet mandrels lies primarily in its role as a direct indicator of overall densification and microstructure uniformity. This test helps determine whether the volumetric properties of the mandrel after sintering and processing meet the support requirements. Density reflects the degree of filling of tungsten particles with the binder phase . High-density mandrels have fewer pores, stronger inertial reaction forces, concentrated energy transfer during riveting impacts, and uniform rivet deformation. Low-density mandrels may have residual porosity, uneven strength distribution, and are prone to localized indentations or fatigue damage during use.

Density testing commonly uses the Archimedes method or gas displacement method, with multiple sampling points to assess the uniformity of the rod . A small density difference between the ends and the middle indicates sufficient sintering rearrangement. Chemically, density is related to the composition ratio; a higher tungsten content results in a higher theoretical density. Test deviations reveal segregation or impurities. Density testing guides process adjustments; if sintering is insufficient, extending the holding time or performing isostatic pressing with additional heat can improve the mechanical properties of the top rod .

The tests also evaluated the effects of heat treatment; a slight change in density after annealing reflected stress release, and the mandrel dimensions remained stable. Density testing after surface finishing verified no material loss and consistent mandrel quality . The importance of density testing in the quality assessment of tungsten alloy rivet mandrels lies in its comprehensive reflection of volumetric properties. Numerical comparisons support reliable tool selection and provide a quality basis for riveting practice. Stable control of density lays the foundation for mass production of mandrels, ensuring balanced support performance for each tool.

3.3.4 testing technology for detecting internal defects in tungsten alloy rivet top bars

Non-destructive testing (NDT) techniques for detecting internal defects in tungsten alloy rivet mandrels primarily employ ultrasonic, X-ray, and eddy current methods. These methods reveal porosity, cracks, or inclusions without damaging the mandrel , aiding in quality control and preventing potential failures. Ultrasonic testing utilizes sound wave reflection to locate internal discontinuities; longitudinal wave scanning of the rod-shaped mandrel detects axial defects; and chemically, the strength of interfacial reflections distinguishes between porosity and cracks. X-ray transmission imaging reveals density differences, clearly showing low-density areas within the mandrel , making it suitable for batch screening.

Eddy current testing detects surface or near-surface defects. The probe has good conductivity , and eddy current disturbances reveal microcracks or segregation. The testing process ensures sample cleanliness, comprehensive probe path coverage, and multi-angle scanning to improve coverage. It combines non-destructive testing techniques, including deep ultrasonic testing, overall X-ray distribution, and eddy current surface sensitivity.

The test results guide rework; defective mandrels are repaired or removed via hot isostatic pressing; and the impact toughness is reliable after the mandrel's interior is cleaned. High chemical purity reduces false signals and improves flaw detection sensitivity. Non-destructive testing technology for detecting internal defects in tungsten alloy rivet mandrels demonstrates the material assurance provided by non-destructive inspection. The collaborative use of multiple methods supports the internal quality of the tool and provides a basis for defect control in riveting supports. The accumulation of flaw detection data lays the foundation for process feedback loops, ensuring the safe performance of mandrel batches .

3.4 Innovative Methods for Preparing Tungsten Alloy Rivet Top Rods

Innovative methods for manufacturing tungsten alloy rivet mandrels primarily focus on expanding upon traditional powder metallurgy and introducing emerging forming technologies. This innovation helps overcome the limitations of conventional processes in handling complex shapes, small dimensions, and batch customization, improving production flexibility and material utilization. Innovative methods include injection molding and additive manufacturing, which expand the design space for mandrels while maintaining the density and hardness advantages of tungsten alloys . Injection molding achieves near-net-shape forming through feed flow , while additive manufacturing allows for the layering and construction of arbitrary geometries.

The driving force behind the innovative approach lies in the diverse needs of riveting tools. Traditional pressing and sintering is suitable for standard rod-shaped parts, while the new method adapts to irregularly shaped or miniature mandrels. Chemically, the innovation preserves the two-phase structure, with tungsten particles providing a support framework and a coordinating binder phase. The process innovation also emphasizes environmental protection, reducing waste and energy consumption. The innovative method for preparing tungsten alloy rivet mandrels reflects modern trends in material forming, supporting the personalized development of tools through technological integration and providing more options in the assembly field.

3.4.1 Potential of Injection Molding in the Production of Tungsten Alloy Rivet Mandrels

injection molding in the production of tungsten alloy rivet mandrels lies primarily in its ability to achieve complex shapes and near-net-shape forming. This method involves mixing tungsten alloy powder with an organic binder to form a feedstock, which is then injected under high pressure into a mold to form a green body, followed by debinding and sintering to obtain the finished product. During feedstock preparation, a high powder loading is achieved, and binders such as wax-based or polymeric binders provide flowability and strength. Chemically, the binder encapsulates the particles to prevent separation. Injection parameters such as temperature and pressure are matched to the feedstock viscosity, and the mold is precisely designed with end face grooves or side holes, allowing for one-step molding and reducing subsequent processing.

The potential lies in the customizable shape of the ejector pins . Multi-level concave surfaces or internal features that are difficult to form with traditional pressing can be easily achieved through injection molding . The ejector pins better accommodate the deformation of special rivets. Thin-walled or slender ejector pins have uniform wall thickness and high density consistency. Injection molding supports small-batch customization, mold changes are quick, and ejector pin specifications are flexible to adapt to different riveting equipment. The debinding process uses solvothermal combined removal of binders, and shrinkage is controllable after sintering, resulting in good dimensional accuracy.

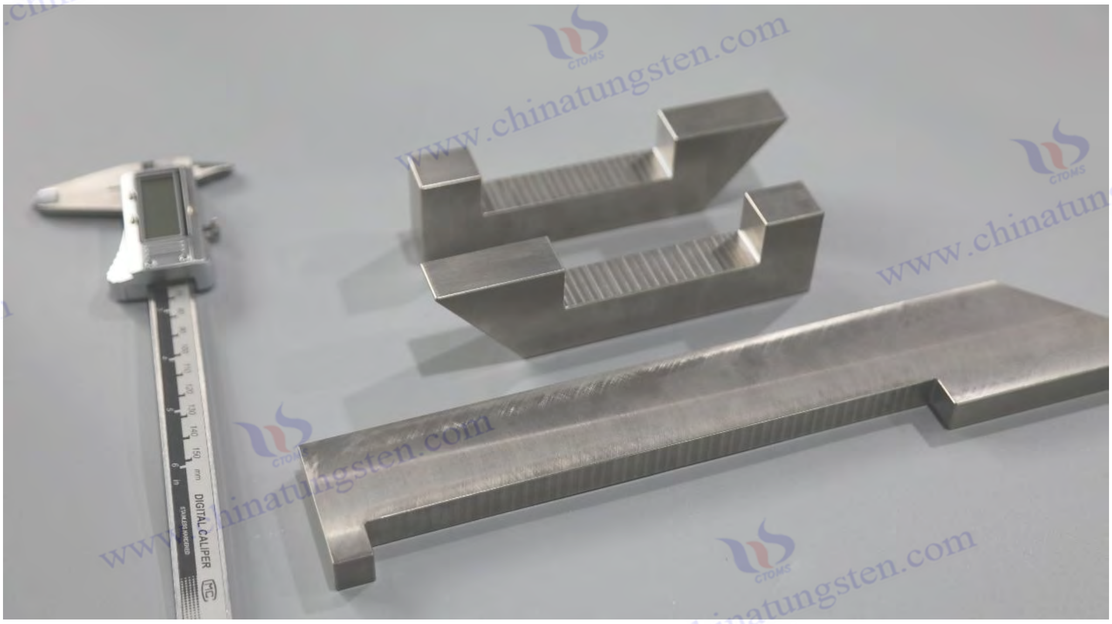
The production potential of this method is also reflected in improved efficiency. Automated injection molding machines operate continuously with short cycle times, making them suitable for medium-volume production. It exhibits good chemical stability, with low additive residue in the feedstock that does not affect the ejector pin's performance . The potential of injection molding in the production of tungsten alloy rivet ejector pins opens new avenues for tool design, supporting the realization of complex functions through flow forming and demonstrating promising applications in precision riveting. The development of this method has also driven the optimization of feedstock formulations, further improving the uniformity of the ejector pin's microstructure.

3.4.2 The Influence of Additive Manufacturing Technology on the Customization of Tungsten Alloy Rivet Top Rods

Additive manufacturing technology on the customization of tungsten alloy rivet mandrels is mainly through the achievement of arbitrary geometry and internal structures through layered construction. Techniques such as selective laser melting (SLM) or binder spraying selectively solidify tungsten alloy powder layer by layer to form mandrels without the need for molds. In powder bed fusion, laser melting of particles chemically results in localized high-temperature liquid-phase wetting, similar to sintering, leading to strong interlayer metallurgical bonding. Binder spraying followed by sintering and debinding is suitable for complex hollow or gradient mandrels.

The impact lies in the high degree of customization freedom, allowing for the direct construction of micro-textures on the ejector pin end face or internal cooling channels, and optimized riveting for heat dissipation or vibration reduction. Multifunctional ejector pins, difficult to form using traditional processes , can be rapidly iterated through digital models, resulting in shorter design cycles. Additive manufacturing supports small-batch personalization, with ejector pin specifications precisely matched to equipment, eliminating waste molds.

The technological impact is also reflected in material utilization, with high powder recovery rates and near-net- shape mandrels reducing machining. Chemically, interlayer diffusion is uniform, resulting in a dense mandrel microstructure with properties approaching those of conventional mandrels. Gradient composition design is possible, leading to high surface hardness and good core toughness in the mandrel. Additive manufacturing technology's influence on the customization of tungsten alloy rivet mandrels has brought about a design revolution in tool production, supporting integrated functional innovation through layering and providing flexible solutions for specialized riveting applications.



CTIA GROUP LTD Tungsten Alloy Rivet Top Rod

Chapter 4 Physical Properties of Tungsten Alloy Rivet Rods

4.1 Density and Thermal Properties of Tungsten Alloy Rivet Top Rods

The density and thermal properties of tungsten alloy rivet mandrels are core components of their physical performance, directly affecting their inertial reaction force, energy transfer, and temperature adaptability during riveting. High density concentrates the mandrel's mass , providing stable support during impact. Thermal properties, including thermal expansion and conduction, determine the mandrel's dimensional and performance retention under localized heating or changes in ambient temperature. The two-phase structure of tungsten alloys endows these properties; the tungsten phase provides the high-density base, while the binder phase regulates thermal expansion matching.

The balanced design of density and thermal properties allows the mandrel to adapt to different riveting conditions. High-density types have high inertia and are suitable for heavy loads, while types with good thermal conductivity dissipate heat quickly, reducing temperature rise. Characteristic testing guides material selection; uniform density ensures consistent reaction force, and low thermal expansion maintains fitting accuracy. The density and thermal properties of tungsten alloy rivet mandrels reflect the engineering application of material physical properties. Characteristic optimization supports the stable performance of the tool in assembly and provides a reliable foundation for riveting practice.

4.1.1 Principle of density measurement in tungsten alloy rivet mandrels

The principle of density measurement in tungsten alloy rivet mandrels is mainly based on volume displacement and mass calculation. This principle helps assess the density and microstructure uniformity of the mandrel , thereby determining its inertial performance in riveting support. The Archimedes method is commonly used, where the mandrel is immersed in a liquid, the volume is calculated using the buoyancy difference, and the density is derived from the mass. Chemically, the liquid is chosen to be non-reactive with the alloy to avoid surface dissolution affecting accuracy. Multi-point measurements of the rod-shaped mandrel assess axial uniformity; consistent density at the ends and center indicates sufficient sintering rearrangement.

The measurement principle also includes gas displacement variants, where pressure changes in an inert gas-filled container reflect volume, suitable for surface-sensitive mandrels. The core of the principle lies in accurate volume acquisition; for mandrels with regular shapes, direct geometric calculation is used, while for irregular shapes, the displacement method is more suitable. A precision balance is used for mass measurement, and ambient temperature is used to correct for liquid density. The application of density measurement principles reveals process effects: insufficient sintering results in low density, while hot isostatic pressing increases density.

Measurement is crucial for quality control of mandrels . High density results in strong inertial reaction force and uniform rivet deformation. Purity affects measurement; impurities and porosity reduce readings . Segmented measurement of the mandrel's length avoids errors. The principle of density measurement in tungsten alloy rivet mandrels provides a quantitative basis for volumetric properties, supports tool inertia assessment through substitution calculations, and contributes practical reference in riveting practice.

4.1.2 Contribution of thermal expansion coefficient to the stability of tungsten alloy rivet mandrel

The coefficient of thermal expansion to the stability of tungsten alloy rivet mandrels is mainly reflected in their ability to maintain size and shape under temperature changes. This contribution ensures that the mandrel fits snugly against the rivet tail when local frictional heating occurs or the ambient temperature changes, avoiding gaps or overpressure. Tungsten alloys have a low coefficient of thermal expansion, the tungsten phase dominates with small volume changes, and the binder phase adjusts the overall coefficient, resulting in limited length increase of the mandrel during heating and good maintenance of the flatness of the working surface .

The contribution mechanism is manifested in the two-phase interaction : tungsten particles constrain the expansion of the binder phase, chemically buffering thermal deformation through interfacial stress, and the mandrel returning to its original position after thermal cycling. The low coefficient of thermal expansion reduces thermal stress cracking, and the mandrel exhibits strong stability with repeated use. During riveting heating, the mandrel expands minimally, ensuring accurate rivet positioning and stable connection quality.

The contribution of the coefficient of thermal expansion also affects equipment compatibility; a good thermal match between the mandrel and the rivet gun ensures a secure assembly. Compositional adjustments optimize the contribution, with molybdenum doping further reducing the coefficient. Heat treatment homogenizes the microstructure, resulting in a more balanced contribution. The contribution of the coefficient of thermal expansion to the stability of tungsten alloy rivet mandrels reflects the material support of thermophysical properties. Low-expansion design optimizes the tool's temperature adaptability, providing a foundation for dimensional reliability in riveting environments.

4.1.2.1 Thermal behavior of tungsten alloy rivet mandrels under high temperature conditions

Tungsten alloy rivet mandrels under high-temperature conditions is mainly manifested in dimensional changes, microstructure evolution, and surface oxidation tendency. This behavior is evident in localized frictional heating or hot riveting conditions , affecting the shape retention and support accuracy of the mandrel . The high melting point of the tungsten phase results in a relatively high overall softening temperature for the mandrel . The binder phase flows and coordinates the tungsten particles at high temperatures . Thermal expansion generates micro-stress, but the interfacial bonding buffers this stress, preventing significant deformation. As the working surface of the mandrel heats up, the surface energy increases, the tungsten particles slightly coarsen, and the diffusion of the binder phase promotes interfacial uniformity.

Thermal behavior also includes thermal fatigue response, grain boundary migration during repeated heating and cooling, slight grain growth in the mandrel (but controllable by heat treatment), chemical diffusion at high temperatures, formation of a thin oxide layer on the mandrel surface , preferential reaction of the binder phase but overall protection by the tungsten phase , thermal conductivity aiding heat dissipation at high temperatures, a gentle temperature gradient in the mandrel , and uniform thermal stress distribution. The thermal behavior of the mandrel under high-temperature conditions is suitable for hot-working riveting, and the reaction force of the mandrel is stable during rivet forming.

Thermal behavior include composition ratio; higher tungsten content results in stronger thermal stability, while a higher copper phase leads to faster heat dissipation. Heat treatment pre-optimizes the microstructure, high-temperature annealing releases stress, and the mandrel recovers well after thermal cycling. Surface coatings or passivation provide additional protection at high temperatures, reducing oxidation losses. The thermal behavior of tungsten alloy rivet mandrels under high-temperature conditions demonstrates the temperature adaptability of refractory composites, maintaining tool dimensions and performance through interphase synergy, contributing practical value in hot assembly.

4.1.2.2 Response of tungsten alloy rivet mandrels in low-temperature environments

Tungsten alloy rivet mandrels in low-temperature environments mainly involves brittle transition tendency and dimensional shrinkage behavior. This response is manifested in cold riveting or low-temperature assembly, affecting the impact toughness and fit accuracy of the mandrel . The body-centered cubic structure of the tungsten phase has fewer slip systems at low temperatures, while the face-centered cubic ductility of the binder phase helps to coordinate the process. The overall brittle transition temperature of the mandrel is relatively low, avoiding sudden fracture. During low-temperature shrinkage, the low coefficient of thermal expansion of tungsten results in small dimensional changes in the mandrel , leading to good matching with the rivet.

The response also includes thermal stress release, residual stress relaxation at low temperatures, and enhanced tendency for healing of microcracks inside the mandrel . Chemically, low-temperature oxygen activity results in slow oxidation of the mandrel surface , maintaining a smooth finish. Impact energy absorption at low temperatures is achieved through deformation of the binder phase, resulting in consistent mandrel reaction force and uniform rivet formation. The mandrel's response in low-temperature environments is suitable for cold-working riveting, ensuring stable equipment load at low operating temperatures.

Factors influencing the response include compositional adjustments; higher nickel content results in better low-temperature toughness, while iron addition regulates the transformation temperature. Low-temperature aging heat treatment strengthens the precipitates and improves the brittle resistance of the mandrel . Surface treatment prevents condensate corrosion, ensuring the mandrel 's stability during low-temperature storage. The response of tungsten alloy rivet mandrels in low-temperature environments demonstrates the wide temperature adaptability of composite materials , maintaining tool mechanical performance through structural coordination and providing reliable support in cold assembly.

4.1.3 Application of Differential Scanning Calorimetry in Tungsten Alloy Rivet Top Rods

Differential scanning calorimetry (DSC) is primarily used in tungsten alloy rivet mandrels to analyze the material's thermal transformation behavior and phase transformation characteristics. This method reveals the endothermic or exothermic processes of the mandrel under temperature changes by comparing the heat flow difference between the sample and a reference, helping to optimize heat treatment processes and assess high-temperature stability. During testing, a small mandrel sample is placed in the instrument crucible and heated or cooled simultaneously with an inert reference. The heat flow curve is recorded, and chemical phase transformations such as the melting or precipitation of the binder phase are represented by peak changes in the curve.

In application, differential scanning calorimetry (DSC) is used to identify the recrystallization temperature of the mandrel , guiding annealing parameters and preventing excessively high temperatures that could lead to grain coarsening. The solution treatment temperature is determined from the endothermic peak of the curve, clearly demonstrating the dissolution behavior of alloying elements in the mandrel . The exothermic peak analysis of aging precipitation indicates the formation of strengthening phases, validating the strength-enhancing mechanism of the mandrel . High-temperature stability assessment is performed by observing heat flow near the melting point, predicting the softening tendency of the mandrel under hot riveting conditions .

The method is also used to study the effects of impurities; residual oxygen or carbon induces additional peaks, from which mandrel purity control benefits. Curve integrals are used to calculate enthalpy change, quantifying changes in mandrel heat capacity . The application of differential scanning calorimetry (DSC) in tungsten alloy rivet mandrels provides detailed thermal behavior information, supports the rational setting of process temperatures through transformation analysis, and contributes experimental evidence to material thermal management. The method's sensitivity allows for the capture of minute phase transitions, opening up a temperature-based perspective for mandrel performance optimization.

4.1.4 Quantification of Tungsten Alloy Rivet Top Rods Based on Thermal Conductivity Measurement

The quantification of thermal conductivity in tungsten alloy rivet mandrels primarily employs steady-state or transient methods. These measurements help assess the mandrel 's heat dissipation capacity during riveting heat generation, guiding material selection under thermal load conditions. Steady-state methods involve heating one end and cooling the other, measuring the temperature gradient and heat flow; axial testing of the mandrel sample reflects actual heat transfer. Transient methods, such as laser scintillation, pulse-heat one side and record the temperature rise on the other side, calculating the thermal conductivity.

Quantitative results reflect the influence of composition. A higher copper phase results in higher thermal conductivity and lower local temperature rise in the mandrel , making it suitable for continuous riveting. A predominantly tungsten phase exhibits relatively mild thermal conductivity but a large heat capacity, buffering peak temperatures. For sample preparation , a section of the mandrel is cut off ; a smooth surface reduces contact thermal resistance. Chemically, a clean interface affects the measurement, as impurity scattering reduces thermal conductivity.

Quantitative thermal conductivity measurements guide applications; high thermal conductivity mandrels dissipate heat quickly, resulting in uniform rivet cooling; low thermal conductivity mandrels offer better insulation, making them suitable for hot riveting . Measurements also evaluate the effectiveness of heat treatment, ensuring uniform microstructure and consistent thermal conductivity after annealing. For mandrels of varying lengths, measurements are taken across multiple segments for averaging, avoiding end-effects. Thermal conductivity measurements provide a basis for quantifying the heat transfer performance of tungsten alloy rivet mandrels , and numerical comparisons support the selection of tools for thermal adaptation, playing a crucial role in riveting thermal management. The systematic nature of the measurements makes the thermal behavior of mandrel batches comparable, contributing quantitative feedback for process improvement.

4.1.5 The role of specific heat capacity in the thermal management of tungsten alloy rivet mandrels

Specific heat capacity in the thermal management of tungsten alloy rivet mandrels is mainly reflected in their ability to absorb and buffer impact-generated heat. This helps control the temperature rise of the mandrel during riveting, preventing localized overheating that could affect its shape or performance. A higher specific heat capacity results in greater heat absorption by the mandrel , smaller temperature changes for the same energy input, a more gradual temperature rise on the working surface, and a smaller heat-affected zone during rivet forming. Tungsten alloys have a large contribution to specific heat capacity, resulting in a high overall heat capacity for the mandrel and slow heat accumulation during continuous operation.

The mechanism of action is reflected in energy distribution: part of the impact kinetic energy is converted into heat, and the heat is dispersed when the specific heat capacity is high, resulting in a gentler temperature gradient inside the mandrel . Chemically, the two-phase structure works synergistically, with tungsten particles storing heat and the binder phase transferring heat , leading to rapid thermal equilibrium in the mandrel. The specific heat capacity also affects the stability of thermal cycling; during repeated riveting, the mandrel recovers to room temperature quickly with minimal dimensional changes.

In thermal management, mandrels with high specific heat capacity are suitable for high-frequency or heavy-duty riveting, offering good temperature rise control and comfortable operation. Composition adjustment plays a significant role; high tungsten content results in high specific heat capacity, while a higher copper phase contributes to thermal conductivity and aids in heat dissipation. Heat treatment homogenizes the microstructure, ensuring a consistent specific heat capacity distribution. The role of specific heat capacity in the thermal management of tungsten alloy rivet mandrels demonstrates the material's buffering function of heat capacity, supporting tool temperature control through its endothermic properties and providing a thermally stable foundation in riveting practice. This enhanced performance allows the mandrel to adapt to more working conditions, extending its operational comfort.

4.2 Electrical and Magnetic Properties of Tungsten Alloy Rivet Tops

The electrical and magnetic properties of tungsten alloy rivet mandrels are primarily influenced by their composition. While these properties are not the main function of the mandrel as a tool, they are valuable for reference in certain assembly environments or auxiliary operations. Electrical properties are mainly characterized by conductivity, while magnetic properties depend on whether the binder phase elements introduce ferromagnetism. Tungsten itself has moderate electrical and thermal conductivity; the binder phase after alloying adjusts the overall levels. The tungsten -nickel-copper system is non-magnetic and has good electrical conductivity, while the tungsten-nickel-iron system exhibits significant magnetism and slightly lower conductivity.

Analysis of the electrical and magnetic properties helps in selecting the right mandrel for specific applications, such as avoiding magnetic interference in electronic assembly and providing conductivity to aid in electrostatic discharge. Property testing guides composition design; tungsten-copper variants exhibit strong conductivity, while tungsten-iron variants possess magnetism suitable for clamping . The electrical and magnetic properties of tungsten alloy rivet mandrels reflect the material modulation of auxiliary elements, and these property differences support the versatility of the tool's applications, providing additional adaptability in riveting practices.

4.2.1 Conductivity in Tungsten Alloy Rivet Top Rods

The conductivity of tungsten alloy rivet mandrels primarily depends on the type and distribution of the binder phase. While not a primary requirement, this does influence static electricity buildup and thermal conductivity. Tungsten itself has moderate conductivity; however, a continuous copper phase network within the alloy results in higher conductivity, smooth current transmission, and easy dissipation of static electricity on the mandrel surface , preventing dust or sparks from adsorbing during assembly. Nickel-iron systems have relatively lower conductivity, but it is still sufficient for mechanical support applications.

The mechanism is manifested in the pseudo-alloy structure, where the copper phase fills the gaps to form channels, resulting in low resistance to electron migration and uniform axial conductivity of the top rod. After sintering, the interface is clean, and the conductive path is continuous. Hot working and rolling elongate the copper phase, resulting in slight anisotropy in conductivity and low overall resistivity of the top rod . Surface polishing reduces the oxide layer, maintaining stable conductivity.

Conductivity also affects thermal management; less Joule heating occurs when current passes through, resulting in a slower temperature rise in the mandrel . Good chemical stability ensures the mandrel's conductivity does not decrease in humid environments. Tungsten-copper variants exhibit even better performance, providing excellent electrostatic control in electronic cleanrooms. The conductivity of tungsten alloy rivet mandrels provides electrical assistance to the tool, supports adaptation to assembly environments through channel optimization, and contributes practical characteristics to riveting operations.

4.2.2 Implications of Magnetic Parameters for the Application of Tungsten Alloy Rivet Tops

Implications of magnetic parameters for the application of tungsten alloy rivet mandrels primarily stem from the ferromagnetism resulting from the addition of iron. This implication provides auxiliary positioning or clamping convenience in certain assembly applications. The tungsten -nickel-iron system exhibits significant magnetism, allowing the mandrel to be attracted by magnetic tools, making it easier to fix or replace during operation, especially providing stable positioning during manual riveting. The tungsten -nickel-copper system is non-magnetic, preventing magnetic field interference in the assembly of electronic or precision instruments, ensuring the components remain unaffected.

The mechanism is reflected in the binder phase solid solution, where iron and nickel form a ferromagnetic phase with moderate magnetization, resulting in slight magnetism in the mandrel without residual strong magnetism. Heat treatment for demagnetization or aging can control the magnetic level, allowing for flexible application of the mandrel . The magnetic parameter inspiration also includes magnetic damping in vibrational environments, leading to better absorption of micro-vibrations by the mandrel .

Application implications: Magnetic mandrels are suitable for mechanical line-assisted positioning, while non- magnetic mandrels are used for sensitive equipment. Chemical purity is controlled by iron content, and magnetic properties are controllable. The implications of magnetic parameters for tungsten alloy rivet mandrel applications demonstrate the practical modulation of auxiliary elements, supporting ease of tool operation through magnetic differences and providing selection options in different assembly scenarios.

4.2.3 Influence of Temperature Coefficient of Resistance on Electrical Stability of Tungsten Alloy Rivet Top Rod

The temperature coefficient of resistance (TCR) on the electrical stability of tungsten alloy rivet mandrels is mainly reflected in the regulation of resistance behavior under temperature changes. This influence helps to understand the conductivity and potential electrostatic response of the mandrel in variable-temperature riveting environments. The TCR describes the trend of resistance change with increasing temperature. In tungsten alloy mandrels , it is jointly determined by the tungsten phase and the binder phase. The tungsten phase has a positive but low TCR , while the binder phase, such as copper or nickel, has a higher coefficient. Overall, the coefficient is positive, and the resistance increases with increasing temperature. The electrical stability of the mandrel is manifested under temperature fluctuations. When the coefficient is low, the resistance change is small, the conductive path remains continuous, and temperature-induced resistance jumps do not affect auxiliary functions such as electrostatic discharge.

The influencing mechanism is manifested in the two-phase interaction : electron scattering from tungsten particles increases with increasing temperature, and changes in carrier concentration in the binder phase regulate the overall resistivity. Heat treatment homogenizes the microstructure, resulting in a consistent coefficient distribution and stable axial resistivity of the top rod. Compositional adjustments affect the coefficient; when the copper phase is more abundant , the coefficient approaches the linear response of copper, and the conductivity of the top rod is more stable under temperature variations . Surface oxide layer formation at high temperatures slightly increases the coefficient, but the protective effect of the coating is mitigated, and the electrical behavior of the top rod remains unchanged. The effect of the temperature coefficient of resistance (TCR) is also used to evaluate the thermal management of the mandrel . A low TCR results in a smaller thermally generated resistance and a self-limiting temperature rise in the mandrel . At low temperatures, the TCR is positive, indicating a decrease in resistance, but this is not directly related to brittleness. The TCR is observed using the four-probe method to guide alloy optimization. The influence of the TCR on the electrical stability of tungsten alloy rivet mandrels provides a material perspective on temperature response. By adjusting the TCR, the conductivity adaptation of the tool is supported, contributing a stable foundation during riveting temperature variations.

4.2.4 Observations of hysteresis loop analysis in tungsten alloy rivet mandrels

Hysteresis loop analysis in tungsten alloy rivet mandrels is primarily used to assess magnetic behavior and remanence, aiding in understanding the mandrel's response and positioning potential in magnetic field environments. The hysteresis loop depicts a cyclic curve of magnetization as a function of an external magnetic field. In tungsten alloy mandrels, this is determined by the ferromagnetism of the binder phase; the tungsten phase is nonmagnetic . The hysteresis loop is wide in the nickel-iron system, with significant coercivity and remanence, while the hysteresis loop is narrow and nearly linear in the nonmagnetic tungsten-copper system . Observations are performed using a vibrating sample magnetometer, with the mandrel sample placed in an alternating magnetic field, and the magnetization curves are recorded.

The observation mechanism is reflected in phase magnetism. The movement of the magnetic domain walls in the ferrous phase produces hysteresis, and the remanence after the top rod is magnetized to saturation is small, facilitating magnetic clamping. Heat treatment adjusts the hysteresis loop shape, and aging refines the pinning of the magnetic domain walls ; changes in the hysteresis loop area reflect the uniformity of the microstructure. Composition affects observation; high iron content results in a wider hysteresis loop and a stronger magnetic response from the top rod; copper systems have narrower hysteresis loops and less magnetic interference from the top rod . Hysteresis loop analysis is applied in mandrel quality control ; abnormal loops reveal segregation or defects, guiding the process towards uniform mixing. Remanence observation assesses the magnetic compatibility of mandrels in electronic assembly, with narrower loop types being more suitable. Surface treatment does not directly affect the loop, but the coating isolates the magnetic field. Hysteresis loop analysis in tungsten alloy rivet mandrels provides a quantitative perspective on magnetic properties, supporting the magnetic selection of tools through curve characteristics and contributing practical insights in specialized assemblies.

4.3 Optical and radiation properties of tungsten alloy rivet mandrels

Tungsten alloy rivet mandrels are primarily influenced by their surface composition and microstructure. While these properties are not a core function when the mandrel is used as a tool, they are significant for understanding light reflection and radiation response in certain assembly environments. Optical properties are mainly characterized by reflectivity, while radiation properties focus on radiation resistance. The two-phase microstructure of tungsten alloys endows these properties; the tungsten phase has a smooth surface and strong reflection, while the binder phase modulates radiation absorption. Analyzing optical and radiation properties helps in selecting mandrels for specific applications, such as avoiding glare in optical assembly and maintaining stability in radiation environments.

between optical and radiation properties allows the mandrel to adapt to varying light or radiation conditions. High reflectivity results in a bright, easy-to-clean surface, while good radiation tolerance minimizes microstructural changes. Characteristic testing guides surface treatment, reflectivity measurement optimizes polishing, and radiation testing assesses phase transitions. The optical and radiation properties of tungsten alloy rivet mandrels reflect the material's response to light, and property tuning supports tool adaptability and provides additional stability in riveting practices.

4.3.1 Correlation of Reflectivity Analysis in Tungsten Alloy Rivet Master Rods

The relevance of reflectivity analysis in tungsten alloy rivet mandrels lies primarily in assessing surface finish and optical response. This analysis helps understand the mandrel's performance and thermal radiation behavior under illumination. Reflectivity describes the proportion of light reflected from a surface and is determined by the surface state of the tungsten and binder phases in the mandrel. Higher reflectivity after polishing results in a brighter appearance, facilitating observation of the rivet deformation process. Chemical surface oxide layers reduce reflectivity, while coatings or passivation restore the mirror effect.

The correlation mechanism is manifested in the microstructure: tungsten particles have a smooth surface with strong reflection, a uniformly distributed binder phase with low light scattering, and consistent reflectivity. After heat treatment, the grains are refined, resulting in a more uniform reflectivity distribution and less glare during the assembly of the mandrel. Reflectivity analysis is used for quality control; high measured values indicate fewer surface defects and better wear resistance of the mandrel . Wavelength response is observed using a spectrophotometer; the metallic luster of the mandrel reflects strong visible light. The correlation analysis also affects thermal management; higher reflectivity results in less radiative heat loss and a slower temperature rise in the mandrel . Surface texture adjusts reflectivity; brushed finish reduces specular reflection, making it suitable for anti-glare applications. Compositional variations also have a correlation; a higher copper phase results in slightly higher reflectivity and a brighter mandrel appearance . The correlation of reflectivity analysis in tungsten alloy rivet mandrels provides a basis for surface optics, supports visual adaptation of the tool through light response evaluation, and contributes practical characteristics in assembly environments.

4.3.2 Evaluation of Radiation Resistance of Tungsten Alloy Rivet Tops

Radiation tolerance in tungsten alloy rivet mandrels is primarily achieved through radiation exposure testing and microstructural observation. This assessment helps understand the structural stability and performance retention of the mandrel under radiation conditions. Radiation tolerance describes a material's resistance to radiation or particles. In the mandrel, the high density of the tungsten phase attenuates radiation, while the binder phase coordinates the damage response. The assessment process involves examining density changes and microscopic defects after sample exposure . The mandrel showed minimal swelling and intact microstructure after radiation.

The evaluation mechanism is reflected in the phase structure: tungsten particles absorb energy to create vacancies, and the binder phase diffuses to heal defects, resulting in good overall stability of the mandrel . Heat treatment improves radiation tolerance, and the high recrystallization temperature hinders damage accumulation. The mandrel is evaluated for use in medical or nuclear-related assemblies; its performance degradation under radiation is slow, and its support is reliable. Testing involves dose gradient exposure to observe crack initiation and phase transitions.

Radiation tolerance assessment also guides composition optimization, rare-earth doping to pinning defects, and increases the tolerance threshold. Surface coatings protect against incident radiation , resulting in minimal changes in the mandrel's microstructure . Assessment results are fed back to the process, demonstrating strong tolerance after sintering and densification. Radiation tolerance assessment of tungsten alloy rivet mandrels provides an environmentally adaptable material perspective, supports the radiation compatibility of the tool through damage analysis, and contributes a stable foundation in special riveting applications.

4.3.3 Characterization of absorption spectrum in the optical properties of tungsten alloy rivet mandrels

The characterization of the optical properties of tungsten alloy rivet mandrels using absorption spectroscopy is primarily achieved through ultraviolet-visible-near-infrared spectroscopy analysis. This characterization helps to understand the light absorption behavior of the mandrel surface and the overall structure, and to evaluate its reflection and transmission characteristics at different wavelengths. Absorption spectra record the absorption intensity of the material for specific wavelengths of light. Testing is performed on polished mandrel samples ; characteristic absorption peaks are generated by electronic transitions in the tungsten phase , while binder phases such as copper or nickel modulate the spectral shape. Chemically, the surface oxide layer increases absorption; polishing removes this layer, resulting in smoother spectral lines.

The key to the characterization process is sample preparation. The probe cross-section or surface must be flat, and the light beam must be incident perpendicularly during testing to record the absorption curve. Tungsten alloy probes exhibit high absorption in the visible region, with a corresponding decrease in reflectivity. The brushed texture of the surface increases light scattering and absorption. Microstructural changes after heat treatment affect the spectral lines; annealing refines the grains and ensures uniform absorption. Compositional adjustments contribute to characterization differences; a higher copper phase content results in stronger near-infrared absorption, and the probe's thermal radiation behavior varies.

The application of absorption spectroscopy is evident in surface quality control; absorption anomalies reveal oxidation or contamination, guiding polishing processes. Absorption spectra of mandrels in illuminated assembly environments assess glare; flat spectral lines indicate softer reflections. Chemical stability testing reveals changes in absorption spectra, with absorption peaks shifting after corrosion. Characterizing the optical properties of tungsten alloy rivet mandrels using absorption spectroscopy provides a spectroscopic perspective on light interaction, supports tool surface optimization through curve analysis, and contributes a basis for visual adaptation during riveting operations.

4.3.4 Contribution of Neutron Absorption Cross Section to Radiation Shielding of Tungsten Alloy Rivet Top Rod

the neutron absorption cross section to the radiation shielding of the tungsten alloy rivet top rod mainly lies in its ability to attenuate neutron flux. This contribution helps reduce the impact of neutron radiation when the top rod is used as an auxiliary shielding component. Tungsten nuclei have high neutron scattering and absorption cross sections, the high-density structure of the top rod enhances volume attenuation, and the bonding phase modulates the overall response. The neutron absorption cross section describes the probability of nuclear reactions; tungsten isotopes contribute mainly to scattering and moderate neutron energy.

The contribution mechanism is manifested in multiple scattering. After entering the top rod , neutrons lose kinetic energy through multiple collisions, and some is absorbed . The attenuation is more pronounced as the top rod thickness increases. Chemically, the introduction of light nuclei such as hydrogen in alloying elements can help moderate the scattering, but the top rod system is dominated by tungsten, so scattering is the primary process. Heat treatment does not change the cross-section but improves the effective scattering pathway by achieving a more uniform microstructure.

The contribution of the neutron absorption cross section was assessed through simulation or experiments. The mandrel acts as a local shield in a radiation environment, reducing the impact of scattered neutrons on the surrounding environment. Compositional adjustments affect the contribution; higher tungsten content results in a stronger cross section and more stable shielding effect. Surface condition influences incident radiation; polishing reduces reflection loss. The contribution of the neutron absorption cross section of the tungsten alloy rivet mandrel provides a nuclear physics perspective on radiation interaction, supporting tool safety in radiation-related assemblies through attenuation and playing a shielding role in special environments.

4.4 MSDS of Tungsten Alloy Rivet Top Rods from CTIA GROUP LTD

The MSDS (Material Safety Data Sheet) for tungsten alloy rivet mandrels manufactured by CTIA GROUP LTD is a safety information document for the tungsten alloy rod-shaped tools produced by CTIA GROUP LTD . This document complies with international standards and relevant national regulations, providing a risk assessment and protective guidance for the materials during production, transportation, storage, use, and disposal. CTIA GROUP LTD's tungsten alloy mandrel products mainly include tungsten -nickel-iron and tungsten-nickel-copper series, used in assembly and connection of components, etc.

The overall structure of an MSDS is typically divided into multiple sections, each analyzing the material's behavior from a chemical perspective. For example, the composition information emphasizes the composite properties of the tungsten alloy mandrel , with tungsten as the main element providing a high-density base, while binder elements such as nickel and iron affect potential skin contact reactions. During the compilation process, CTIA GROUP LTD considered the powder metallurgy preparation characteristics of the alloy. Sintering and rolling processes may introduce trace impurities; therefore, the document specifies purity control measures to avoid additional risks caused by oxides or carbides. The transportation section discusses the stability of the alloy mandrel in solid form, emphasizing moisture-proof packaging to prevent surface oxidation. Waste disposal guides recycling, complying with environmental requirements, and recovering tungsten resources through chemical reduction .

For tungsten alloy riveting mandrels details the alloy's chemical composition. Typically, tungsten is the dominant component, providing the foundation for high density and hardness, supplemented by nickel, iron, or copper as binder phases. The proportions are adjusted according to the series; for example, in a tungsten-nickel-iron system, the nickel-iron ratio balances wetting and strengthening. Trace elements such as carbon and oxygen are controlled at low levels to avoid the formation of embrittlement phases. Chemically, this section uses CAS numbers to identify elements; tungsten CAS 7440-33-7, nickel CAS 7440-02-0. Impurities are disclosed, including potential contaminants such as phosphorus and sulfur, originating from raw materials, emphasizing purification processes to reduce their content.

The tungsten alloy mandrel also includes a description of the alloy phase structure. In the two-phase composite, the tungsten particles are body-centered cubic, and the binder phase is a face-centered cubic solid solution. It is chemically stable with no volatile components. Solubility analysis shows that the material is insoluble in water, reacts slowly in weak acids, and releases tungstate. The purity declaration states that the alloy mandrel is prepared by powder metallurgy and has high batch-to-batch consistency.

For tungsten alloy rivet mandrels from CTIA GROUP LTD systematically assesses the health, physical, and environmental risks of the material based on the chemical reactivity of the alloy composition. Health hazards primarily focus on dust or debris generated during processing; tungsten particles may cause mechanical irritation, while nickel has sensitizing potential, leading to skin or respiratory allergic reactions. Physical hazards include the impact risk due to the high density of the alloy mandrel , and the potential ignition source from sparks generated during cutting. Environmental hazard assessment considers the low solubility of tungsten alloys, which do not easily leach into soil upon disposal; however, the powder form may affect aquatic organisms through sedimentation accumulation.

The identification method adopts the GHS standard, and the tungsten alloy top rod is classified as a non-hazardous solid.

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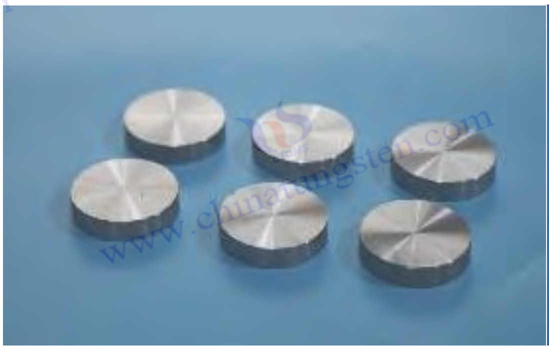
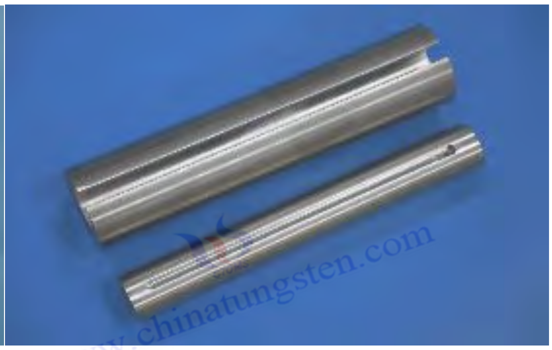

Chapter 5 Mechanical Properties of Tungsten Alloy Rivet Rods

5.1 Strength and Hardness of Tungsten Alloy Rivet Tops

Tungsten alloy rivet mandrels are core mechanical properties, determining their resistance to deformation and durability during riveting impacts and support processes. Strength includes tensile, compressive, and impact resistance, while hardness reflects the surface's resistance to indentation or wear. The dual-phase structure of tungsten alloys endows these properties; tungsten particles provide a high-hardness skeleton, while the binder phase coordinates toughness, preventing brittle fracture. This balance of strength and hardness allows the mandrel to withstand repeated loads, resulting in uniform rivet formation.

The strength and hardness originate from the powder metallurgy process, followed by heat processing to refine the microstructure after sintering and densification, resulting in high axial strength and uniform surface hardness of the mandrel. Chemically, the interfacial bonding is strong, and the stress distribution is gradual. Standardized testing methods are employed, with strength evaluated through tensile or impact tests and hardness measured by indentation. Performance optimization is achieved through adjustments to composition and heat treatment; higher tungsten content results in greater hardness, while a higher proportion of binder phase promotes better toughness.

Tungsten alloy rivet mandrels in riveting tools translate to reliable support, minimal mandrel deformation , and stable rivet connection quality. In applications, strength and hardness are matched to the rivet material; high-strength mandrels are used for steel rivets, while balanced mandrels are used for aluminum rivets . The strength and hardness of tungsten alloy mandrels demonstrate the mechanical advantages of composite materials, supporting improvements in assembly processes through performance coordination and providing practical value in industrial connections.

5.1.1 Method for tensile strength testing in tungsten alloy rivet mandrels

The tensile strength testing method for tungsten alloy rivet mandrels primarily employs the standard tensile test. This method assesses the tensile load-bearing capacity and fracture behavior of the mandrel through uniaxial loading , helping to understand the material's response under tensile stress. Test samples are cut from the mandrel or machined into dumbbell or cylindrical shapes using a special blank , with smooth surfaces to avoid stress concentration. The testing machine clamps both ends of the sample, applies uniform tension, and records the load-displacement curves. Chemical dislocation slip and interface separation dominate the deformation process.

The method involves preload alignment , continuous loading, and post-fracture measurement. The binder phase of the mandrel coordinates the deformation of tungsten particles, and the tensile curve shows both elastic and ductile segments. Fracture surface observation and analysis reveal a ductile fracture mechanism with dimples indicating ductile fracture and brittle tendencies in the cleavage planes. The testing environment is room temperature controlled; any temperature-related effects must be noted. This tensile strength testing method for tungsten alloy mandrels reveals a two-phase synergy: the tungsten phase bears high loads, while the binder phase absorbs energy.

The test is applied in material acceptance and process verification. After sintering, the tensile strength of the mandrel is assessed for density, and the strengthening effect is compared after heat treatment. Chemical purity affects the test; impurities reduce strength. The rod-like nature of the mandrel allows for axial sampling, reflecting the actual stress. The tensile strength test method in tungsten alloy rivet mandrels provides a quantitative approach to tensile properties, supports tool strength assessment through curve analysis, and contributes a reference for riveting design.

5.1.1.1 Fracture Mechanism of Tungsten Alloy Rivet Tops under Static Loading

Tungsten alloy rivet mandrels under static loading mainly involves the stress response and damage accumulation of the two-phase microstructure. This mechanism is demonstrated in tensile or bending tests, helping to analyze the failure mode of the mandrel under slow loading. In the initial stage, elastic deformation occurs, with the tungsten particle skeleton bearing the principal stress and the binder phase coordinating the strain. As loading increases, dislocations multiply in the binder phase, stress concentrates at the interface, and while chemically the element diffusion zone provides buffering, impurity segregation easily leads to the formation of micropores.

In the later stages of the process, micropores coalesce to form voids, leading to necking of the tungsten grains. The binder phase between tungsten grains becomes stretched and thinned, and interface separation or grain fracture dominates the final failure. Fracture characteristics show a mixture of dimples and cleavage , with more dimples in the binder phase and flat cleavage surfaces in the tungsten phase. Heat treatment optimizes the mechanism; annealing refines the grains, reduces void initiation, and improves the fracture ductility of the tungsten grains .

The static loading mechanism is also influenced by composition. The nickel-copper system has a high dimple ratio and large fracture elongation; the nickel-iron system has high strength but a slightly stronger tendency for cleavage. Lower chemical purity results in fewer impurities and a more ductile mechanism. The force on the rod-shaped mandrel is axial, and the mechanism is distributed along its length. The fracture mechanism of the tungsten alloy rivet mandrel under static loading reflects the failure path of composite materials, supports the strength design of the tool through microstructure regulation, and provides a mechanistic understanding in riveting supports.

5.1.1.2 Effect of Dynamic Loading on Tungsten Alloy Rivet Top Rod

dynamic loading on tungsten alloy rivet mandrels are mainly manifested in impact energy absorption and deformation response. This effect is evident in high-speed riveting or vibration conditions, where the mandrel acts as a support component bearing instantaneous high loads. During dynamic loading, energy is rapidly input, the tungsten particle skeleton resists compression, the bonding phase coordinates deformation to absorb part of the kinetic energy, the indentation on the mandrel's working surface is uniform, and the rivet tail is uniformly shaped. Chemical dislocations multiply rapidly, stress waves propagate within the mandrel , and the interface bonding buffers and prevents separation.

The effects also include strain rate effects, with a slight increase in strength under dynamic loading and enhanced resistance to deformation of the mandrel , but excessive loads may induce micro-damage. Thermal effects accompany dynamic loading, with frictional heating causing localized temperature rises, and the thermal conductivity of the tungsten alloy aiding in heat dissipation, resulting in a small temperature gradient in the mandrel . Repeated dynamic loading accumulates fatigue, leading to slower propagation of micro-defects in the mandrel and a stable service life. Factors influencing dynamic loading include the mandrel diameter and end face shape; larger diameters result in stronger inertia and better energy absorption, while concave surfaces reduce stress concentration and minimize deformation. Heat treatment optimization also plays a role; annealing reduces residual stress, leading to a smoother dynamic response in the mandrel . The impact of dynamic loading on tungsten alloy rivet mandrels reflects the material behavior in impact environments, supporting the tool's dynamic adaptation through absorption and coordination, contributing to practical stability in high-speed riveting.

5.1.2 Quantification of Vickers hardness in tungsten alloy rivet mandrels

The quantification of Vickers hardness in tungsten alloy rivet mandrels is primarily achieved through diamond indenter testing. This quantification helps assess the mandrel's surface resistance to indentation, reflecting its durability performance during riveting wear. The test involves polishing the mandrel sample , applying a load with the indenter to create a square indentation, and measuring the diagonal to calculate the hardness value. Chemically , the tungsten phase dominates the hardness , while the binder phase modulates the overall hardness. High hardness on the working surface of the mandrel contributes to its resistance to rivet indentation. The uniformity of the quantification process is assessed through multi-point measurements; consistent hardness along the axial direction and end face of the rod indicates stable microstructure. Heat treatment affects quantification; annealing reduces hardness and increases toughness, while aging precipitation increases hardness and strengthens the surface. Compositional adjustments quantify differences; higher tungsten content increases hardness, while higher copper phase content provides moderate hardness. Surface treatments such as plating quantify surface hardness and improve the wear resistance of the rod . Vickers hardness quantification guides mandrel selection ; high-hardness mandrels are used for hard rivets, while low-hardness mandrels balance impact absorption. Quantification also assesses machining results, ensuring uniform hardness and a consistent mandrel surface after grinding . The quantification of Vickers hardness in tungsten alloy rivet mandrels provides a numerical reference for surface properties, supports tool wear resistance assessment through indentation analysis, and contributes quality assurance in riveting practice.

5.1.3 Evaluation of Tungsten Alloy Rivet Rods by Tensile Testing

Tungsten alloy rivet mandrels is mainly achieved through uniaxial tensile testing. This evaluation helps to understand the load-bearing capacity and fracture behavior of the mandrel under tensile stress, providing a strength reference for riveting supports. The test sample is cut from the mandrel into a standard shape, clamped, and stretched at a constant speed. The load-displacement curve is recorded. Chemically, the binder phase extends and coordinates the tungsten particles. The curve shows the elastic segment and the plastic segment.

The evaluation process analyzed yield point and elongation at fracture. A high proportion of the binder phase in the mandrel resulted in good plasticity, while the tungsten phase dominated, leading to high strength. Fracture surface observation assessed the mechanism; dimples indicated ductility, while cleavage planes showed a tendency towards brittleness. Heat treatment was evaluated for its effectiveness; annealing improved elongation and mandrel toughness . Compositional differences were assessed; the nickel-copper system exhibited strong ductility, while the nickel-iron system had high strength.

Tensile testing evaluates the axial properties of mandrels , while bar-shaped stress simulates lateral loads. The evaluation guides the manufacturing process; sintering ensures stable tensile strength, while hot working and fiberization increase strength. Tensile testing provides an experimental perspective on the tensile response of tungsten alloy rivet mandrels , supporting the understanding of tool strength through curves and fracture surfaces, and contributing an evaluation basis to riveting design.

5.1.4 Evaluation of Tungsten Alloy Rivet Tops by Compression Testing

Tungsten alloy rivet mandrels through compression testing is mainly achieved through axial compression tests. This evaluation helps to understand the compressive bearing capacity and deformation behavior of the mandrel in riveting support, providing a reference for the tool's performance under impact loads. The test sample is a short cylindrical section cut from the mandrel , with parallel and smooth end faces. An axial load is applied by the testing machine, and the stress-strain curve is recorded. Chemically, the tungsten particle skeleton resists compression, while the binder phase coordinates lateral expansion, avoiding premature barrel deformation.

The evaluation process analyzed the yield point and ultimate strength. The two-phase structure of the mandrel caused the compression curve to show a plastic plateau after the elastic segment, with the binder phase extending and absorbing energy. Lateral bulging was observed in the fractured sample; uniform deformation was observed when the mandrel had good toughness. The testing environment was controlled at room temperature, and high-temperature variants were used to evaluate thermal softening. The compression test evaluation of the tungsten alloy mandrel revealed the compressive response; high tungsten content resulted in stable strength, and the binder phase ratio was well-balanced with toughness.

Compression testing provides guidance for the evaluation process. Sintered densification results in high compressive strength, while hot-working fibrousization enhances axial compressive strength. Chemical purity affects the evaluation; impurities reduce strength. The rod-like characteristics of the mandrel allow for compression simulation of actual support. Compression testing provides an experimental perspective on compressive stress in the evaluation of tungsten alloy rivet mandrels . Curve analysis supports the understanding of tool load-bearing capacity and contributes to the evaluation foundation in riveting practice.

5.1.4.1 Study on the Influence of Strain Rate on Tungsten Alloy Rivet Mandrels

Studies on the effect of strain rate on tungsten alloy rivet mandrels primarily focus on the response of loading rate to deformation and strength. This research helps analyze the differences in mandrel performance at different riveting speeds. At low strain rates, mandrel deformation is slow, the binder phase effectively coordinates the tungsten particles, resulting in stable strength and a long plastic plateau. At high strain rates, such as during impact riveting, dislocation multiplication is rapid, leading to increased mandrel strength but decreased plasticity. Chemically, the binder phase exhibits strain rate sensitivity, modulating the overall response.

The study employed graded-rate compression or drop-weight tests, recording curves to compare yield and fracture behavior. At high strain rates, adiabatic heating resulted in localized softening of the mandrel, but the tungsten framework provided constraint, leading to good deformation control. The study revealed a two-phase synergy: the tungsten particle ratio was insensitive, providing rigidity, while the binder phase ratio was sensitive, absorbing energy. Heat treatment was investigated, showing that annealing reduced the rate of change, and the mandrel adapted to a wide range of compression rates.

The study of the effect of strain rate guides applications; manual riveting with low strain rate exhibits good toughness, while pneumatic riveting prioritizes strength with high strain rate. Chemical composition studies show that copper phase predominates , resulting in low strain rate sensitivity and high-speed stability of the mandrel . The study of the effect of strain rate in tungsten alloy rivet mandrels provides a material perspective on dynamic loading, and rate comparisons support tool speed adaptation, contributing research insights into variable-speed riveting.

5.1.4.2 Insights from Fracture Surface Analysis into Tungsten Alloy Rivet Tops

Fracture surface analysis provides insights into tungsten alloy rivet mandrels primarily through scanning electron microscopy (SEM) observation of compression or tensile fracture surfaces. This analysis reveals failure mechanisms and microstructural characteristics, aiding in the improvement of impact-resistant mandrel design. Fracture surface features show a mixture of dimples and cleavage ; the depth of dimples in the bonded phase region reflects ductility, while the flatness of tungsten grain cleavage surfaces indicates overall brittleness. Chemically, elemental distribution is observed in the interfacial separation zones, with significant impurity segregation observed when bonding is weak.

Post-fracture cleaning of the sample revealed a complex fracture path in the top rod , with high-magnification electron microscopy imaging showing that the fracture extended along the binder phase, and tungsten particles showed minimal fracture. Analysis of different loading conditions revealed numerous dimples in the static fracture surface and distinct shear bands in the dynamic fracture. Heat treatment analysis showed uniform dimples after annealing, while aging altered the fracture path due to pinning precipitation.

Fracture surface analysis provides insights into process control, revealing sintering defects at the fracture surface and enabling optimized densification to reduce void sources. Compositional analysis reveals a high proportion of dimples in the copper phase , resulting in good brittleness resistance in the mandrel . Fracture surface analysis provides a microscopic perspective on failure modes in tungsten alloy rivet mandrels , supporting a mechanistic understanding of the tool through morphological studies and contributing to improvements in riveting durability.

5.1.5 Supplementary Verification of Bending Strength on the Mechanical Properties of Tungsten Alloy Rivet Mandrels

the bending strength of tungsten alloy rivet mandrels is mainly achieved through three-point or four-point bending tests. This verification helps evaluate the mandrel's load-bearing capacity and deformation behavior under lateral loads, providing additional reference for its lateral stability in riveting supports. The test sample is a rectangular strip cut from the mandrel , with parallel end faces. A bending load is applied by the testing machine, recording the deflection and fracture load. Chemically, the tungsten particle skeleton resists bending stress, and the binder phase coordinates surface tension and compression, preventing premature fracture. The bending curve shows plastic deformation after the elastic segment. The two-phase structure of the mandrel results in a long curve plateau, indicating good toughness before fracture.

The stress distribution was analyzed during the verification process. During bending, the neutral layer of the mandrel shifted slightly, and the surface stress gradient was gentle. Post-fracture, the crack path was observed, extending along the binder phase, with tungsten particles bridging and delaying propagation. Heat treatment verified the effect: annealing improved bending elongation and mandrel flexibility . Compositional differences were verified: the nickel-copper system showed balanced bending strength, while the nickel-iron system had higher strength but slightly lower flexibility.

The bending strength test further validates the axial-outward performance of the mandrel , with the rod-shaped structure simulating lateral impact. The validation guides the process; the bending strength remains stable after sintering and densification, and the external bending strength increases after hot working and fiberization. Chemical purity affects the validation, with impurities reducing strength. The bending strength validation of the mandrel provides an experimental perspective on lateral response, supporting the mechanical understanding of the tool through curves and fracture surfaces, and contributing a validation foundation to riveting design.

5.2 Toughness and Fatigue Behavior of Tungsten Alloy Rivet Tops

Tungsten alloy rivet mandrels are important aspects of their mechanical properties. This behavior, manifested under repeated impacts and cyclic loading, helps the mandrel maintain long-term support stability and prevent sudden failure. Toughness includes impact toughness and fracture toughness, while fatigue behavior focuses on damage accumulation and lifespan. The two-phase structure of tungsten alloys endows these behaviors; tungsten particles provide a hard barrier, while the binder phase absorbs energy and coordinates deformation. Toughness prevents the mandrel from brittle fracture upon rivet impact, while fatigue behavior supports high-frequency use.

The behavioral mechanisms are manifested in microscopic damage: twinning slip of the binder phase during impact, and the formation of persistent bands due to dislocation accumulation during fatigue cycles. Heat treatment optimizes this behavior; annealing releases stress and improves toughness, while aging pins precipitates to enhance fatigue resistance. Compositional adjustments influence behavior, resulting in good toughness in the nickel-copper system and high fatigue strength in the nickel-iron system. Behavioral testing guides applications: impact tests assess energy absorption, and fatigue tests simulate cyclic life. Tungsten alloy rivet mandrels in riveting tools demonstrate durability and reliability, with minimal mandrel deformation and stable connection quality. In applications, behavior is matched to working conditions; high-toughness mandrels are used in vibrating environments, while fatigue-resistant mandrels are suitable for continuous operation. The toughness and fatigue behavior of tungsten alloy mandrels reflect the dynamic response of composite materials, and behavior optimization supports tool life extension, providing reliable performance in assembly practice.

5.2.1 Effect of impact toughness on the durability of tungsten alloy rivet mandrels

The impact toughness of tungsten alloy rivet mandrels primarily contributes to their ability to absorb instantaneous energy and resist sudden damage. This effect is demonstrated during riveting hammer impacts , helping the mandrel maintain structural integrity and support continuity. Impact toughness is assessed through Charpy or drop hammer tests. The mandrel sample exhibits high energy absorption at the notch, with the chemically binding phase extending and bridging the crack, while tungsten particles block the propagation path. The mechanism involves a two-phase synergy: the rigid tungsten skeleton absorbs some kinetic energy, while the binding phase plastically deforms and consumes the remainder, preventing brittle fracture.

The impact process is divided into stages: elastic absorption in the initial stage, plastic deformation in the middle stage, and slow crack propagation in the later stage. Heat treatment enhances the effect; annealing refines the grains and increases toughness, while aging precipitation strengthens the boundaries. Composition also plays a role; the presence of a copper phase contributes to good toughness and ensures coordinated deformation under mandrel impact . Impact toughness guides the durability of mandrels in high-frequency riveting, resulting in good energy absorption and a long service life. Impact toughness provides material support for dynamic loads on mandrel durability, supports tool impact adaptation through an absorption mechanism, and contributes to the durability foundation in riveting practice.

5.2.2 Application of Cyclic Fatigue Analysis in Tungsten Alloy Rivet Tops

Cyclic fatigue analysis in tungsten alloy rivet mandrels primarily involves simulating damage accumulation and failure behavior under repeated loading. This analysis helps understand the durability performance of the mandrel in high-frequency riveting environments and guides material optimization to improve overall lifespan. Cyclic fatigue analysis typically employs rotating bending or axial tension/compression tests, placing the mandrel sample in a periodic stress field and recording the number of cycles and damage evolution. Chemically, the binder phase coordinates micro-stress during cycles, while the tungsten particle skeleton resists fatigue crack propagation. The analysis process is conducted in stages: first, a low-stress threshold is assessed, then high-stress accelerated damage is observed. The two-phase structure of the mandrel results in a smoother SN-shaped fatigue curve, with damage initiation at the surface or interface.

In applications, cyclic fatigue analysis reveals the fatigue mechanism of the mandrel . Initially, dislocation accumulation forms a persistent band; in the middle stage, microcracks initiate in the binder phase; and in the later stage, propagation through tungsten particles leads to fracture. Heat treatment optimization during analysis shows that annealing reduces residual stress and increases the fatigue threshold. Differences in composition indicate that the nickel-copper system exhibits good fatigue toughness but shows bending crack paths under cyclic loading; the nickel-iron system has high strength but is slightly more susceptible to fatigue. Analysis guides mandrel design ; surface polishing reduces initiation points, resulting in mandrels with strong cyclic loading resistance.

Cyclic fatigue analysis also incorporates fracture surface observation, with scanning electron microscopy revealing fatigue striations and cleavage planes . Damage path analysis of the mandrel optimizes the microstructure. Strain control analysis assesses low-cycle fatigue, revealing minimal mandrel deformation and long service life in high-frequency riveting. Environmental factors are included in the analysis, with corrosive media accelerating fatigue, while the mandrel coating provides protection. The application of cyclic fatigue analysis in tungsten alloy rivet mandrels provides an experimental perspective for service life prediction, supports tool durability optimization through damage studies, and contributes to mechanistic understanding in riveting practice.

The systematic analysis ensures consistent fatigue across batches of mandrels , allowing for adjustments to sintering parameters based on production feedback. The fatigue behavior of tungsten alloys is characterized by phase synergy: the binder phase absorbs cyclic energy, while the tungsten phase prevents cracking. Applications are extended to simulation software, where finite element analysis predicts fatigue hotspots, and mandrel shape optimization reduces stress concentration. Cyclic fatigue analysis for tungsten alloy rivet mandrels provides dynamic assessment for materials engineering, enabling tool life management through cyclic response and demonstrating practical value in the assembly field.

5.2.3 Method for measuring fracture toughness in tungsten alloy rivet mandrels

Fracture toughness measurements in tungsten alloy rivet mandrels are primarily achieved through three-point bending tests or compact tensile tests on pre-cracked samples. This method helps assess the mandrel's resistance to crack propagation in the presence of cracks, guiding the material's fracture resistance in impact supports. The test sample is a rectangular strip or disc cut from the mandrel , with a pre-crack introduced to simulate actual damage. Bending or tensile loads are applied using a testing machine, and the crack propagation curve is recorded. The chemically bonded phase bridges the crack, and tungsten particles block the path. The curve shows the load peak and the stable propagation segment.

The measurement process includes pre-crack preparation, fatigue cycling or notching to introduce a tip crack, and a mandrel with a two-phase structure to initiate the crack in the binder phase. Bending tests involve clamping the sample at both ends and applying a load to the center; crack opening displacement is measured to calculate toughness parameters. A compact tensile method stretches both ends of the sample, with clamps fixing the crack zone; when the mandrel has good toughness, crack propagation is slow. The testing environment is room temperature controlled; high-temperature variants are used to evaluate thermal fracture toughness.

Fracture toughness measurement methods reveal the push rod mechanism : cracks propagate along the binder phase, and tungsten grain dimple formation delays propagation. Heat treatment measurements show that annealing improves toughness, and the push rod fracture path becomes more flexural. Compositional differences reveal that the nickel-copper system has high toughness and more crack bridging; nickel-iron has high strength but moderate toughness. Measurements guide the process: sintering densifies the structure, resulting in stable toughness; hot working and fibrous treatment increase bending toughness.

Fracture toughness measurement in tungsten alloy rivet mandrels provides an experimental perspective on crack resistance, supports the understanding of tool toughness through extended analysis, and contributes an evaluation basis in riveting design. The systematic application of the measurement ensures consistent toughness across batches of mandrels , allowing for parameter adjustments based on production feedback. The fracture behavior of tungsten alloys is demonstrated in the measurement as phase synergy, with the binder phase bridging energy and the tungsten phase hindering propagation. Applications are extended to simulation software, with finite element analysis predicting toughness hotspots and mandrel shape optimization reducing crack susceptibility. The evaluation of tungsten alloy rivet mandrels through fracture toughness measurement provides damage assessment for materials engineering, enables toughness management of tools through measurement response, and demonstrates practical value in the assembly field. The depth of analysis makes the toughness of the mandrel predictable under high-load conditions, promoting improved safety in use.

5.2.4 Prediction of the life of tungsten alloy rivet mandrels due to high-cycle fatigue

High-cycle fatigue on the life of tungsten alloy rivet mandrels is mainly achieved through SN curves and damage accumulation models. This prediction helps analyze the durability performance of the mandrel under low stress and high cyclic loading, guiding the service life assessment of the tool in high-frequency riveting environments. High-cycle fatigue refers to the condition where the stress is below the yield but the number of cycles is high. Mandrel samples are tested on rotary bending or axial tension/compression machines, and the number of cycles and failure behavior are recorded. The binder phase coordinates micro-damage in high-cycle fatigue, and the tungsten particle skeleton resists crack propagation.

The prediction method involves plotting SN curves and testing lifespan at multiple stress levels. The two-phase structure of the mandrel results in a gentler curve slope and a higher fatigue limit. Damage accumulation models, such as Miner's rule, integrate variable loads to predict lifespan under actual operating conditions. High-cycle fatigue prediction of the mandrel considers surface condition; polishing reduces the starting point and extends lifespan. Heat treatment is also considered in the prediction process; annealing reduces residual stress and increases the fatigue limit.

High-cycle fatigue prediction reveals the top-bar mechanism : micro-damage begins with dislocation accumulation, followed by grain boundary crack initiation and propagation, leading to failure. Compositional differences in prediction show that the nickel-copper system exhibits good high-cycle toughness and slow damage under cycling; nickel-iron systems offer high strength but moderate fatigue limits. Predictive guidance applies to applications: manual riveting prioritizes low-cycle strength, while high-frequency pneumatic systems focus on high-cycle lifespan. Chemical purity management minimizes impurities and reduces the initiation of high-cycle damage.

Analysis provides a mathematical perspective on cyclic response for predicting the life of tungsten alloy rivet mandrels . Model analysis supports an understanding of tool life and contributes a predictive foundation to riveting design. The systematic application of predictions ensures consistent batch life of mandrels , allowing production feedback for adjusting sintering parameters. The high-cycle behavior of tungsten alloys is reflected in the prediction as a synergistic effect, with the binder phase absorbing cyclic energy and the tungsten phase preventing damage. High-cycle fatigue prediction provides a dynamic model for assessing the life of tungsten alloy rivet mandrels , enabling tool life management through predicted response and demonstrating practical value in assembly. The depth of analysis allows for predictability of mandrel life under continuous operation, driving the optimization of maintenance plans.

5.3 Friction and Wear Characteristics of Tungsten Alloy Rivet Tops

Tungsten alloy rivet mandrels primarily stem from the contact interaction between their surface and the rivet tail. These characteristics influence the surface damage rate and overall durability of the mandrel during riveting . Friction characteristics relate to the sliding resistance between the contact surfaces, while wear characteristics describe the material removal process. The two-phase structure of tungsten alloys results in a smooth surface at low friction and a hard phase that resists scratches during slow wear. Characteristic analysis helps optimize the stability of the mandrel during repeated use and reduces surface pitting accumulation.

The mechanism of friction and wear is manifested on the working surface of the mandrel . The high hardness of tungsten particles reduces embedded wear, while the toughness of the binder phase reduces adhesion. Friction increases when a chemical oxide layer forms on the surface, and its properties improve after polishing removal. Characteristic testing guides material selection; a low coefficient of friction ensures smooth rivet deformation, resulting in low wear rate and long service life. The friction and wear characteristics of tungsten alloy rivet mandrels reflect the surface response of composite materials. Characteristic control supports tool durability and provides a stable foundation in riveting practice.

5.3.1 Optimization of Tungsten Alloy Rivet Top Rod Based on Friction Coefficient Measurement

Tungsten alloy rivet mandrels through friction coefficient measurement is mainly achieved through sliding friction testing. This measurement helps assess the resistance behavior of the mandrel surface when in contact with the rivet, guiding surface treatment and composition adjustment to reduce friction and improve riveting efficiency. A pin-disc or ball-disc apparatus is commonly used for measurement. The mandrel sample is fixed as the disk, and a load is applied to the grinding pin while it slides. The ratio of frictional force to normal force is recorded. Chemically, the coefficient of selective wetting influence is measured, and it is low after polishing.

The process analysis measurement curves were optimized. Lubrication was added when the dry friction coefficient was high, and the effect of coolant was tested during wet friction. The tungsten phase in the ejector pin exhibits high hardness and a low coefficient; a higher proportion of the binder phase results in better plasticity and more stable friction. Measurement variations included high-temperature friction, simulating hot riveting conditions , and the coefficient increasing during ejector pin oxide layer formation, which was mitigated by coating protection. The application of friction coefficient measurement for ejector pin optimization is reflected in production control; when the coefficient is high, surface texture is adjusted, and wire drawing reduces mirror friction.

Measurement of the guiding composition shows that the copper phase has a high coefficient and low friction coefficient, resulting in smoother deformation of the mandrel . Changes in the coefficient after heat treatment are measured, indicating a clean and stable frictional surface after annealing. Friction coefficient measurement provides a quantitative approach to optimizing the surface interaction of tungsten alloy rivet mandrels , supports friction control of the tool through force ratio analysis , and contributes to efficiency improvements in riveting operations.

5.3.2 Discussion on Wear Mechanism in Tungsten Alloy Rivet Top Bars

The study of wear mechanisms in tungsten alloy rivet mandrels mainly involves adhesive wear, abrasive wear, and fatigue wear. This research helps to understand the material removal process on the mandrel's working surface under rivet contact, guiding wear-resistant design and maintenance strategies. Adhesive wear originates from the softening and transfer of the binder phase to the rivet during high-temperature contact, followed by a chemical interfacial reaction to form an adhesive layer, leading to pitting accumulation on the mandrel surface . Abrasive wear is manifested in hard rivets, where embedded particles scratch the tungsten phase, resulting in groove formation on the mandrel surface .

Fatigue wear manifests under repeated impacts, with micro- vibrations leading to surface layer peeling and fatigue crack propagation in the bonded phase of the mandrel . Mechanism exploration was conducted through wear test simulations, recording volume loss under load and sliding conditions using a pin-disc device , and observing the morphology using scanning electron microscopy. Chemical oxidation wear was observed, accompanied by accelerated removal of the surface layer due to porosity. The findings guide optimization, including surface hardening to reduce adhesion, coating to protect against abrasive particles, and heat treatment to improve fatigue resistance. The exploration of the wear mechanism in tungsten alloy rivet mandrels provides a material understanding of the damage path, supports tool wear resistance improvement through type analysis, and contributes mechanistic insights to riveting practice.

5.3.3 Analysis of Abrasive Wear on the Surface Damage of Tungsten Alloy Rivet Rods

abrasive wear on the surface damage of tungsten alloy rivet mandrels mainly focuses on the cutting and scratching effects of hard particles during contact. This analysis helps to understand the surface change mechanism of the mandrel in riveting hard rivets or in environments containing impurities. Abrasive wear originates from the embedding of rivet tails or fragments into the working surface of the mandrel . During relative motion, the particles plow grooves or micro-cut the surface. Chemically, tungsten particles have high hardness and resist cutting, while the bonding phase is relatively soft and easily forms grooves. In the early stages of damage, fine scratches appear, and with continued action, the grooves deepen and the surface roughness increases.

The analysis process was simulated through wear tests, where the push rod sample slid against the abrasive medium, recording volume loss and morphological changes. Scanning electron microscopy (SEM) was used to observe the groove morphology; the tungsten phase surface showed shallow scratches, while the binder phase exhibited deep furrows. The damage mechanism was staged: initial micro-machining removed a small amount of material, mid-stage fatigue spalling, and later, groove accumulation affecting adhesion. Heat treatment analysis revealed the influence of heat treatment; annealing improved the toughness of the binder phase, reducing spalling, while age hardening decreased groove depth.

The analysis of abrasive wear also considers the working conditions; high-speed riveting results in high abrasive kinetic energy and rapid damage, while low-speed continuous friction leads to long grooves. Surface treatment analysis is also important; coatings or hardened layers buffer abrasive particles, thus slowing damage to the mandrel . Chemical purity management minimizes impurities and reduces self-generated abrasive particles. The analysis of abrasive wear on the surface damage of tungsten alloy rivet mandrels provides a material response to the frictional environment, and morphological studies support tool wear resistance optimization, contributing to damage understanding in riveting practice.

5.3.4 behavior during the contact process of tungsten alloy rivet setter

Adhesive wear in the contact process of tungsten alloy rivet mandrels mainly involves the transfer of surface material under high temperature or high pressure. This leads to localized adhesion between the mandrel and the rivet tail, affecting separation and surface integrity. Adhesive wear originates from the instantaneous high-temperature softening of the contact surface. Chemically, the binder phase, with its lower melting point, softens first , forming micro-welds with the rivet material. During relative sliding, these welds break, transferring material to the opposite side. Initially, it manifests as rough spots on the

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surface; with continued action, pits or protrusions form, reducing the surface finish of the mandrel's working surface .

The mechanism manifests at the interface: frictional heat accumulation leads to a localized temperature rise, causing the binder phase to flow and adhere to the rivet; upon cooling, the bond point solidifies. Sliding shear fracture occurs at the bond point, resulting in material detachment from the mandrel or attachment to the rivet. The high hardness of tungsten particles reduces adhesion initiation and lowers the tendency for mandrel adhesion . High thermal conductivity results in rapid thermal diffusion, a rapid temperature drop at the bond point, and reduced transfer.

Adhesive wear is also affected by load; high pressure results in tight contact and strong adhesion, while low pressure facilitates separation. Surface treatments also play a role; polishing reduces initial adhesion, and coatings isolate and reduce reactions. Good chemical stability is also important; a thin oxide layer on the mandrel leads to slower adhesion. The adhesive wear performance of tungsten alloy rivet mandrels during contact reflects the material interaction during high-temperature friction. Transfer analysis supports surface management of the tool and provides a performance reference for riveting operations.

CTIA GROUP LTD Tungsten Alloy Rivet Top Rod

Chapter 6 Corrosion and Durability of Tungsten Alloy Rivet Pins

6.1 Electrochemical Corrosion Behavior of Tungsten Alloy Rivet Tops

Tungsten alloy rivet mandrels is mainly influenced by their two-phase structure and the environmental medium. This behavior is particularly pronounced in humid or chemically cleaned environments, affecting the surface stability and long-term performance of the mandrel . Electrochemical corrosion involves anodic dissolution and cathodic reduction. The tungsten phase is chemically inert, while the binder phases, such as nickel or copper, are highly reactive and readily become corrosion initiation sites. Behavioral analysis was conducted using polarization curves and impedance spectroscopy. Potential scanning of the mandrel in the electrolyte revealed changes in corrosion potential and current density.

The corrosion behavior also includes pitting and uniform corrosion tendency; the binder phase preferentially dissolves to form micro-cells, and corrosion is slow after tungsten particles are exposed. It exhibits good chemical stability, self-passivating in the atmosphere and forming a thin protective layer on the surface. The environment affects the behavior; acidic environments accelerate the dissolution of the binder phase, while neutral or alkaline environments are relatively mild. The electrochemical corrosion behavior of tungsten alloy rivet mandrels reflects the electrochemical response of composite materials. This behavioral study supports the optimization of tool corrosion resistance and provides an environmental adaptation reference for riveting maintenance.

6.1.1 Application of polarization curves in the corrosion study of tungsten alloy rivet mandrels

Application of polarization curves in the corrosion study of tungsten alloy rivet mandrels is mainly achieved through dynamic potential scanning. This method helps assess the corrosion potential, passivation range, and corrosion current density of the mandrel in the electrolyte, guiding improvements in corrosion resistance. The test uses the mandrel sample as the working electrode, immersing it in a simulated medium in a three-electrode system. Potential scanning records the current response; chemically, the anodic branch reflects dissolution behavior, and the cathodic branch reflects the reduction process. The curves show the corrosion potential and passivation plateau, with an increased current in the active region of the binder phase and a low passivation current in the tungsten phase .

During the process, the sample surfaces were uniformly polished, and the environment was simulated using media such as sodium chloride or sulfuric acid solutions. Polarization curves were used to differentiate corrosion types; high sensitivity was observed when the pitting breakdown potential was low, and a wide plateau was observed after the top rod was coated . Tafel extrapolation was used to quantify the corrosion rate; the rate increased when the proportion of adhesive phase on the top rod was high. Dynamic scanning was used to observe repassivation, revealing strong recovery ability of the top rod after damage .

The polarization curves were also used to evaluate the effect of heat treatment in the study. Annealing expanded the passivation range, resulting in better resistance to localized corrosion in the mandrel .

Differences in composition showed stable passivation in the tungsten-copper system , while the magnetic properties of nickel-iron did not directly affect the curves. Comparing the curves in different media, the mandrel corroded rapidly in acids and exhibited strong passivation in alkalis. The use of polarization curves in the corrosion study of tungsten alloy rivet mandrels provides an experimental perspective on electrochemical parameters. Curve analysis supports the understanding of tool corrosion resistance and contributes an evaluation method to maintenance practice.

6.1.2 protects tungsten alloy rivet top bars

Tungsten alloy rivet mandrels by passivation layer formation is mainly achieved through spontaneous or artificial oxide films on the surface. This protection reduces the corrosion rate of the mandrel in humid or cleaning agent environments, maintaining surface smoothness and functional stability. The passivation layer forms naturally in air or neutral media, with the tungsten phase forming a dense oxide layer, and nickel or copper also participating as binder phases. Chemically, this thin layer blocks oxygen diffusion and ion migration. The protective mechanism is electrochemically manifested: the passivation layer increases the corrosion potential and reduces the anolyte current.

The formation process is influenced by the environment, with slow passivation in the atmosphere and accelerated thickening by electrochemical anodic treatment. After polishing the top rod , passivation is rapid, but the rough surface layer is porous and offers weak protection. Heat treatment promotes formation, and annealing controls oxygen content to ensure uniformity in the lower layer. The protective effect is reflected in resistance to pitting corrosion; the passivation layer has a high breakdown potential, and the top rod experiences less localized damage.

The passivation layer provides protection for the mandrel , including mechanical stability. Its thin layer exhibits strong adhesion, making it resistant to peeling during riveting friction. After chemical cleaning, the layer regenerates, resulting in good mandrel durability . Composition influences formation; the copper phase passivation layer provides electrical conductivity, while the nickel phase layer is dense. The passivation layer's protection of the tungsten alloy rivet mandrel demonstrates the barrier effect of surface chemistry, supporting the tool's corrosion resistance through layer stability and providing a long-term foundation in riveting environments.

6.1.2.1 Stability of tungsten alloy rivet top bars in acidic environments

Tungsten alloy rivet mandrels in acidic environments is mainly affected by the pH value and ion type of the medium. This stability is particularly evident in cleaning or acid mist workshops, where the behavior of the passivation layer on the mandrel surface determines the corrosion rate. Acidic conditions activate the dissolution of the binder phase, and nickel or copper elements readily form soluble ions. While the tungsten phase is chemically relatively inert, micro-cells at the interface accelerate localized corrosion. The overall stability of the mandrel depends on the thickness of the passivation layer; a thinner polished surface layer slightly reduces stability, while acid erosion is slowed after plating or pre-passivation treatment .

The stability mechanism is manifested in the two-phase interaction : the binder phase preferentially reacts and consumes hydrogen ions; after tungsten particles are exposed, the surface oxide layer regenerates; and the corrosion morphology of the mandrel tends to be uniform rather than deep pits. Increased acid concentration decreases stability, but the tungsten alloy system exhibits relative stability in dilute acids, and the smooth surface of the mandrel is maintained for a long time. Heat treatment affects stability; annealing results in a uniform microstructure but slow acid penetration. Compositional adjustments improve stability; a higher copper phase promotes conductivity but leads to faster acid dissolution, while the nickel phase offers slightly better acid resistance .

It can be restored by wiping after immersion . Surface treatment enhances stability; chemical passivation forms a thick layer, resulting in minimal corrosion under acid mist . Immersion tests assess stability; minimal change in mandrel mass indicates good acid resistance. The stability of the tungsten alloy rivet mandrel in acidic environments demonstrates the composite material's media adaptability. The protective layer supports surface maintenance of the tool, contributing to its durability in acidic operations.

6.1.2.2 Response of tungsten alloy rivet mandrel under alkaline conditions

Tungsten alloy rivet mandrels under alkaline conditions mainly involves enhanced surface passivation and slight dissolution behavior. This response is observed in alkaline washing or alkaline coolant environments, and the mandrel exhibits good overall stability. Alkaline media promote the formation of stable oxides on the tungsten phase surface . Chemically, the binder phases, nickel or copper, have low solubility in alkali, resulting in a slow corrosion rate for the mandrel . In the initial stage of the response, the surface passivation layer thickens, preventing further reactions and maintaining the smoothness of the mandrel . The response mechanism is manifested in phase selectivity: tungsten particles are highly inert in alkali, the binder phase reacts slightly to form a protective precipitate, and the top rod surface layer is dense. The response changes little with increasing alkali concentration, and the top rod exhibits uniform corrosion rather than pitting. Heat treatment affects the response; annealing results in cleaner grain boundaries and less alkali penetration. Compositional differences lead to better passivation of the nickel phase in alkali, while the copper phase is slightly more active but generally stable.

The ejector pin 's response under alkaline conditions is suitable for alkaline washing maintenance, and the surface shows no significant damage after immersion . Surface pretreatment enhances the response, and a thick passivation layer ensures the ejector pin's stability under alkaline mist conditions . Response evaluation through alkaline immersion tests shows minimal morphological change , indicating good adaptability. The response of the tungsten alloy rivet ejector pin under alkaline conditions reflects the material's alkalinity adaptability, supporting tool cleaning tolerance through passivation and providing a surface foundation for alkaline operations.

6.1.3 Characterization of tungsten alloy rivet mandrels by corrosion potential measurement

Tungsten alloy rivet mandrels by corrosion potential measurement is mainly achieved through open-circuit potential and potentiodynamic scanning. This characterization helps assess the thermodynamic

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stability of the mandrel in the medium and guides the judgment of corrosion resistance. The mandrel sample is immersed in an electrolyte, and the stable potential is recorded. Chemically, a high potential indicates a strong passivation tendency and difficulty in initiating corrosion . The open-circuit potential stabilizes over time, and the potential of the mandrel's two-phase structure lies between that of the tungsten and the binder phase .

The characterization process involved multi-medium comparison; low potential in acidic media led to easy corrosion, while high potential in alkaline media resulted in stable passivation. Potential dynamic scanning extended the characterization process, revealing that the zero current point represents the corrosion potential, and the push rod exhibited a wide passivation range and good corrosion resistance. Surface condition was measured as a limiting factor; polishing resulted in a high potential, while roughness caused potential fluctuations. Heat treatment characterization showed that annealing increased the potential and resulted in a more uniform microstructure .

Corrosion potential measurement characterizes the adaptability of tungsten alloy rivet mandrels to various applications ; higher potentials result in more stable mandrels in humid environments. Compositional differences are also considered: tungsten-copper mandrels exhibit moderate potentials, while nickel-iron mandrels show slightly lower potentials but stronger passivation. Measurements guide protection measures; lower potentials improve coating performance. Corrosion potential measurement provides an experimental perspective on the electrochemical stability of tungsten alloy rivet mandrels , supports corrosion assessment of tools through potential analysis, and contributes a characterization basis to environmental durability.

6.1.4 Application of Impedance Spectroscopy Analysis in Corrosion Kinetics of Tungsten Alloy Rivet Mandrels

The application of impedance spectroscopy in the corrosion kinetics of tungsten alloy rivet mandrels is mainly achieved through AC impedance measurement. This application helps reveal the interfacial reactions and corrosion rate changes of the mandrel in the electrolyte, guiding the evaluation and improvement of corrosion resistance. Impedance spectroscopy involves applying a small AC signal, recording the frequency response curve, and fitting an equivalent circuit model. Chemically, the passivation layer on the mandrel surface behaves as a capacitive-resistive element, and the dissolution of the binder phase corresponds to the transfer resistance. In the application process, the mandrel sample is used as the working electrode, immersed in a simulated medium, and the frequency is scanned from high to low. The arc shape of the curve reflects the integrity of the passivation layer.

In applications, impedance spectroscopy analysis distinguishes corrosion stages; a large initial arc indicates stable passivation, while a smaller arc over time accelerates corrosion. The biphase structure of the mandrel is evident in the analysis, with the tungsten phase exhibiting high impedance and the binder phase controlled by low-frequency diffusion. Equivalent circuit fitting parameterizes the process, quantifying interfacial behavior through electrolyte resistance, double-layer capacitance, and transfer resistance, from which the mandrel corrosion kinetics are derived. The analysis guides heat treatment;

after annealing, the impedance arc increases, the microstructure becomes more uniform, and corrosion resistance is improved. Depending on the composition, the tungsten-copper system exhibits high impedance and stable passivation, while nickel-iron has slightly lower impedance but recovers faster.

Impedance spectroscopy analysis also evaluates the effectiveness of surface treatment; the change in arc shape after coating reflects the contribution of the protective layer. Media influence analysis reveals that low impedance in acids leads to rapid corrosion, while a large arc in alkalis promotes strong passivation. Applications are extended to dynamic monitoring; the time-varying impedance curve of the mandrel after long-term immersion predicts its lifespan. Chemical purity management ensures fewer impurities, resulting in a clear and interference-free impedance arc . The application of impedance spectroscopy in the corrosion kinetics of tungsten alloy rivet mandrels provides a frequency domain perspective on interfacial dynamics, supports the understanding of tool corrosion mechanisms through curve fitting, and contributes analytical methods to environmental durability.

6.1.5 Corrosion behavior of oxidation reaction on tungsten alloy rivet top bars

Tungsten alloy rivet mandrels due to oxidation primarily involves surface changes related to oxygen in the atmosphere or surrounding medium . This behavior is manifested when the mandrel is exposed to air or at high temperatures, affecting its surface stability and service life. The oxidation reaction begins with the adsorption of oxygen molecules on the mandrel surface . Chemically binding phase elements such as nickel or copper are first oxidized to form a thin layer, while the tungsten phase slowly forms oxides. The corrosion behavior of the mandrel tends to moderate after the oxide layer forms. A thick layer hinders further oxygen diffusion, but corrosion accelerates when the layer is porous.

The behavioral mechanism is manifested in phase selectivity: the binder phase oxidation preferentially consumes oxygen, generating nickel oxide or copper oxide, while the tungsten phase oxidation forms a dense layer, and the overall behavior of the mandrel changes from rapid oxidation to passivation stability. High temperature accelerates the reaction; when the mandrel is heated by friction, a thick local oxide layer forms, resulting in changes in surface color. Moisture in the medium participates in oxidation, making the behavior more active in humid environments, and the hydrate layer on the mandrel surface increases corrosion tendency. The influence of the oxidation reaction on the corrosion behavior of the mandrel guides protection; pre-passivation forms a uniform layer, resulting in more stable behavior. Compositional adjustment behavior: the copper phase oxide layer is conductive and assists in corrosion, while the nickel phase layer is dense. Heat treatment affects behavior; annealing results in a clean surface and slower oxidation. The corrosion behavior of the oxidation reaction on tungsten alloy rivet mandrels reflects an oxygen-interactive surface process, supporting tool corrosion resistance assessment through layer formation and contributing behavioral references in maintenance practice.

6.1.6 Control over the Chemical Properties of Tungsten Alloy Rivet Tops

Environmental factors on the chemical properties of tungsten alloy rivet mandrels is mainly achieved through temperature, humidity, medium, and atmospheric composition. This influence affects the surface reaction rate and microstructure stability of the mandrel , which are manifested under different workshop or storage conditions. Increased temperature regulates the oxidation rate, chemically thermally activating molecular collisions and accelerating the formation of the oxide layer on the mandrel surface . However, the high melting point of the tungsten phase moderates the overall behavior. Increased humidity involves water vapor, and the adsorption of water on the mandrel surface promotes hydroxide formation, shifting the chemical properties towards a corrosion-prone state.

Medium regulation, such as acids and alkalis, regulates chemical activity by dissolving the binder phase in acids, while alkalis stabilize the passivation layer and regulate good corrosion resistance. Atmospheric composition, such as oxygen and nitrogen, regulates oxidation and nitridation; the top rod is chemically stable in clean air, but corrosion is accelerated in polluted environments. Light or ultraviolet radiation regulates surface photochemical reactions, and the chemical properties of the top rod remain largely unchanged during outdoor storage.

Environmental factors also influence the chemical properties of tungsten alloy rivet mandrels, including vibration and stress. Mechanical stress, by exposing cracks, accelerates corrosion initiation. Protective measures, such as coatings, isolate the environment and maintain the original chemical properties. Compositional factors regulate environmental response; the high conductivity of the copper phase regulates electrochemical behavior, while the nickel phase regulates alkali resistance. The influence of environmental factors on the chemical properties of tungsten alloy rivet mandrels reflects the material interaction with external conditions. Factor analysis supports the chemical adaptation of the tool and contributes to the regulatory framework within the usage environment.

6.2 High-Temperature Oxidation Mechanism of Tungsten Alloy Rivet Top Rods

Tungsten alloy rivet mandrels mainly involves the interaction between the surface and oxygen. This mechanism manifests when the mandrel is exposed to high-temperature air or in a hot-working environment, affecting its surface stability and overall durability. The oxidation mechanism begins with oxygen molecules adsorbing onto the mandrel surface . Chemically, binder elements such as nickel or iron first combine with oxygen to form oxides, followed by the slow oxidation of the tungsten phase to form a dense layer. The process proceeds in stages: at low temperatures, diffusion controls the slow growth of the oxide layer, while at high temperatures, the reaction rate increases, leading to a thicker layer.

The core mechanism lies in phase selectivity. The highly reactive binder phase preferentially oxidizes, forming a loose oxide layer, while the inert tungsten phase forms a compact tungsten oxide layer. The overall mechanism of the mandrel changes from rapid oxidation to self-limitation. Element diffusion at the interface participates in the mechanism, with the binder phase oxide reacting with tungsten to form a composite layer, resulting in a change in the mandrel surface color. Heat treatment affects the mechanism; after annealing, the microstructure is more uniform and there are fewer oxidation initiation points. Differences in composition mechanisms also play a role: in the tungsten-copper system, the copper phase oxide layer is conductive, while in the tungsten-nickel system, the nickel phase layer is dense.

The high-temperature oxidation mechanism also includes volatilization; tungsten oxide vaporizes at high temperatures, carrying away the surface layer, resulting in a gradual loss of mandrel mass . A protective atmosphere control mechanism is also involved; inert gas reduces oxygen contact, leading to a thinner oxide layer on the mandrel . Mechanism analysis, using thermogravimetric analysis to observe mass changes, shows that a flat oxidation curve indicates good durability. The high-temperature oxidation mechanism of tungsten alloy rivet mandrels reflects the oxygen response of refractory composites, supporting tool surface maintenance through layer formation and providing a mechanistic basis for operation in thermal environments.

6.2.1 Effect of Oxidation Kinetics on Tungsten Alloy Rivet Top Rods

Oxidation kinetics on tungsten alloy rivet mandrels is mainly reflected in the regulation of reaction rate and layer growth behavior. This influence determines the degree of surface damage and durability of the mandrel under high-temperature exposure . Oxidation kinetics describes oxygen diffusion and reaction rate. The binder phase in the mandrel has high kinetic activity, resulting in a rapid initial layer formation, while the tungsten phase has slow kinetics and self-limiting layer growth. The influencing mechanism is manifested in diffusion control, with oxygen migrating inward through interlayer gaps, driven by a chemical concentration gradient, and the layer thickness increase of the mandrel slowing down over time.

Kinetic effects also include temperature dependence: increasing temperature lowers the activation energy but increases the rate; at high temperatures, the capillary layer thickness increases but passivation stabilizes. Compositional kinetics differ: copper phases exhibit fast kinetics, conducting heat and aiding in heat dissipation, while nickel phases, being denser, exhibit slow kinetics. Heat treatment kinetics also play a role: annealing results in cleaner grain boundaries and shorter diffusion paths, leading to lower capillary oxidation rates. Surface state kinetics regulate oxidation: polished surfaces have lower initial oxidation rates, while rough surfaces have more active sites and higher rates.

The impact analysis of oxidation kinetics, through thermogravimetric curve fitting, uses linear or parabolic mandrel kinetic models to reflect the layer growth type. This influence guides protection, altering the kinetic initiation of coating changes and improving mandrel durability . The oxidation kinetics of tungsten alloy rivet mandrels demonstrates the rate-controlled material response, supports tool durability assessment through diffusion analysis, and contributes a kinetic basis to hot operation .

6.2.2 Application of protective coating in tungsten alloy rivet mandrels

The application of protective coatings in tungsten alloy rivet mandrels primarily involves forming a barrier through plating or passivation. This application reduces oxidation and corrosion on the mandrel surface , maintaining its stability and service life in the environment. The coating mechanism blocks oxygen and media diffusion; chemically, plating layers such as nickel-phosphorus or chromium-nitrogen bonds densely to the substrate, maintaining a smooth mandrel surface . Application processes include electroplating or chemical vapor deposition, and the coating adheres uniformly after polishing the mandrel .

The advantages of this application lie in selective protection; the coating slows down damage during friction on the wear-resistant mandrel and resists corrosion in corrosive media. Passivation coatings are self-generating, and the oxide layer on the mandrel in air thickens to protect the substrate. Differences in composition result in conductive coatings (tungsten-copper system) and high-hardness coatings (tungsten-nickel system). Heat treatment ensures coating stability, and annealing provides strong adhesion.

The application of protective coatings in mandrels also assesses durability; peel tests check the bonding, and the coating does not peel off with repeated use. The coating fills in surface texture, resulting in a low coefficient of friction for the mandrel . It exhibits good chemical stability, and the coating does not introduce new sources of corrosion. The application of protective coatings in tungsten alloy rivet mandrels embodies a surface engineering protection strategy, supporting tool durability through a barrier effect and contributing application value in the operating environment.

6.2.3 Damage to tungsten alloy rivet top bars caused by the formation of volatile oxides

to tungsten alloy rivet mandrels caused by volatile oxide formation mainly occurs in high-temperature air environments. This damage is caused by the unstable transformation of the surface oxide layer, leading to gradual material loss and affecting the dimensional accuracy and surface integrity of the mandrel . Volatile oxides, such as tungsten oxide, change from a solid to a gaseous state at high temperatures, escaping from the mandrel surface . Chemically, they undergo an oxidation reaction to form tungsten oxide, which further volatilizes upon heating, resulting in a thinner working surface and increased roughness. The damage process begins with oxygen adsorption on the mandrel surface ; the binder phase oxidizes first to provide the initial layer, followed by the tungsten phase, generating volatilization products.

The damage mechanism is manifested in the temperature gradient; volatilization is rapid in high-temperature zones, and surface oxides rapidly vaporize when local friction generates heat in the mandrel , accelerating material removal and forming pits or unevenness. Volatile oxides disrupt the uniformity of the mandrel , with more volatilization at the edges and less in the center, resulting in a gradual change in the mandrel shape and unstable rivet support. Chemical stability also affects the damage; volatilization is slower when the binder oxide layer is dense, and accelerated when it is porous due to tungsten exposure.

The damage caused by volatile oxide formation extends to the interior of the mandrel. After the surface layer peels off, the new layer oxidizes, leading to cumulative mass loss and shortened service life. The damage response changes after heat treatment; annealing results in a more uniform microstructure and fewer volatilization initiation points. Compositional regulation causes damage; a higher copper phase leads to better thermal conductivity and reduced heat dissipation, resulting in less volatilization; the nickel phase forms stable oxides, constraining volatilization. Damage analysis, through thermogravimetric analysis (TGA), observes mass changes; a flat volatilization curve in the mandrel indicates good durability. The damage to tungsten alloy rivet mandrels caused by volatile oxide formation reflects the material consumption from high-temperature gas-solid reactions. The product escape supports tool life assessment and provides a reference for damage mechanisms in hot environments.

6.2.4 Regulation of oxidation resistance of tungsten alloy rivet mandrels by alloying elements

tungsten alloy rivet mandrels by alloying elements is mainly achieved through the formation of a stable oxide layer or the adjustment of reaction kinetics. This regulation slows down surface damage in high-temperature air, maintaining smoothness and durability. Alloying elements such as nickel, iron, or copper participate in the oxidation process. Chemically, nickel forms a dense nickel oxide layer, blocking oxygen diffusion and improving the oxidation resistance of the mandrel . Iron forms an iron oxide composite layer, regulating the oxidation rate and slowing down the color change of the mandrel surface . Copper phase regulates thermal conductivity, resulting in rapid heat dissipation, reducing localized high temperatures, and delaying the initiation of oxidation.

The regulatory mechanism is manifested in the synergistic effect: the binder phase preferentially oxidizes and consumes oxygen, generating a non-volatile layer to protect the tungsten phase, resulting in strong overall oxidation resistance of the mandrel . Micro-doping of rare earth elements regulates grain boundary purification, reducing oxidation initiation points and slowing the increase in mandrel layer thickness . Heat treatment regulates the response, ensuring uniform element diffusion after annealing and consistent oxidation resistance. The composition ratio regulates oxidation tendency, resulting in a thicker, more multi-layered binder phase for better protection and improved mandrel durability .

The regulation of the oxidation resistance of mandrels by alloying elements was also evaluated through surface treatment. The coating and elements synergistically formed a multi-layered protection, resulting in a thin oxide layer on the mandrel . Chemical stability was regulated, with selective oxidation of elements producing stable products and minimal loss of mandrel mass . Regulation analysis, through oxidation tests observing layer thickness and morphology, showed that the flat oxidation resistance curve of the mandrel indicated effective regulation. The regulation of the oxidation resistance of tungsten alloy rivet mandrels by alloying elements reflects a material strategy of compositional optimization. Layer formation supports the surface stability of the tool and provides a basis for regulation during hot operation .

6.3 Environmental durability test of tungsten alloy rivet top bar

Tungsten alloy rivet mandrels primarily assesses their performance retention in humid or corrosive environments by simulating conditions such as salt spray and humidity cycling. This testing helps understand the long-term stability of the mandrel's surface and overall structure, guiding material selection and protective measures. Test methods include salt spray testing, which simulates marine or salt spray environments, and humidity cycling testing, which assesses the effects of temperature and humidity changes. The dual-phase structure of tungsten alloys is evident in the tests: the tungsten phase exhibits strong corrosion resistance, while the binder phase is susceptible to chloride ions or moisture. Surface changes, mass loss, and performance degradation are observed after exposure to the test samples, and chemical analysis of corrosion products reveals the underlying mechanisms. The significance of environmental durability testing lies in predicting the performance of mandrels in actual workshops or outdoor storage. Salt spray testing accelerates pitting corrosion due to chloride ions, while humidity cycling induces stress corrosion. Testing standards reference industry specifications, and exposure times and conditions are matched to application scenarios. Results guide surface treatments, coatings, or passivation to improve durability. Environmental durability testing of tungsten alloy rivet mandrels demonstrates the material's adaptability to complex conditions, supports tool life prediction through experimental simulation, and provides practical reference for riveting maintenance.

6.3.1 Evaluation of Tungsten Alloy Rivet Top Rods by Salt Spray Testing

Tungsten alloy rivet mandrels through salt spray testing primarily involves simulating a neutral or acidic salt spray environment, exposing the mandrel samples, and observing changes in corrosion morphology and rate. This evaluation helps determine the surface stability and durability of the mandrels under chlorine-containing humid conditions. In the test , the mandrels are placed in a salt spray chamber, where sodium chloride is sprayed. Chemically, chloride ions adsorb onto the surface, destroying the passivation layer, and the binder phase preferentially dissolves, forming pitting or uniform corrosion. The evaluation process records surface rust spots, pits, and mass loss after exposure time. The tungsten phase in the mandrel exhibits strong chlorine resistance, and corrosion initiates in the binder phase region.

The evaluation mechanism is reflected in the microcells: the binder phase dissolves at the anodic galvanic end, the tungsten phase provides cathodic protection , and while the top rod shows low pitting corrosion tendency, localized damage is significant. Surface treatment effectiveness is assessed: the coating exhibits long salt spray tolerance and few corrosion products. Heat treatment impact is evaluated: annealing results in uniform microstructure and slow chlorine penetration. Compositional differences are assessed: the tungsten-copper system exhibits conductivity-assisted corrosion reduction, while the tungsten-nickel-iron system's magnetic properties do not directly affect corrosion, but interfacial bonding regulates corrosion propagation.

Salt spray testing assesses the suitability of mandrel applications . Mandrels used in marine workshops require high salt spray resistance, while those meeting general environmental standards are sufficient. The assessment guides maintenance, emphasizing regular cleaning of salt spray-sensitive mandrels . Chemical analysis of corrosion products and oxide types reveals the underlying mechanisms. Salt spray testing provides a simulated perspective on chlorine-enhanced corrosion in tungsten alloy rivet mandrels , supporting understanding of tool salt spray resistance through morphological observation and contributing to the assessment foundation in humid operations.

6.3.2 The role of humidity cycling in the durability of tungsten alloy rivet mandrels

humidity cycling in the durability of tungsten alloy rivet mandrels is mainly reflected in simulating stress corrosion and oxidation behavior induced by alternating temperature and humidity. This effect helps assess the long-term performance of the mandrel in varying humidity environments and guides storage and usage conditions. The cycling process alternates between high humidity and high temperature followed by low humidity and low temperature. Chemically, moisture adsorption on the surface promotes oxidation, and temperature changes generate thermal stress, leading to repeated damage and repair of the mandrel's passivation layer . The mechanism is manifested in water vapor condensation; under high humidity, a liquid film forms on the surface, forming an electrolyte, and the binder phase slightly dissolves; under low humidity, drying stress is released.

The effects also include fatigue accumulation, repeated micro-stress during cycling, and slow propagation of micro-damage at the mandrel interface . Surface effects are significant; the oxide layer thickness increases at high humidity and cracks at low humidity , gradually reducing the smoothness of the mandrel surface . Heat treatment also has an impact; annealing results in lower stress and less cyclic damage. Compositional differences also play a role; the copper phase has rapid thermal conductivity and dissipation with minimal humidity influence, while the nickel phase provides passivation stability and good cycle tolerance.

Humidity cycling is used to assess the storage durability of rivet tops. Tops for temperate or tropical environments require high cycling adaptability. This study guides protection measures, including sealed packaging to reduce humidity exposure. Chemical analysis of post-cycle products and oxide distribution reveals the mechanism. The role of humidity cycling in the durability of tungsten alloy rivet tops provides a simulation perspective of humid conditions, supports tool life assessment through cyclic response, and contributes to the basis of its role in environmental storage.

6.3.3 Integration of Multi-Scale Simulation in Tungsten Alloy Rivet Tops

The integration of multi-scale simulations in tungsten alloy rivet mandrels primarily combines atomic-level, microscopic, and macroscopic models. This integration helps predict the behavior of the mandrel under complex stresses and environments, guiding material design and performance optimization. The multi-scale approach begins with quantum mechanical calculations of elemental interactions, followed by chemical analysis of the bonding energy between tungsten and the binder phase to determine diffusion paths. This extends upwards to molecular dynamics simulations of dislocation motion and grain boundary responses, and finally to finite element macroscopic models for evaluating stress distribution.

The integration process reveals the impact of alloy element segregation on interfacial strength at the atomic scale, and predicts microcrack initiation in the stress concentration zone of the mandrel . Microscale discrete dislocation dynamics simulation of impact deformation clarifies the two-phase coordination mechanism of the mandrel . A macroscopic continuum model integrates microscopic parameters, enabling estimation of the overall fatigue life of the mandrel . Simulation integration is achieved through parameter transfer; atomic simulation outputs bond energy to microscopic inputs, and microscopic results calibrate the macroscopic constitutive model.

In applications, multi-scale simulations evaluate the damage evolution of mandrels under riveting loads. Environmental factors such as humidity are incorporated into the corrosion model to predict the stress

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corrosion sensitivity of the mandrels . Composition optimization and integration simulate the performance changes of different binder phase ratios, achieving a balance between the toughness and strength of the mandrels . Heat treatment simulations demonstrate grain evolution, clearly defining the path to improve the durability of the mandrels .

The integration of multi-scale simulations in tungsten alloy rivet mandrels provides a computational perspective from the atomic to the component level, supports performance prediction of the tool through model nesting, and contributes simulation guidance to design improvements. The integrated systematic approach makes mandrel development more forward-looking and opens up computational pathways for durability optimization.

6.3.4 Sensitivity test of stress corrosion cracking on tungsten alloy rivet mandrels

Tungsten alloy rivet mandrels to stress corrosion cracking is primarily tested through constant load or slow strain rate tensile tests. These tests apply stress in a simulated corrosive medium, observing the crack initiation and propagation behavior to help assess their durability under humid loading conditions. Samples are pre-notched or smoothed and immersed in a chlorine- or sulfur-containing medium. Chemically, the stress promotes anodic dissolution, leading to synergistic cracking with the medium's corrosion. Constant load tests maintain a fixed stress and observe the results until fracture. Slow strain rate tensile tests dynamically load and record the curve changes.

The testing process is divided into stages. In the initial stage, the passivation layer is damaged, the binder phase dissolves, inducing pitting corrosion, and stress concentration leads to crack initiation. In the middle stage, cracks propagate along grain boundaries or interfaces, and the crack path bends in the two-phase structure of the top bar. In the later stage, fracture accelerates, and propagation is slow when the top bar has good toughness. The temperature and humidity of the testing environment are controlled, and accelerating factors such as chloride ions increase sensitivity.

Sensitivity testing assesses the suitability of mandrel applications ; mandrels used in humid workshops require low sensitivity, while those in dry environments meet standards. Heat treatment testing has an impact; annealing stress reduces sensitivity. Compositional differences contribute to lower sensitivity; nickel-copper systems exhibit lower sensitivity, and mandrels show better resistance to stress corrosion cracking. Testing guides protection; coatings isolate the medium, reducing sensitivity. Sensitivity testing of tungsten alloy rivet mandrels through stress corrosion cracking provides an experimental perspective of load-medium synergy, supporting tool durability assessment through crack observation and contributing to the testing foundation in wet environments . The systematic nature of the testing ensures batch-to-batch consistency in mandrel sensitivity, providing a feedback path for process improvements.

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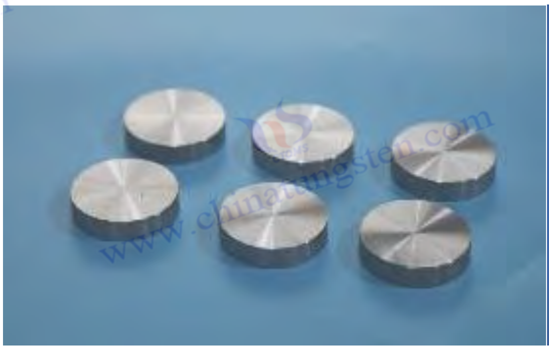
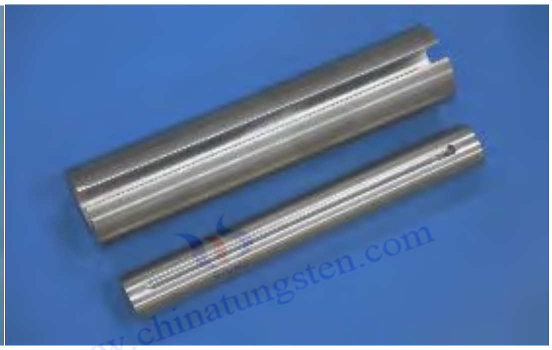

Chapter 7 Application of Tungsten Alloy Rivet Rods

7.1 Application of tungsten alloy rivet top bars in riveting process

Tungsten alloy rivet mandrels are primarily used as reverse support tools in riveting processes. This application is evident in the permanent joining of metal sheets or components, helping the rivet tail deform evenly to form a strong joint. The mandrel is placed at one end of the rivet, bearing the impact of hammering or pressure. The high density and hardness of the tungsten alloy concentrate the reaction force, allowing for smooth plastic flow at the rivet head. Applications cover manual riveting, pneumatic riveting guns, and automated assembly lines. The mandrel's shape matches the rivet type, and its smooth surface reduces friction.

Riveting processes , the role of the ejector pin is to control the deformation zone. The flat or concave working surface of the ejector pin accommodates the tail expansion, ensuring consistent connection strength. Tungsten alloy ejector pins, with their impact resistance, support high-frequency operation, exhibit slow surface wear, and require minimal maintenance . Applications extend to riveting different materials; aluminum alloy rivets are paired with ejector pins of balanced hardness, while steel rivets require high-strength ejector pins. The chemical stability of the ejector pin makes it resistant to coolant or oil contamination, ensuring good adaptability to assembly environments.

Tungsten alloy rivet mandrels in riveting processes demonstrates the engineering value of tool materials, improving connection efficiency through support optimization and providing reliable performance in industrial assembly. With the diversification of riveting technologies, this application is expanding, contributing practical support to connection processes.

7.1.1 Mechanical Action of Tungsten Alloy Rivet Mandrel During Rivet Forming

During the rivet forming process, the mechanical role of the tungsten alloy rivet mandrel is mainly reflected in providing reverse support and energy transfer. This role allows the rivet tail to undergo uniform plastic deformation under impact or pressure, forming a reliable joint. As a rigid reaction component, the mandrel bears the hammer load. The high density and strong inertia of tungsten alloy concentrate the reaction force at the rivet tail, while the head flows smoothly without deflection. The mechanical mechanism is manifested in the stress distribution; the working surface of the mandrel fits snugly against the tail, ensuring uniform stress and preventing local overload, resulting in symmetrical rivet deformation.

Its functions also include vibration absorption, with the top rod bonding phase coordinating with micro-deformation to reduce equipment backlash and ensure smooth operation. Chemically, it exhibits low interfacial friction, a smooth top rod surface reducing heat accumulation, and a slow temperature rise during rivet forming. The top rod body has high strength, preventing bending under axial load and providing stable support. Mechanical effects are manifested in different rivet types: blind rivet top rods accommodate expansion, while self-piercing rivet top rods resist shear.

The mandrel during rivet forming optimizes the connection quality. The mandrel's hardness matches the rivet material, ensuring controlled deformation and preventing cracking. In application, the mandrel fixes the rivet gun, ensuring direct load transfer and consistent rivet locking force. The mechanical action of the tungsten alloy rivet mandrel demonstrates the mechanical contribution of a support tool, reliably controlling riveting deformation through reaction force coordination, providing a mechanical basis for assembly practice.

7.1.2 Interaction Mechanism between the Top Rod and Rivet Materials

The interaction mechanism between the mandrel and rivet materials mainly involves contact surface friction, heat conduction, and deformation coordination. This mechanism determines the connection quality and mandrel durability during riveting . The mechanism begins with the mandrel's working surface contacting the rivet's tail; upon impact, friction generates shear; chemically, a smooth surface results in a low coefficient of friction, minimizing rivet slippage and ensuring uniform deformation. The interaction includes heat exchange: the rivet's plastic deformation generates heat, which is conducted to the mandrel; the tungsten alloy provides thermal conductivity and assists in heat dissipation; and the temperature gradient is gentle.

The mechanism also involves material transfer: when the rivet is soft, a small amount adheres to the mandrel; when the mandrel is hard, less material is transferred, and the surface is easier to clean. The adhesive phase coordinates with micro-deformation, absorbing the rivet's rebound energy, thus stabilizing the mandrel's shape . A chemical stability mechanism is also involved: the passivation layer on the mandrel surface resists corrosion from rivet oxides, and the mandrel maintains its smoothness after interaction.

The interaction mechanism is influenced by the rivet material; aluminum rivets exhibit soft, mild interaction, while steel rivets require high wear resistance from the mandrel due to strong friction. Optimized surface treatment mechanisms reduce adhesion in the mandrel plating , resulting in smoother rivet formation. The interaction mechanism between the mandrel and rivet materials reflects the material response to contact interaction, supporting the stability of the riveting process through frictional -thermal coordination , and contributing a fundamental mechanism to the joining process.

7.1.2.1 Analysis of Contact Stress Distribution in Tungsten Alloy Rivet Top Rod Applications

Analysis of contact stress distribution in tungsten alloy rivet mandrel applications mainly focuses on the pressure transmission and local load characteristics between the mandrel's working surface and the rivet tail. This analysis helps to understand the uniformity of support and deformation control effect of the mandrel during riveting. The contact stress distribution originates from the reaction force between the mandrel end face and the rivet tail. The high hardness of tungsten alloy causes stress to concentrate at the contact center, with stress gradually decreasing at the edges, forming a gradient distribution. Chemically, interfacial friction affects the distribution; a smooth surface results in more uniform stress, while a rough surface leads to higher local peak stresses.

The analysis was conducted through finite element simulation or indentation tests. The mandrel exhibits strong axial rigidity, with slow stress decay along the radius, and consistent pressure in the deformation zone at the rivet tail. The concave design of the mandrel adjusts the stress distribution, accommodating tail expansion and diffusing stress towards the edges to avoid overload at the center. After hot working, the microstructure becomes fibrous, resulting in stronger axial stress transmission and a more stable stress distribution in the mandrel . Compositional analysis also reveals the influence of high tungsten content, leading to high rigidity and concentrated distribution, while the presence of a high binder phase ensures a more flexible and evenly distributed stress.

The analysis of contact stress distribution also evaluated rivet material matching; soft rivets exhibited a wide and uniform stress distribution, while hard rivets required a high- hardness mandrel . Surface treatment analysis revealed that the coating reduced the coefficient of friction and optimized the stress distribution. Chemical stability analysis showed that the mandrel surface remained unchanged without a reactive layer. The analysis of contact stress distribution in tungsten alloy rivet mandrel applications provides a mechanical perspective on pressure interaction, and the optimized distribution supports the tool's support performance, contributing an analytical basis to riveting processes.

7.1.2.2 Influence of Deformation Coordination on the Durability of Tungsten Alloy Rivet Tops

Deformation coordination on the durability of tungsten alloy rivet mandrels is mainly reflected in the response of the dual-phase microstructure to stress and strain. This influence allows the mandrel to absorb energy during riveting impacts, reducing damage accumulation. The deformation coordination mechanism originates from the synergy between the rigid skeleton of tungsten particles and the plastic network of the binder phase. During impact, the tungsten phase resists compression, while the binder phase extends to buffer lateral expansion, resulting in small overall deformation of the mandrel and a gentle indentation of the working surface.

The impact process occurs in stages: initially, elastic coordination and uniform stress occur; in the middle stage, plastic deformation occurs, and the binder phase slips and absorbs energy, resulting in minimal micro-damage to the mandrel ; in the later stage, recovery occurs, and the mandrel shape is maintained. Chemically, the interfacial bonding is strong, and coordination is achieved without separation. Heat treatment affects coordination; annealing results in lower dislocation density and better coordination, leading to stronger fatigue resistance in the mandrel . Composition also affects coordination; the nickel-copper system exhibits superior ductility and coordination, resulting in faster recovery of the mandrel after impact.

The impact of deformation coordination also assesses surface damage; good coordination results in uniform wear of the mandrel and a longer service life. High rivet hardness requires strong coordination , and a moderate mandrel bonding ratio is essential. Surface treatment affects coordination; flexible coatings aid in deformation absorption. The influence of deformation coordination on the durability of tungsten alloy rivet mandrels reflects an interphase response material mechanism, supporting tool life performance through optimized coordination and contributing a durability foundation in riveting practice.

7.1.3 Requirements for the performance of tungsten alloy rivet setters in high-strength riveting

Requirements for tungsten alloy rivet mandrels in high-strength riveting mainly focus on impact resistance, hardness distribution, and dimensional stability. These requirements stem from the fact that high-strength rivets, such as titanium alloy or high-strength steel rivets, require greater reaction force and precise support during deformation. The mandrel needs high hardness to resist indentation wear at the rivet tail. The tungsten particle skeleton of the tungsten alloy provides rigidity, and the bonding phase coordinates micro-deformation, preventing rapid denting or chipping of the mandrel's working surface . Chemically, it exhibits strong interfacial bonding, preventing separation under stress concentration, and ensuring uniform overall load-bearing capacity.

Requirements also include fatigue resistance; high-strength riveting often involves high-frequency operations, and damage accumulation under cyclic impact of the mandrel is slow, with tissue fibrosis enhancing fatigue resistance. High thermal stability is also crucial, with low mandrel softening tendency under riveting heat or hot riveting conditions, minimizing dimensional changes and maintaining a close fit. High density ensures strong inertial reaction force, concentrated pressure in the rivet deformation zone, and consistent connection strength.

High-strength riveting requires a smooth surface on the mandrel , a low coefficient of friction to reduce heat accumulation, and a slow temperature rise . Chemical stability is required to resist coolant corrosion, ensuring the mandrel's surface remains free of pitting even after long-term use. The end face shape must be concave to accommodate large deformations, providing stable support . The performance requirements of tungsten alloy rivet mandrels in high-strength riveting reflect the tool's adaptability to heavy loads, supporting connection quality through a balance of hardness and toughness, and providing reliable performance in demanding assemblies.

7.1.4 Adaptability of tungsten alloy rivet top bars in automated riveting equipment

Tungsten alloy rivet mandrels in automated riveting equipment is mainly reflected in their rapid replacement, positioning accuracy, and durability. This adaptability allows the mandrel to seamlessly integrate with robots or CNC riveting guns , improving assembly efficiency. The mandrel's fixed end features a standard interface for quick installation via snap-fit or thread. The high roundness of the tungsten alloy mandrel ensures good positioning repeatability, and the equipment clamps it stably without deviation. The chemically treated surface is smooth with low friction, allowing for smooth insertion of the mandrel into the equipment.

Adaptability of the mandrel during automated high-frequency operation reduces resonance damage. High hardness adapts to high-speed impacts; uniform wear on the mandrel's working surface extends its lifespan, reducing downtime for replacements. Thermal stability adapts to continuous riveting; the mandrel's heat dissipation assists in slow temperature rise, minimizing impact on accuracy due to unchanged dimensions. Moderate density adapts to equipment load; the mandrel's mass does not increase the burden on the robotic arm.

Automated equipment , the adaptability of mandrels requires diverse end faces, with concave- flat switching to support different rivets, and standardized mandrel inventory . Chemical stability adapts to cooling media, resulting in slow corrosion and minimal maintenance . The adaptability of tungsten alloy rivet mandrels in automated riveting equipment demonstrates the coordination between tools and machinery, supporting assembly automation through interface and performance matching, contributing efficiency value to the production line.

7.2 Application of tungsten alloy rivet top bars in aerospace structural connections

Tungsten alloy rivet mandrels are primarily used in aerospace structural connections as support tools for high-strength riveting. This application is seen in the assembly of aircraft fuselages, engine components, and satellite structures, helping to achieve reliable connections of lightweight, high-strength materials. The high density and hardness of the mandrel provide stable reaction force, the two-phase microstructure of tungsten alloy coordinates impact deformation, and the smooth working surface of the mandrel reduces material damage. Aerospace connections emphasize weight control and fatigue resistance; tungsten alloy mandrels, with their moderate density and good durability, are suitable for environments with repeated loading.

Applications , the mandrel supports titanium alloy or composite material rivets, with an end face design matching the rivet shape. The concave surface accommodates tail expansion, while the flat surface provides temporary precision support. It exhibits strong chemical stability, resisting aerospace cleaning agents, and its surface does not corrode, thus not affecting the connection. It has good compatibility with automated riveting equipment, with standardized mandrel interfaces , allowing for high precision robotic operation. The application of tungsten alloy rivet mandrels in aerospace structural connections demonstrates the engineering adaptability of tool materials, improving connection quality through support optimization and providing reliable performance in lightweight structural assembly.

7.2.1 Selection Principles of Tungsten Alloy Rivet Tops in Titanium Alloy Riveting

Tungsten alloy rivet mandrels in titanium alloy riveting are mainly based on hardness matching, impact resistance, and surface compatibility. These principles ensure that the mandrel provides stable support during deformation of high-strength titanium rivets, preventing damage or uneven deformation. The hardness principle requires the working surface of the mandrel to have a harder surface than the titanium alloy, with the tungsten phase skeleton resisting indentation, resulting in less mandrel indentation and more uniform reaction force. The impact resistance principle considers the high strength required for titanium rivets and the high density and strong inertia of tungsten alloys, concentrating energy transfer through the mandrel .

Selection principles also include surface compatibility, a smooth mandrel to reduce titanium shavings adhesion, no risk of galvanic corrosion, and mandrel plating or passivation. Size principles include matching the rivet diameter, a slightly larger mandrel body to accommodate the tail, and a moderate end-face concavity for aesthetic appeal. Durability principles assess lifespan; tungsten alloy mandrels exhibit good toughness , slow fatigue, and require fewer replacements in high-frequency riveting.

The principle of thermal stability is reflected in the hot riveting of titanium rivets , with the mandrel softening and maintaining dimensional stability. The principle of chemical purity minimizes impurities, avoiding contamination of the titanium surface. The selection principle of tungsten alloy rivet mandrels in titanium alloy riveting reflects the coordination between tools and materials. This principle-based matching supports the achievement of high-strength connections and provides selection guidance in aerospace structures.

7.2.2 Requirements for the Surface Properties of Tungsten Alloy Rivet Tops in Composite Material Riveting

Requirements of tungsten alloy rivet mandrels in composite riveting mainly focus on smoothness, friction control, and non-destructive contact. These requirements stem from the sensitivity of composite materials to surface scratches and delamination, ensuring the structural integrity after riveting. High smoothness is required; the working surface of the mandrel is mirror-polished to reduce fiber breakage or resin damage, and to prevent particle shedding and contamination of the interlayer when the rivet tail deforms .

Friction control requirements are manifested in a low coefficient of friction, a brushed or coated surface on the ejector pin , smooth sliding to avoid excessive torque causing distortion of the composite board. Chemically, the ejector pin is highly inert, with no reaction products affecting resin curing. The non-damaging requirement necessitates a smooth transition at the ejector pin end face , uniform pressure distribution, and no indentations or micro-cracks in the composite material when supported by the ejector pin .

Requirements also include moderate conductivity, rapid electrostatic discharge from the rivet , and prevention of spark damage to the carbon fiber. Good heat conduction is required, with rapid heat dissipation during riveting and low temperature rise in the rivet to protect the composite's thermal sensitivity. Easy cleaning is also essential, with no adsorbed resin residue on the rivet surface . The surface characteristics of tungsten alloy rivet rivets used in composite riveting reflect the interaction between the tool and the sensitive material. Optimized characteristics support non-destructive joining, providing surface protection in aerospace composite structures.

7.2.3 Stability Analysis of Tungsten Alloy Rivet Tops under Vibration Environment

Stability analysis of tungsten alloy rivet mandrels under vibration environments primarily focuses on their response behavior under cyclic mechanical loads. This analysis helps understand the shape retention and support reliability of the mandrel during dynamic assembly or use. Vibration environments are commonly seen in mechanical oscillations during equipment operation or continuous operation on assembly lines. As a support tool, the mandrel must withstand these loads without significant deformation or damage. The two-phase structure of the tungsten alloy is reflected in the analysis: the tungsten particle skeleton provides rigidity to resist vibration, while the binder phase coordinates micro-strain absorption of energy . The overall stability of the mandrel depends on the interaction between the phases.

The analysis process was simulated through vibration tests. The top rod was fixed to a vibration table, and different frequencies and amplitudes were applied. Displacement and stress changes were recorded. Stronger chemical interfacial bonding resulted in faster vibration decay and a lower tendency for the top rod to resonate . Stability analysis assessed the resonant frequency . A large aspect ratio of the top rod indicated sensitivity at low frequencies; a shorter, thicker design optimized stability. Thermal effects accompanied the vibration; frictional heat generation was mitigated by the top rod's thermal conductivity , which aided in heat dissipation, resulting in a slower temperature rise and better stability.

Vibration analysis also includes fatigue accumulation; under cyclic vibration, the propagation of micro-damage in the mandrel is slow, and the binder phase recovers quickly, allowing for life prediction derived from the analysis. Compositional analysis also plays a role; the nickel-copper system exhibits good damping and high vibration absorption, while nickel-iron systems demonstrate high strength and stability. Surface treatment analysis further enhances this effect; brushed textures scatter vibration energy, improving mandrel stability . Purity management minimizes impurities, resulting in fewer defect initiation points during vibration.

Stability analysis of the mandrel under vibration conditions guides the design; a flat end face provides uniform support, resulting in a smooth stress distribution during vibration. Heat treatment analysis reveals the impact of annealing, which releases residual stress and improves stability. Vibration stability analysis of tungsten alloy rivet mandrels demonstrates dynamic response material assessment, supports tool vibration adaptation through load simulation, and contributes to the analytical foundation within the assembly environment. The systematic nature of the analysis makes the mandrel 's performance under oscillating conditions predictable, providing a feedback path for process improvement.

7.2.4 Special Requirements for Tungsten Alloy Rivet Tops in Low-Temperature Riveting Process

Special Requirements for tungsten alloy rivet mandrels in cryogenic riveting processes mainly focus on low-temperature toughness and dimensional stability. These requirements stem from the increased brittleness and shrinkage behavior of materials at low temperatures, ensuring reliable support and coordinated deformation of the mandrel during cold assembly. Low-temperature environments are common in cryogenic warehouses or cold chain equipment riveting, where the mandrel needs to resist the risk of brittle fracture. The dual-phase structure of tungsten alloys is reflected in these requirements: the tungsten phase exhibits less slip at low temperatures, while the binder phase extends and coordinates to improve toughness.

Requirements include a low low-temperature brittle transition temperature, ensuring the mandrel absorbs more energy during sub-zero temperature impacts to prevent sudden fracture. Special compositional requirements exist: nickel-copper systems exhibit good low-temperature toughness and strong cold impact resistance in the mandrel ; nickel-iron systems require additives to regulate the transition temperature. Heat treatment requires low-temperature aging to strengthen grain boundaries through precipitation, resulting in a low tendency for mandrel brittleness .

Dimensional stability requires minimal low-temperature shrinkage, a low coefficient of thermal expansion for the mandrel , and consistent fit with the rivet during support. A smooth surface is required to minimize friction when supporting rivet deformation at low temperatures and to prevent the effects of condensation and freezing. Chemical stability requires resistance to low-temperature oxygen, with no frost corrosion on the mandrel surface . These specific requirements for tungsten alloy rivet mandrels in low-temperature riveting processes reflect the material requirements for cold environment adaptability. Their toughness and stability support the tool's low-temperature performance, contributing to the fundamental requirements in cold assembly.

7.3 Application of Tungsten Alloy Rivet Top Rods in Automobile and Rail Transportation Manufacturing

Tungsten alloy rivet mandrels are primarily used as riveting support tools in automotive and rail transportation manufacturing. This application is evident in structural connections of car bodies, cabins, or chassis, helping to achieve high-strength riveting of lightweight materials. Automotive manufacturing emphasizes lightweight and high strength, while rail transportation prioritizes durability and vibration resistance. The high density and hardness of the mandrel provide stable reaction force, and the dual-phase structure of the tungsten alloy coordinates impact deformation. Applications cover riveting of aluminum alloys, steel plates, and composite materials, with the mandrel end face design matching the rivet type.

In automotive body assembly lines, top rods support self-piercing or blind riveting, ensuring consistent connection strength and long impact resistance. In rail transit vehicle manufacturing, top rods are used for riveting stainless steel or aluminum alloys, providing stable support in vibration environments. They exhibit good chemical stability, resisting workshop coolant and oil contaminants. They also demonstrate strong automation compatibility, with standardized interfaces allowing for smooth robot operation. The application of tungsten alloy rivet top rods in automotive and rail transit manufacturing demonstrates the engineering adaptability of tool materials, improving connection efficiency through support optimization and providing reliable performance in transportation structure assembly.

7.3.1 Adaptability of tungsten alloy rivet top bars in lightweight vehicle body riveting

In lightweight vehicle body riveting, the adaptability of tungsten alloy rivet top bars is mainly reflected in their ability to support aluminum alloy or high-strength steel rivets. This adaptability helps to achieve weight reduction while maintaining connection strength. Lightweight vehicle bodies often use aluminum sheets or hybrid materials, and riveting requires controlling deformation to avoid damage. The high hardness of the top bar resists the pressing of aluminum rivets, the smooth working surface reduces scratches, and the support is even and the rivet forming is symmetrical.

The adaptive mechanism is manifested in mechanical equilibrium; the tungsten alloy has a moderate density, concentrating reaction forces without increasing equipment load; the inertia of the top rod assists energy transfer; and the rivet tail expands smoothly. The adhesive phase is coordinated with minimal deformation, resulting in good vibration absorption during top rod impact and no additional stress on the body panels. Chemical stability adapts to assembly line coolant, and the top rod surface is free from corrosion affecting the connection. The end face design is flat or shallowly concave , accommodating self-piercing or solid rivets, ensuring high precision in top rod fitting .

Adaptability of top rods in lightweight riveting also includes automation compatibility, good rod roundness for stable robot clamping, and long service life during high-frequency operations. After heat treatment, the microstructure is uniform, the top rod has strong fatigue resistance, and requires fewer replacements on continuous production lines. Surface polishing adaptability is good, friction is low, rivet slippage is minimal, and forming quality is stable. The adaptability of tungsten alloy rivet top rods in lightweight car body riveting demonstrates the tool's coordination with weight-reducing materials, supporting a lightweight yet strong bond in car body connections through optimized support , contributing practical value to automobile manufacturing.

7.3.2 Investigation on the Wear Behavior of Tungsten Alloy Rivet Top Rods under High-Frequency Riveting Process

Investigation on the Wear Behavior of tungsten alloy rivet mandrels in high-frequency riveting primarily focuses on the evolution of surface damage under continuous rapid impact. This investigation helps to understand the durability performance of mandrels in automated, high-paced assembly lines. High-frequency riveting involves impact frequencies of tens or even higher per minute, with the mandrel's working surface repeatedly contacting the rivet tail. Friction and indentation accumulation lead to wear. The dual-phase structure of tungsten alloys is evident in the study: the high hardness of tungsten particles resists indentation, while the bonding phase coordinates micro-deformation to absorb energy, resulting in a uniform and fine wear morphology for the mandrel .

The investigation was conducted through simulation experiments or production line monitoring. A high-frequency riveting gun was fixed with a top rod , and surface roughness and volume loss were recorded after the number of cycles. Chemically, the binder phase preferentially wore down, forming shallow pits. After the tungsten particles were exposed, the abrasive action slowed down. The wear behavior was phased: initially, the polished surface was smooth and the wear was slow; in the middle stage, micro-pits accumulated, increasing roughness; and in the later stage, the wear rate stabilized. Thermal effects accompanied by high frequency: frictional heat generation accelerated oxidative wear, while the heat conduction of the top rod aided in heat dissipation, mitigating the wear.

The high-frequency process investigation also evaluated the influence of end-face shape. Concave surfaces exhibit a wider wear distribution due to deformation, while planar surfaces show temporary but uniform wear. Surface treatment effectiveness was assessed; plating or hardening resulted in low initial wear, but later, with the substrate exposed, the wear behavior reverted. Compositional differences were considered: tungsten-copper systems showed good thermal conductivity and low thermal impact on wear, while nickel-iron systems exhibited high hardness and strong abrasive resistance. The high-frequency riveting process provided a continuous load damage perspective for examining the wear behavior of tungsten alloy rivet mandrels . Behavioral analysis supported tool life assessment and contributed durability references in automated assembly.

7.3.3 Compatibility of Tungsten Alloy Rivet Tops in Multi-Material Connections

Tungsten alloy rivet mandrels in multi-material connections is mainly reflected in their adaptability to different rivet materials and sheet metal. This compatibility is evident in hybrid structure riveting such as aluminum-steel or aluminum composite material connections, ensuring stable and undamaged support from the mandrel . This compatibility stems from the balance between the mandrel's hardness and surface finish; the high hardness of tungsten alloy resists the indentation of steel rivets, while the smooth surface reduces scratches on aluminum or composite plates. Chemically, the mandrel is highly inert, with no galvanic coupling or reaction affecting the interface between dissimilar materials.

The compatibility mechanism is reflected in deformation coordination: when the working surface of the mandrel is in contact with a soft rivet, the reaction force is mitigated, preventing the composite layer from being crushed; when using a hard rivet, it exhibits high rigidity, resulting in concentrated deformation and good forming. The end face design is compatible with various applications, with shallow concave areas accommodating aluminum rivet expansion and flat surfaces providing temporary steel rivet support. Thermal conduction compatibility ensures rapid heat dissipation, and the mandrel maintains a stable temperature rise despite varying heat generation from different materials . Surface treatment compatibility ensures flexible coatings, and the mandrel's contact with the composite resin is pollution-free.

Compatibility of mandrels in multi-material joining also assesses vibration response. Hybrid structures exhibit complex vibrations, and mandrels with coordinated damping minimize damage. Chemical stability ensures compatibility with cleaning media, preventing corrosion products from contaminating the joint area. Compositional compatibility and adjustment, with tungsten-copper conductivity assisting in electrostatic discharge, make them suitable for carbon fiber composites. The compatibility of tungsten alloy rivet mandrels in multi-material joining demonstrates the tool's adaptability to dissimilar materials. Through coordinated hardness and surface finish, they support reliable riveting of hybrid structures, contributing a foundation for compatibility in lightweight manufacturing.

7.4 Application of Tungsten Alloy Rivet Rods in Precision Mechanical Assembly

Tungsten alloy rivet mandrels are primarily used in precision mechanical assembly as support tools for miniature or high-precision riveting. This application is evident in structural connections in fields such as instrumentation, medical devices, and optical equipment, helping to reliably secure small components. Precision mechanical assembly emphasizes damage-free connections, precise deformation, and dimensional consistency. The high hardness and smooth surface of the mandrel provide stable reaction force, while the dual-phase structure of the tungsten alloy mitigates micro-impact, preventing scratches or stress concentrations on components.

applications , the mandrel has a small diameter and a mirror-polished working surface, ensuring uniform pressure distribution when supporting micro-rivets. It exhibits strong chemical stability, making it resistant to cleanroom environments and preventing particle shedding that could contaminate precision parts. Compatible with both manual and electric precision riveting guns , the miniaturized mandrel interface allows for flexible operation. The application of tungsten alloy rivet mandrels in precision mechanical assembly demonstrates the precise adaptation of tool materials, improving the quality of small connections through optimized support and providing reliable performance in high-precision manufacturing.

7.4.1 Requirements for the dimensional accuracy of tungsten alloy rivet top bars in micro-riveting

Requirements for tungsten alloy rivet mandrels in micro-riveting mainly focus on the mandrel diameter, working surface flatness, and coaxiality. These requirements ensure accurate positioning and uniform pressure of the mandrel when supporting small rivets, preventing deformation or displacement of precision components. The mandrel diameter must match the tail of the micro-rivet with minimal deviation to ensure a tight fit. Chemically, a smooth surface reduces friction, and high dimensional accuracy results in symmetrical rivet formation. Flatness requires a smooth working surface without localized high points during support, and no indentations on precision instrument components.

The mechanism must be reflected in tolerance control, with high coaxiality of the rod body to avoid eccentric loads, and uniform stress distribution during impact . Consistent length accuracy is required, the ejector pin must be stably positioned in the equipment, and its position must remain unchanged during repeated riveting. High dimensional stability is required after heat treatment, with minimal thermal shrinkage of the ejector pin , and accuracy must be maintained despite fluctuations in the assembly environment temperature.

The dimensional accuracy requirements for mandrels in micro-riveting also include end-face shape control, precise shallow concave or flat-head forming, and the ability to accommodate micro-riveting expansion without overflow. Low surface roughness requires auxiliary precision, and low mandrel friction ensures smooth deformation. Chemical purity management minimizes impurities and ensures consistent dimensional processing. The dimensional accuracy requirements for tungsten alloy rivet mandrels in micro-riveting reflect the geometric constraints of precision tools. Precision optimization supports the reliable realization of small connections and contributes to the dimensional foundation of instrument assembly.

7.4.2 The role of surface modification in the precision application of tungsten alloy rivet mandrels

Surface modification in precision applications of tungsten alloy rivet mandrels is primarily achieved through plating, passivation, or microtexturing. This process enhances the surface stability and functional adaptability of the mandrel in high-precision riveting. Precision applications emphasize non-destructive contact and long-term smoothness. Surface modification forms a protective layer that chemically blocks environmental corrosion, slows wear on the mandrel's working surface , and facilitates smooth rivet formation. Platings such as nickel-phosphorus or chromium-nitrogen increase hardness, helping the mandrel resist micro-rivet pressing, and low surface roughness reduces scratches.

The modification effect is reflected in friction control, resulting in a low surface friction coefficient, less slippage between the ejector pin and rivet, and uniform deformation of precision parts. Whether the passivation layer is self-generated or artificial, the ejector pin oxidizes slowly in a humid cleanroom, maintaining a smooth finish. Micro-texture modification scatters light, reducing glare during ejector pin operation and improving visual comfort. Improved chemical stability after modification makes the ejector pin resistant to cleaning agents, ensuring no residual contamination during precision assembly.

Surface modification also affects thermal management; the coating's thermal conductivity aids heat dissipation, and the ejector pin's temperature rise is slowed, protecting heat-sensitive components. Controlling the modification thickness ensures the ejector pin's dimensional accuracy remains unchanged. In precision applications, modification optimizes contact, and the ejector pin's containment of micro-rivets prevents overflow . The role of surface modification in the precision application of tungsten alloy rivet ejector pins demonstrates the refined contribution of surface engineering, supporting the tool's surface performance through a protective layer and providing a stable foundation for high-precision assembly.

7.4.3 Cleanroom Environment Requirements for the Purity of Tungsten Alloy Rivet Top Rod Material

The purity requirements for tungsten alloy rivet top rods in cleanroom environments stem primarily from the need to prevent particle shedding and chemical contamination. This requirement is evident in the riveting of precision instruments or medical devices, ensuring that the top rods do not introduce impurities that could affect assembly cleanliness. For high-cleanroom environments, the top rod materials must have low dust emission. Tungsten alloy powder metallurgy processes purify impurities, and chemically, low oxygen and carbon content reduces oxide shedding, resulting in a top rod surface free of loose particles.

The demand mechanism is reflected in surface cleanliness; after polishing, the ejector pin leaves minimal residue, reducing the risk of detachment during operation. It boasts high component purity, with no volatile elements in the binder phase , ensuring stability under high temperatures or vacuum. Heat treatment requires vacuum annealing to completely remove internal gaseous impurities, preventing release during use. Chemical cleaning requires mild solvents, making it easy to remove residues from the ejector pin surface .

Cleanroom Environment Requirements for top rods in cleanroom environments also include non-magnetic variants; the tungsten-copper system avoids magnetic dust adsorption. The coating requires inert materials to prevent peeling of the top rod's protective layer . Purity requirements are assessed through dust emission testing; the top rod exhibits minimal vibration or friction particles to meet the required standards. The purity requirements for tungsten alloy rivet top rods in cleanroom environments reflect the material constraints of high-cleanliness assembly. Purification supports the tool's contamination-free performance and contributes to a clean foundation in precision environments.

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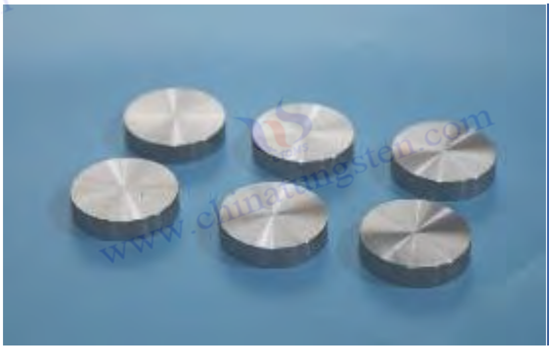
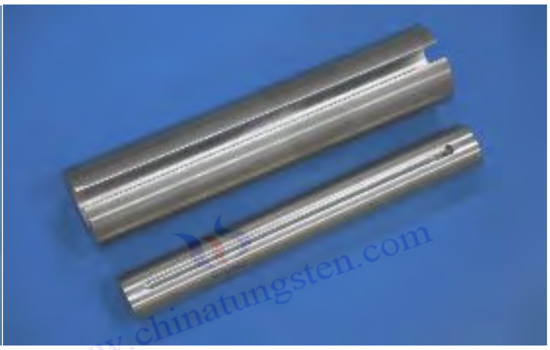

Chapter 8 Common Problems with Tungsten Alloy Rivet Tops

8.1 Defect Formation in the Manufacturing Process of Tungsten Alloy Rivet Tops

Tungsten alloy rivet mandrels during manufacturing primarily stem from process fluctuations in various stages of powder metallurgy. These defects affect the uniformity of the mandrel's microstructure and the consistency of its mechanical properties. Types of defects include residual porosity, particle segregation, cracks, and inclusions, originating from raw material mixing to post-sintering treatment. Inhomogeneous mixing leads to localized enrichment of the binder phase, stress gradient compression induces delamination, and deviations in the sintering temperature window result in insufficient rearrangement or excessive flow.

The defect formation mechanism is manifested in the interphase interaction . When tungsten particles are not sufficiently wetted with the binder phase, there are many interfacial pores, and chemically, impurities react with oxygen and carbon to generate gas-closed pores. Improper release of thermal stress leads to microcracks, and the rod-shaped aspect ratio of the top rod amplifies the end defects. Defect control is achieved through parameter optimization and auxiliary processes, with ball milling improving uniformity and hot isostatic pressing closing pores.

Analysis of defects during the fabrication process guides quality improvement; microscopic observation and density testing reveal problems; and mandrel performance provides feedback for process adjustments. Defect formation in the fabrication of tungsten alloy rivet mandrels demonstrates the challenges of powder metallurgy. Process control supports reliable tool production and lays a quality foundation for riveting applications.

8.1.1 Influence of uneven sintering on the microstructure of tungsten alloy rivet mandrels

Sintering inhomogeneity on the microstructure of tungsten alloy rivet mandrels are mainly manifested in density gradient and phase distribution deviation. This effect is more pronounced in the long dimensions of the mandrel billet , affecting the overall strength and impact resistance consistency. Sintering inhomogeneity originates from temperature field or atmosphere fluctuations, the timing of liquid phase appearance between the billet center and edge, and the degree of rearrangement. In areas with insufficient liquid phase flow, tungsten particles have less contact and more residual pores.

The influencing mechanism is reflected in particle rearrangement. In the non-uniform region, tungsten particles exhibit poor spheroidization, stress concentration at sharp corners, and high local brittleness of the mandrel . The binder phase segregation region shows good toughness but low strength, resulting in fluctuations in the axial properties of the mandrel . Inhomogeneous interfacial bonding and varying thicknesses in the chemical diffusion zone increase the risk of mandrel separation upon impact. After hot working, non-uniformity is amplified, fiber texture becomes discontinuous, and the bending strength of the mandrel decreases.

The effects of sintering inhomogeneity also include differences in grain size, resulting in coarsening in the high-temperature zone and finer grains in the low-temperature zone, leading to more fatigue crack initiation points in the mandrel . Uneven impurity volatilization exacerbates the impact, causing localized embrittlement phase formation in the mandrel. Analysis of density distribution through cross-sectional metallographic observation guides multi-zone furnace temperature control. The impact of sintering inhomogeneity on the microstructure of tungsten alloy rivet mandrels demonstrates the challenge of achieving uniformity in the high-temperature process. Field optimization supported reliable microstructure formation, contributing a structural basis to tool durability.

8.1.2 Sources and control of impurity contamination in tungsten alloy rivet mandrels

Contamination in tungsten alloy rivet mandrels primarily originates from raw material powder, process atmosphere, and equipment contact. This contamination affects the purity and microstructure of the mandrel , potentially inducing brittleness or corrosion defects. Raw material sources include residual oxygen and carbon, incomplete reduction of tungsten powder leading to oxide formation, and adsorption of gases by the binder phase powder. Process atmosphere sources include high hydrogen dew point and water vapor reaction, chemically generating volatile closed-cell or embrittled phases.

Sources of contamination also include equipment wear, and particles from molds or boats falling into the billet. Residual ball milling media and localized hard spots on the ejector rod also contribute. Control measures include raw material purification, multi-stage reduction of tungsten powder to reduce oxygen , and chemical cleaning of alloy powder to remove surface impurities. Atmosphere control involves hydrogen drying and filtration, with a low dew point to prevent re-oxidation. Vacuum sintering variants reduce gas contamination, resulting in high ejector rod cleanliness .

Control measures also include equipment management, inert materials for mold linings, and high-purity boats to prevent shedding. Mixing with media-free materials or ceramic balls minimizes introduction of contaminants. Chemical cleaning after heat treatment removes volatile residues. The sources and control of impurities in tungsten alloy rivet ejector pins embody the materials engineering principles of purity management. Multi-source control supports the cleanliness of the material, laying the foundation for ejector pin performance . The systematic nature of these controls ensures batch-to-batch consistency of ejector pin impurities, providing purity assurance for durability.

8.1.3 Mechanism of crack initiation during the pressing stage of tungsten alloy rivet mandrel

Mechanism of crack initiation in the pressing stage of tungsten alloy rivet mandrels mainly involves stress concentration and deformation incoordination between powder particles. This mechanism is manifested during green forming and affects subsequent sintering and the integrity of the finished product. During the pressing process, powder fills the mold, and particle rearrangement and plastic deformation occur during pressure transmission. Tungsten powder has high hardness and high deformation resistance. Chemically, interparticle friction generates local shear stress, and the stress gradient at the edges or corners is steep, leading to the initiation of microcracks.

Mechanism is divided into stages. In the initial stage, the elastic compressive stress is uniform. In the middle stage, the sliding friction of particles increases , and cracks initiate at weak interface joints . In the later compaction stage, the springback effect occurs, and the stress release at the large aspect ratio end of the mandrel is uneven, leading to surface crack propagation. Insufficient lubrication exacerbates the mechanism, resulting in high tensile stress and numerous cracks due to particle sticking to the mold . Uneven powder particle size affects the mechanism, with poor filling of voids due to the mixture of coarse and fine particles, and numerous stress concentration points. The crack initiation mechanism is also affected by the pressing method. Cold isostatic pressing with uniform liquid pressure results in fewer cracks, while molding with a large unidirectional pressure gradient easily leads to cracks. The mechanism changes with increasing temperature; warm pressing softens the binder, resulting in better coordination and fewer cracks. Chemical purity management reduces impurities and brittle particles, thus reducing the initiation source. The crack initiation mechanism in the pressing stage of the tungsten alloy rivet mandrel reflects the material response to forming stress. Pressure control supports the integrity of the green blank and contributes to the understanding of the mechanism in process optimization.

8.1.4 Analysis of the causes of porosity residue in tungsten alloy rivet top bars

The analysis of the causes of porosity residues in tungsten alloy rivet mandrels mainly focuses on gas confinement and insufficient particle filling during the pressing and sintering stages. This leads to uneven mandrel density and localized strength reduction. During the pressing stage, air or adsorbed gas between powder particles is compressed and sealed, and chemically, residual water vapor or hydrogen forms closed pores. Porosity is higher when the green body density is low. Wide particle size distribution is a clear cause; coarse particles have large gaps and are difficult to fill, while fine powder bridges the confined gas. The causes also include insufficient sintering rearrangement, limited particle movement when the liquid phase is small, slow pore shrinkage, and more residual pores. A low temperature window is a prominent cause, indicating incomplete melting and poor wetting of the binder phase. A high atmosphere dew point exacerbates the cause, as water vapor reacts to form volatiles, leaving residual pores. The long, rod -shaped top rod amplifies the cause, with slow liquid phase flow and concentrated pores at its ends.

Analysis of the causes of residual porosity assesses the impact of processes; hot isostatic pressing reduces closed pores, and mechanical compression during repressurization further reduces residual porosity. Chemical purity management minimizes impurity volatilization and reduces porosity sources. Origin analysis guides optimization; pre-pressurization and venting reduce gas emissions, and extended insulation promotes shrinkage. The analysis of the causes of residual porosity in tungsten alloy rivet mandrels provides a material perspective on volumetric defects, supports improvements in densification processes through tracing the causes, and contributes an analytical basis to mandrel quality .

8.2 Failure Modes of Tungsten Alloy Rivet Tops in Use

Tungsten alloy rivet mandrels during use mainly include mechanical overload fracture, wear accumulation, and fatigue damage. These modes manifest in high-frequency or heavy-load riveting environments, affecting the mandrel's support stability and service life. The failure modes originate from the repeated interaction between the mandrel and the rivet tail, resulting from the combined effects of mechanical stress, frictional heat, and environmental factors. Overload mode manifests as sudden fracture, wear mode involves surface material removal, and fatigue mode involves the propagation of micro-damage.

mode analysis was achieved through fracture surface observation and wear measurement. The two-phase structure of the mandrel influences the failure path; tungsten particles resist damage, while the binder phase coordinates deformation but is prone to fatigue. Chemical surface oxidation accelerates wear, and media corrosion exacerbates failure. The study of failure modes guides mandrel selection and maintenance; high-strength mandrels resist overload, and wear-resistant types have long service life. The failure modes of tungsten alloy rivet mandrels in use reflect the material behavior of tool load response. Mode analysis supports durability optimization and provides a reference for failure prevention in riveting practice.

8.2.1 Mechanism of fracture of tungsten alloy rivet mandrel due to mechanical overload

Tungsten alloy rivet mandrels due to mechanical overload mainly involves damage evolution under instantaneous high stress. This mechanism manifests during accidental heavy impacts or equipment failures, where the mandrel, as a support component, bears a load exceeding its design capacity. The mechanism begins with stress concentration, where local strain is large at the working surface or corner of the mandrel. Chemically, the binder phase undergoes plastic deformation first, and the tungsten particle skeleton bears the main load. Overload increases dislocation accumulation, raises interfacial stress, and microcracks initiate in the binder phase or between particles.

The fracture mechanism unfolds in stages: initially, energy is absorbed through ductile coordination; in the middle stage , cracks propagate along weak interfaces , with the two-phase structure of the top bar slowing propagation through bending; in the later stage, rapid fracture occurs, with the fracture surface showing a mixture of dimples and cleavage , the binder phase exhibiting deep dimples, and the tungsten phase showing flat cleavage surfaces. Thermal effects, accompanied by overload, cause frictional heating, softening the binder phase and accelerating the fracture. Due to differences in composition, the nickel-copper system exhibits ductile coordination and slower fracture, while nickel-iron exhibits higher strength but a slightly stronger tendency towards brittle fracture.

The mechanical overload fracture mechanism is also influenced by surface condition; smooth rivet mandrels exhibit uniform stress and late crack initiation, while scratches lead to early crack initiation. Optimized heat treatment mechanisms result in low residual stress after annealing and good overload tolerance. Controlled chemical purity minimizes impurities and reduces brittle initiation points. The mechanical overload-induced fracture mechanism of tungsten alloy rivet mandrels reflects high-load response material failure. Path analysis supports tool load assessment and contributes to mechanistic understanding in riveting safety.

8.2.2 Cumulative Effects of Wear and Fatigue in Tungsten Alloy Rivet Tops

The cumulative effect of wear and fatigue in tungsten alloy rivet mandrels is mainly achieved through the synergistic effect of repeated contact and cyclic stress. This effect gradually manifests in high-frequency riveting, affecting the surface finish and overall durability of the mandrel . Wear accumulation leads to surface material removal, while fatigue accumulation leads to the propagation of micro-damage, and the two interact to accelerate failure. In the early stages of wear, friction scratches the working surface, chemically softening and transferring the binder phase, and exposing tungsten particles to abrasive action. In the early stages of fatigue, dislocations accumulate, and microcracks initiate during cyclic oscillation. In the two -phase structure of the mandrel , the binder phase fatigues first.

The cumulative effect mechanism manifests itself in the interaction : worn, rough surfaces have more stress concentration points, leading to rapid fatigue crack initiation; fatigue microcracks expose new surfaces, accelerating wear. Cumulative thermal effects include frictional heat generation softening the surface and increasing wear, while the rise in ejector pin temperature promotes fatigue. Accumulated environmental factors, such as synergistic corrosion from humid media, also contribute to rapid ejector pin damage .

Wear and fatigue accumulation are also affected by usage frequency, with a significant effect at high frequencies, resulting in deep pits and numerous cracks on the rivet surface . Surface treatment slows down the accumulation, and coatings provide low initial wear and good fatigue protection. Compositional differences also contribute to wear accumulation; tungsten-copper exhibits slower heat dissipation and wear accumulation, while nickel-iron, with its high hardness, results in slower wear. The cumulative effect of wear and fatigue in tungsten alloy rivet rivets reflects the synergistic damage of long-term loads. Effect analysis supports tool life management and provides a cumulative reference for riveting maintenance.

8.2.3 The reduction in service life of tungsten alloy rivet mandrels due to corrosive environments

The reduction in service life of tungsten alloy rivet mandrels due to corrosive environments is primarily achieved through the dissolution of surface materials and the accumulation of structural damage. This reduction is particularly noticeable in humid or chemically treated workshops, where the surface finish of the mandrel decreases, affecting support stability. Corrosive environments include moisture, salt spray, or cleaning agents. Chemically, the binder phase elements are highly reactive and readily react with the medium to form dissolved or porous layers, gradually leading to pitting on the mandrel surface . The reduction mechanism is also observed in micro-cells, where the binder phase undergoes anodic dissolution, while the tungsten phase, though relatively inert, exhibits corrosion propagation at the interface, resulting in localized thinning of the mandrel .

The corrosion reduction process is phased. In the initial stage, the surface passivation layer is destroyed, and the corrosion rate is slow. In the middle stage, pitting or uniform corrosion occurs, increasing the roughness of the ejector pin and friction. In the later stage, damage accumulates, resulting in uneven ejector pin reaction force and poor rivet formation. High humidity accelerates corrosion, as moisture promotes ion migration. Acidic media result in significant corrosion, with rapid dissolution of the binder phase. Alkaline media are relatively mild, but long-term exposure leads to a porous layer. Thermal effects accompany corrosion; as temperature increases, the reaction rate increases, shortening the ejector pin's lifespan .

Corrosive environments also reduce the lifespan of internal components, leading to stress concentration in pitting and earlier fatigue crack initiation. Surface treatment reduces the lifespan more gradually, while coatings isolate the medium and improve the durability of the rivet . Compositional differences contribute to the reduction; the tungsten-copper system improves conductivity but the copper phase is more prone to corrosion , while nickel-iron provides good passivation. The reduction in tungsten alloy rivet lifespan due to corrosive environments reflects material consumption caused by medium interaction, supports tool life assessment through damage accumulation, and provides an environmental reference for maintenance practices.

8.2.4 Cracking of tungsten alloy rivet mandrels caused by thermal shock

Cracking of tungsten alloy rivet mandrels caused by thermal shock mainly stems from the concentration of thermal stress under rapid temperature changes . This phenomenon is manifested in hot riveting or alternating temperature conditions, where the propagation of microcracks on or inside the mandrel affects durability. During the thermal shock process, the rapid heating and cooling, combined with the difference in thermal expansion, generates tensile and compressive stresses. The incomplete matching of the coefficients of the binder phase and the tungsten phase leads to high interfacial stress and the initiation of cracking. Cracking occurs in stages: initially, thermal stress is elastic, and the mandrel remains undamaged ; in the middle stage, repeated impacts accumulate residual stress, and microcracks initiate on the surface or in the binder region; in the later stage, cracks propagate, leading to mandrel fracture or spalling of the working surface. Frictional heating and strong local impact increase the tendency to crack. Microstructure also plays a role: coarse grains are more prone to cracking, while fine grains buffer stress more effectively.

Thermal shock cracking is also influenced by the medium; moisture condensation exacerbates stress, and wet-heat cycling of the mandrel accelerates cracking. Surface condition phenomena are also relevant; a loose oxide layer leads to more crack initiation points. Compositional differences also play a role; copper phases exhibit rapid thermal conductivity and dissipation, resulting in slower cracking, while iron phases show stable expansion regulation. The thermal shock-induced cracking of tungsten alloy rivet mandrels demonstrates temperature-responsive damage behavior. Stress analysis supports the thermal adaptation of the tool and contributes to understanding the phenomenon in variable-temperature operations.

8.2.5 Influence of Surface Peeling on the Function of Tungsten Alloy Rivet Setters

Influence of surface spalling on the function of tungsten alloy rivet mandrels is mainly due to material layer separation, leading to uneven contact surfaces and unstable support. This effect manifests after high-frequency friction or fatigue accumulation, and damage to the mandrel's working surface reduces the rivet forming quality. Spalling originates from surface fatigue or adhesive wear, chemically loosened oxide or transfer layers, and peeling under cyclic loading. Initially, the surface is rough, making it difficult for the rivet to slide due to frictional rise of the mandrel ; in the middle stage, spalling pits form, and uneven reaction forces cause rivet deflection.

The influencing mechanism is reflected in damage accumulation, with microcracks extending to the surface layer and causing detachment, leading to reduced surface finish and difficulty in cleaning. Thermal effects influence detachment; temperature rise softens the binder phase, resulting in rapid detachment. The medium affects the corrosion layer, making it loose and easier to detach. Composition influences detachment; copper phases tend to adhere and transfer more readily , leading to stronger detachment, while nickel phases are more stable and detach more slowly.

Influence of surface spalling on the function of the mandrel extends to accuracy; after spalling, dimensional changes lead to inaccurate support. Maintenance is significantly affected, as spalled mandrels require polishing or replacement. Surface treatment affects spalling, delaying the hardening process and improving mandrel durability . The impact of surface spalling on the function of tungsten alloy rivet mandrels reflects the performance degradation caused by surface damage. Spalling analysis supports surface management of tools and contributes to the reference of impact on riveting durability.

8.3 Performance Optimization and Fault Diagnosis of Tungsten Alloy Rivet Tops

Tungsten alloy rivet mandrels are primarily achieved through composition adjustment, process improvement, and non-destructive testing. This optimization and diagnosis help mitigate defects in use and improve tool durability. Optimization focuses on composition and heat treatment, while diagnosis emphasizes defect identification and failure analysis. Composition adjustment alleviates brittleness or wear, process optimization promotes uniform microstructure, and non-destructive testing detects internal problems early. The combination of optimization and diagnosis forms a closed loop, with diagnostic results feeding back into optimization, leading to continuous improvement in mandrel performance . Chemically, elemental ratios and impurity control are key to optimization, while physical testing and microscopic observation are the foundation for diagnosis.

8.3.1 Mitigation of Common Problems in Tungsten Alloy Rivet Tops through Composition Adjustment

Alleviate common problems in tungsten alloy rivet mandrels primarily through optimizing the tungsten-to-binder ratio or microalloying. These adjustments provide a balanced material solution addressing defects such as brittle fracture, wear, and fatigue. Increasing the tungsten content alleviates wear, increases the hardness of the mandrel's working surface , strengthens rivet indentation resistance, and reduces surface indentation. Improving the binder ratio mitigates brittleness, improves the mandrel's impact toughness , and lowers the tendency for sudden fracture.

The adjustment mechanism is reflected in the two-phase synergy: the nickel-copper system alleviates fatigue, extends and coordinates cyclic stress, and reduces damage during high-frequency use of the mandrel . Rare earth micro-doping alleviates oxidation and grain boundary weakening, ensuring surface stability of the mandrel in high-temperature or humid environments. Iron addition adjusts magnetism and strengthens the binder phase, resulting in stable fatigue resistance of the mandrel . Chemically, impurity control adjusts purity, reducing oxygen and carbon levels and minimizing embrittlement sources, leading to fewer overall defects in the mandrel .

The application of composition adjustment is reflected in the production formulation, with high tungsten content in high-strength mandrels and moderate binder phase in durable mandrels . Adjustments to heat treatment, including solution treatment and aging precipitation strengthening, significantly alleviate common mandrel problems. Cost considerations are also taken into account, with economical elements replacing precious metals, making mandrels more versatile . Composition adjustment provides formulation-level material optimization for alleviating common problems in tungsten alloy rivet mandrels , supports tool defect control through proportional coordination, and contributes to riveting durability.

8.3.2 Application of Non-Destructive Testing Methods in Defect Identification of Tungsten Alloy Rivet Mandrels

Application of non-destructive testing methods in defect identification of tungsten alloy rivet mandrels mainly employs techniques such as ultrasound, X-ray, and magnetic particle testing. This approach reveals internal pores, cracks, or inclusions without damaging the mandrel , aiding in quality control and fault prevention. Ultrasonic testing utilizes sound wave reflection to locate defects. Longitudinal wave scanning of the mandrel sample reveals strong signals at interface discontinuities and significant chemical scattering by pore gases. X-ray transmission imaging displays density differences, revealing low-density areas within the mandrel , making it suitable for batch inspection.

The application process involves sample cleaning and positioning, with ultrasonic probe coupling agent assisting signal transmission, and multi-angle scanning of the push rod's axial end face for comprehensive coverage. Magnetic particle testing detects surface cracks; the push rod's magnetic system is applicable, and powder adsorbs defect lines. This combination of non-destructive testing methods utilizes deep ultrasonic testing, overall X-ray distribution, and surface-sensitive magnetic particle testing. The test results quantify defect size and location; severely defective push rods are removed or repaired.

The application of non-destructive testing (NDT) is evident in production acceptance. After sintering, ultrasonic testing of the mandrel is used to check for porosity, and X-ray verification of cracks is performed after machining. High chemical purity reduces false signals and ensures accurate detection. Post-heat treatment detection of microstructure changes allows for early identification of stress cracks in the mandrel . The application of NDT methods in defect identification of tungsten alloy rivet mandrels provides non-destructive material assessment, supports tool quality assurance through multi-technology collaboration, and contributes a foundation for reliable riveting.

8.3.3 Improvement of the durability of tungsten alloy rivet mandrels by heat treatment process

Tungsten alloy rivet mandrels through heat treatment is mainly achieved by adjusting the microstructure and releasing internal stress. This improvement slows down the accumulation of damage in repeated impact and friction environments, resulting in more stable overall performance. Heat treatment includes steps such as annealing, solution treatment, and aging. Annealing involves heating and holding at a temperature under vacuum or a protective atmosphere, where chemical diffusion drives dislocation migration and annihilation, reducing residual stress in the mandrel and preventing the initiation of microcracks during use. During the holding period, grain boundary migration refines the grains, resulting in a coordinated improvement in the strength and toughness of the mandrel .

The improvement mechanism is reflected in the two-phase interaction : the spheroidization of tungsten particles reduces surface energy, the binder phase uniformly coats the interface with strong bonding, and the fatigue resistance of the mandrel is enhanced. Solution treatment dissolves elements at high temperatures, and rapid cooling locks in the supersaturated state, increasing the mandrel's hardness and improving wear resistance. Aging precipitation produces fine phases that pin dislocations, resulting in strong resistance to deformation under cyclic loading . Heat treatment improvements also include surface stability, uniform oxide layer control, and reduced spalling during mandrel friction .

The application of heat treatment technology is evident in post-production processing. Annealing of sintered billets releases compressive stress, while post-processing aging strengthens the surface. Temperature windows are adjusted according to composition; higher temperatures in the tungsten-nickel-iron system promote recovery, while tungsten-nickel-copper systems offer faster thermal conductivity and more uniform heat dissipation. Chemical purity management minimizes impurities, resulting in consistent improvement. Heat treatment provides microstructural optimization for improving the durability of tungsten alloy rivet mandrels , supporting tool life performance through stress release and strengthening, thus contributing significant technological value in riveting practice.

8.3.4 Improvement of wear resistance of tungsten alloy rivet mandrels by surface strengthening technology

Surface strengthening technology enhances the wear resistance of tungsten alloy rivet mandrels primarily through methods such as ion implantation, plating, or nitriding. This improvement increases the working surface of the mandrel's resistance to rivet friction and indentation, reducing surface pitting and material loss. Ion implantation bombards the surface with high-energy particles, chemically forming a gradient hardened layer, increasing the surface hardness and scratch resistance of the mandrel . Plating, such as nickel-phosphorus or chromium-nitrogen deposition , results in a dense coating, leading to a low coefficient of friction and slowed wear.

The enhancement mechanism is reflected in the surface modification: nitriding allows nitrogen atoms to diffuse and form nitrides, resulting in lower brittleness and resistance to spalling on the mandrel surface . The reinforcing layer bonds well with the matrix, preventing detachment during impact and maintaining the mandrel's shape . Improved chemical stability is achieved, with the reinforcing layer blocking media erosion and minimizing environmental damage to the mandrel . Heat treatment combined with strengthening and aging precipitation synergistically hardens the surface.

The application of surface strengthening technology is evident after the finishing of the mandrel . Ion implantation results in no dimensional changes and allows for thin coating control. Differences in composition make it easier to achieve conductive coatings in tungsten-copper systems , while tungsten-nickel-iron systems offer high hardness and good implantation performance. Improved wear testing results in less volume loss and longer lifespan for strengthened mandrels . Surface strengthening technology provides durability optimization through surface engineering to enhance the wear resistance of tungsten alloy rivet mandrels . It supports the tool's surface performance through modification and contributes to improved performance in riveting friction.

8.3.5 The Role of Failure Case Analysis in the Optimization of Tungsten Alloy Rivet Mandrels

The Role of failure case analysis in the optimization of tungsten alloy rivet mandrels is mainly through fracture surface observation and usage record traceability mechanisms. This helps identify common problems and guides material and process improvements, thereby enhancing the overall reliability of the mandrel . The analysis process involves collecting failed mandrels , observing the fracture morphology using scanning electron microscopy, revealing the fracture mode through chemical fracture dimples or cleavage characteristics, and recording the load frequency and environment under usage conditions.

The mechanism of action is reflected in the feedback loop. Case studies show that surface strengthening is improved when wear is too rapid, and heat treatment is optimized when there are many fatigue cracks. Fracture surface analysis distinguishes between overload and corrosion failure, and the ejector bar design adjusts the end face or composition. Case studies highlight frequently occurring problems, and batch optimization of ejector bars is highly targeted.

Failure case analysis is applied to production improvements, with surface peeling cases leading to coating upgrades and brittle fracture cases resulting in increased adhesion. Chemical analysis of corrosion products leads to improvements in mandrel protection measures. Its role also includes user feedback, allowing for adjustments to mandrel operating procedures to reduce human-caused failures. In the optimization of tungsten alloy rivet mandrels, failure case analysis provides a material perspective on actual damage, supports continuous tool improvement through case tracing, and contributes analytical value to riveting durability.

8.4 Comparison of the properties of tungsten alloy rivet mandrels with other mandrel materials

Comparison of the properties of tungsten alloy rivet mandrels with other mandrel materials mainly focuses on hardness, toughness, impact resistance, and machinability. This comparison helps to understand the relative performance and applicability of tungsten alloy mandrels in riveting support. Common comparison objects include cemented carbide mandrels, high-speed steel mandrels, and ceramic mandrels, each material having its own emphasis on the balance between strength and toughness. The two-phase structure of tungsten alloy mandrels provides a balance between hardness and toughness, while cemented carbide mandrels have outstanding hardness but relatively moderate toughness.

Comparative analysis begins with mechanical properties: tungsten alloy mandrels exhibit good impact resistance and toughness, high-speed steel offers excellent machinability, and ceramics are heat-resistant but brittle. In terms of chemical stability, tungsten alloys demonstrate good corrosion resistance, while high-speed steel is prone to rusting. Regarding thermal behavior, tungsten alloys exhibit moderate thermal conductivity, while ceramics provide thermal insulation. This performance comparison guides mandrel selection : tungsten alloys offer a good balance for high-strength riveting , while ceramics cause no damage for precision micro-rivets. The performance comparison of tungsten alloy rivet mandrels with other mandrel materials highlights the diversity of tool material choices and supports the optimization of riveting processes through characteristic comparison, providing valuable reference for assembly applications.

8.4.1 Performance Comparison of Carbide Ejector Rods and Tungsten Alloy Rivet Ejector Rods

Cemented carbide mandrels and tungsten alloy rivet mandrels mainly focuses on hardness, impact toughness, and machinability, reflecting the different emphases of the two materials in riveting support. Cemented carbide mandrels, primarily composed of tungsten carbide particles and a cobalt binder phase , exhibit high hardness, strong resistance to rivet indentation and wear on the working surface , and slow accumulation of surface indentations. Tungsten alloy mandrels, with their dual-phase tungsten particle skeleton coordinated with nickel-copper or nickel-iron binder phases, offer moderate hardness but better toughness. Under impact loads, the mandrel deforms to absorb energy, preventing brittle fracture.

The impact resistance of the ejector pins showed significant differences. The cemented carbide ejector pin exhibited high rigidity and concentrated reaction force, but was prone to chipping under high loads . The tungsten alloy ejector pin, with its extended and buffering binder phase, demonstrated stable overall fatigue resistance. In terms of thermal stability, cemented carbide maintained good hardness at high temperatures, resulting in less softening during hot riveting . Tungsten alloy, with its conductive properties, aided in heat dissipation, leading to a slower temperature rise in the ejector pin . Regarding chemical stability, the cobalt phase in cemented carbide was prone to oxidation, resulting in a porous surface layer. Tungsten alloy, with its binder phase controlling oxidation, exhibited slower oxidation and better resistance to environmental corrosion.

Comparing processing adaptability, cemented carbide mandrels are difficult to grind and shape, and their high brittleness leads to a high risk of machining cracks; tungsten alloy mandrels offer flexibility in both hot and cold working, and can be produced in various shapes . Comparing fatigue behavior, cemented carbide mandrels exhibit rapid microcrack propagation under cycling, while tungsten alloy mandrels show milder and more manageable damage. This performance comparison between cemented carbide and tungsten alloy rivet mandrels provides an engineering perspective for material selection, supporting the matching of mandrels to different riveting conditions through property balancing, and contributing a comparative basis for tool applications.

8.4.2 Performance Comparison of Steel Top Rods as Replacements for Tungsten Alloy Rivet Top Rods

Performance Comparison of steel rivet mandrels as alternatives to tungsten alloy rivet mandrels mainly involves differences in hardness, impact toughness, density, and cost. This comparison helps assess the feasibility of steel rivet mandrels in specific riveting conditions. Steel rivet mandrels are typically made of high-strength alloy steel or tool steel, with hardness adjusted through heat treatment. The working surface of the mandrel has strong resistance to indentation, but its hardness is relatively mild compared to tungsten alloys. Tungsten alloy rivet mandrels , with their tungsten phase skeleton providing higher hardness and slower surface indentation accumulation, are suitable for supporting high-strength rivets. The comparison shows significant differences in impact toughness. Steel rivet mandrels have good plasticity and absorb energy, resulting in coordinated deformation upon impact and preventing brittle fracture. Tungsten alloy rivet mandrels have bonded tungsten particles , achieving a balanced toughness but with high density and strong inertial reaction force. In terms of density , steel rivet mandrels are lower , making them lighter and more maneuverable , while tungsten alloys have higher density and more concentrated energy transfer. Regarding thermal stability, steel rivet mandrels have a moderate softening temperature , while tungsten alloys have better heat resistance and less deformation during high-temperature riveting.

In terms of processing adaptability, steel mandrels are easy to work with both hot and cold, offer diverse shapes, and are low-cost; tungsten alloy mandrels require heat assistance but offer high precision. Regarding fatigue behavior, steel mandrels experience slower damage accumulation under cyclic conditions, while tungsten alloys exhibit strong fatigue resistance and stability during high-frequency use. In terms of chemical stability, steel mandrels are prone to rust and require protective measures, while tungsten alloys offer good corrosion resistance and require less maintenance. This performance comparison of steel mandrels as alternatives to tungsten alloy rivet mandrels reflects the engineering trade-offs in material selection. The differences in properties support the substitution of mandrels in light-load or cost-sensitive applications, providing a comparative reference for riveting practice.

8.4.3 Performance Comparison of Ceramic Material Mandrels and Tungsten Alloy Rivet Mandrels

Performance Comparison of ceramic rivet mandrels and tungsten alloy rivet mandrels mainly focuses on differences in hardness, heat resistance, and toughness. This comparison reflects the performance characteristics of ceramic mandrels in special riveting environments. Ceramic mandrels are made of materials such as alumina or silicon nitride, exhibiting extremely high hardness. Their working surfaces offer strong resistance to scratches and indentation, and maintain a smooth surface for a long time. Tungsten alloy mandrels have moderate hardness but better toughness, and their deformation absorbs energy upon impact .

The differences in heat resistance are significant. Ceramic mandrels show less hardness decay at high temperatures and maintain shape stability during hot riveting or high-temperature environments; tungsten alloy mandrels exhibit better thermal conductivity and facilitate heat dissipation, resulting in a slower temperature rise . In terms of toughness , ceramic mandrels are brittle and prone to chipping upon impact; tungsten alloy mandrels exhibit better bonding and fracture resistance. Finally, ceramic mandrels have lower density , making them lighter and easier to handle; tungsten alloy mandrels have higher density and more concentrated reaction force.

Terms of processing adaptability, ceramic mandrels are mainly difficult to grind and have simple shapes; tungsten alloy mandrels are flexible in both hot and cold working. Regarding wear behavior, ceramic mandrels exhibit extremely high wear resistance with minimal surface damage, while tungsten alloy mandrels demonstrate balanced toughness and uniform wear. In terms of chemical stability, ceramic mandrels are highly inert and non-corrosive, while tungsten alloy mandrels require protection of the binder phase. The performance comparison between ceramic mandrels and tungsten alloy rivet mandrels highlights the characteristics of inorganic materials. Their hardness and heat resistance support their application in high-temperature or non-damaging environments, contributing a fundamental aspect to precision riveting.

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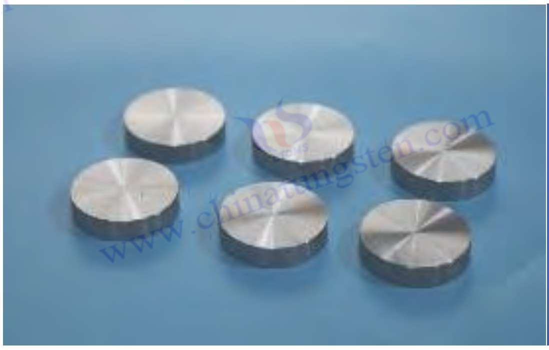
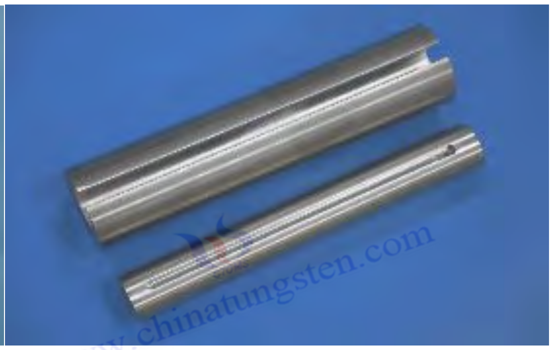

Appendix A: Chinese Standard for Tungsten Alloy Rivet Top Rods

China's tungsten alloy rivet mandrel standards mainly references relevant non-ferrous metal industry specifications and powder metallurgy tool material standards. These standards are the responsibility of the National Nonferrous Metals Standardization Technical Committee and cover composition, performance, dimensions, and testing methods. As a high-density tool material, the standards for tungsten alloy rivet mandrels emphasize tungsten content, binder phase ratio, and microstructure uniformity to ensure a balance between hardness and toughness in riveting support. The standard system includes national standards (GB/T series) and industry standards (YS/T series), applicable to mandrel products in tungsten -nickel-iron, tungsten-nickel-copper, and other similar systems .

The standard specifies the range of chemical composition, density distribution, hardness, and impact toughness indicators. The surface finish and dimensional tolerances of the mandrel must meet assembly requirements. Standardized chemical analysis methods ensure impurity control. The standard also addresses heat treatment conditions and surface treatment requirements, supporting the reliable application of mandrels in industrial riveting. In recent years, standard revisions have considered environmental protection and resource utilization, encouraging the recycling of tungsten materials. The Chinese standard for tungsten alloy rivet mandrels provides a normative framework for production and quality control, achieving stable tool performance through composition and performance guidelines, and contributing practical value to the assembly field.

National Standards (GB/T Series)

National standards (GB/T series) provide general technical requirements for tungsten alloy rivet mandrels . These standards cover the chemical composition, mechanical properties, and testing methods of high-density alloys, ensuring the consistency of mandrels in riveting tools. The relevant GB/T standards specify the composition range of tungsten alloy rods, with tungsten as the dominant component and a balanced binder phase ratio to maintain toughness. The standards include density and hardness indicators, and verify the uniformity of the mandrels after sintering and hot working.

The standard is developed with reference to powder metallurgy processes, and uses chemical analysis methods such as gravimetric determination of tungsten content to support precision control. The GB/T standard also covers heat treatment requirements, with annealing processes optimizing the microstructure and avoiding stress concentration. Dimensional tolerances and surface roughness specifications support precision assembly. National standards (GB/T series) provide fundamental specifications for the production of tungsten alloy rivet mandrels , ensuring reliable material application through performance requirements and contributing standard support to industrial tools.

Industry Standards (YS/T Series)

Industry standards (YS/T series) provide detailed guidance on the chemical analysis and processing of tungsten alloy rivet mandrels . These standards are applicable to tungsten-based high -density alloy rods, ensuring accurate composition and stable performance. The YS/T standards focus on methods for determining tungsten content, achieving analysis through dissolution-precipitation separation, suitable for verifying the proportion of the binder phase in mandrels . The standards specify hardness distribution and surface requirements, supporting wear-resistant riveting applications.

The YS/T series standards cover bar specifications for tungsten -nickel-iron and tungsten-nickel-copper systems, with low impurity levels for chemical purity management. The standards are developed in accordance with industry characteristics and incorporate resource utilization requirements. The industry standards (YS/T series) provide in-depth specifications for the technical details of tungsten alloy rivet mandrels , achieving production specialization through analysis and process guidance, and contributing industry value to tool manufacturing.

Enterprise and local standards

Enterprise and local standards provide supplementary specifications for the production of tungsten alloy rivet mandrels . These standards are based on the national framework and incorporate enterprise process experience to ensure batch consistency. Enterprise standards, such as internal regulations for non-ferrous metal enterprises, specify mandrel rolling and heat treatment procedures, and chemically optimize the distribution of binder phases to improve toughness. Local standards are common in tungsten producing areas and emphasize purity control based on resource characteristics.

These standards cover mandrel dimensions and surface treatments, extending to impact toughness testing. Enterprise standards emphasize quality systems, with batch tracking ensuring consistency. Local standards promote regional collaboration, and standardized mandrel specifications support the supply chain. Enterprise and local standards provide a flexible complement to the production of tungsten alloy rivet mandrels , enabling regional companies to compete through experience-based standardization and contributing practical guidance in tool application.

Appendix B International Standard for Tungsten Alloy Rivet Top Rods

International standards for tungsten alloy rivet mandrels are primarily developed by ASTM International and ISO. These standards provide a globally unified regulatory framework covering the composition, properties, and testing methods of high-density tungsten alloy rods, ensuring interoperability of materials in tooling applications. International standards emphasize the classification of tungsten heavy alloys, defining specifications based on tungsten content and binder phase. Standard development involves multinational collaboration and references general requirements for powder metallurgy.

The international standard standardizes tungsten content and impurity limits through chemical analysis, supporting trade certification. Performance indicators, including density and hardness, are applicable to the verification of heat treatment of bars. The standard is integrated into the quality management system to ensure consistent production. The international standard for tungsten alloy rivet mandrels provides a unified benchmark for global applications, facilitating material exchange through a specification framework and contributing international value to the tooling industry.

ASTM International Standard

ASTM international standards provide core specifications for tungsten alloy rivet mandrels , such as ASTM B 777, which classifies tungsten heavy alloy bars, defines density grades, and mechanical requirements. These standards apply to the production and testing of mandrels , chemically specifying tungsten content ranges, binder phase ratios, and impurity thresholds to ensure two-phase equilibrium.

The ASTM standard provides detailed specifications for chemical composition and physical properties, and verifies uniformity in the hot working of sintered bars. The standard includes test methods to support precision control. The ASTM international standard provides global recognition for the specification of tungsten alloy rivet mandrels , achieving consistent quality through specification definition and contributing a standard foundation to tool applications.

ISO international standard

ISO international standards provide a unified framework for tungsten alloy rivet mandrels , such as the ISO quality management system integration, extending to general specifications for tungsten heavy alloy bars. These standards apply to powder metallurgy production, chemically specifying purity and impurity control to ensure trade compliance .

ISO standards specify chemical analysis and physical testing, and the sintering process meets requirements. The standards include global certification guidelines and support export verification. ISO international standards provide quality assurance for the globalization of tungsten alloy rivet mandrels , standardize production through management systems, and contribute normative value to international cooperation.

Appendix C: Standards for Tungsten Alloy Rivet Top Bars in Europe, America, Japan, and South Korea

mandrel standards systems in countries such as the US, Europe, Japan, and South Korea are diverse. The US standard is primarily based on ASTM, while Europe references EN, Japan uses JIS, and South Korea uses KS. These standards cover the composition, properties, and processing of tungsten alloy rods, emphasizing regional needs. US standards focus on tool application, European standards on environmental protection, Japanese standards on precision, and South Korean standards on electronic compatibility. Standard development involves industry collaboration, referencing international standards while incorporating local characteristics.

These national standards chemically specify tungsten content and impurity limits, and properties including density and hardness. In applications, they support the use of mandrels in assembly tools.

Revisions have been made to responsive technologies, incorporating alloy innovations. Certified laboratories are implemented to verify batch compliance. The tungsten alloy rivet mandrel standards of countries such as the US, Europe, Japan, and South Korea reflect the diversity of regional specifications, supporting global supply chain coordination through specifications and contributing standard value to tool manufacturing.

American Standards (ASTM Series)

American standards (ASTM series) provide benchmarks for tungsten alloy rivet mandrels . For example, ASTM B 777 classifies tungsten heavy alloy bars, defining density grades and mechanical specifications. These standards apply to mandrel powder metallurgy and machining, chemically specifying the proportion of the tungsten -nickel-iron alloy binder phase. The ASTM series standards detail chemical composition and test methods, and validate post-sintering heat treatment of the bars. The standards are geared towards tooling applications and emphasize fatigue strength. American standards provide a leading framework for the specification of tungsten alloy rivet mandrels , enabling high-quality production through specifications and contributing American value to the tooling industry.

European Standards (EN Series)

European standards (EN series) provide requirements for tungsten alloy rivet mandrels . These standards apply to the composition and properties of tungsten heavy alloy rods, chemically limiting impurities to ensure environmental compliance . EN standards regulate sintering processes and dimensional tolerances, supporting European trade. The standards emphasize sustainable production. European standards provide a framework for environmental regulations on tungsten alloy rivet mandrels , achieving market harmonization through requirements and contributing value to EU tools.

Japanese Standards (JIS series)

Japanese Standards (JIS series) provide specifications for tungsten alloy rivet setters . These standards refine chemical compositions and are suitable for precision tooling applications. JIS standards emphasize purity and machining accuracy, supporting Japanese industry. The detailed specifications for tungsten alloy rivet setters enable high-tech applications and contribute Japanese value to tool manufacturing.

Korean Standard (KS Series)

Korean standards (KS series) provide specifications for tungsten alloy rivet mandrels , supporting tool exports and specifying chemical properties. KS standards define testing methods to support Korean manufacturing. These standards provide a framework for export specifications of tungsten alloy rivet mandrels , enabling global competitiveness through performance and contributing Korean value to the tool industry.

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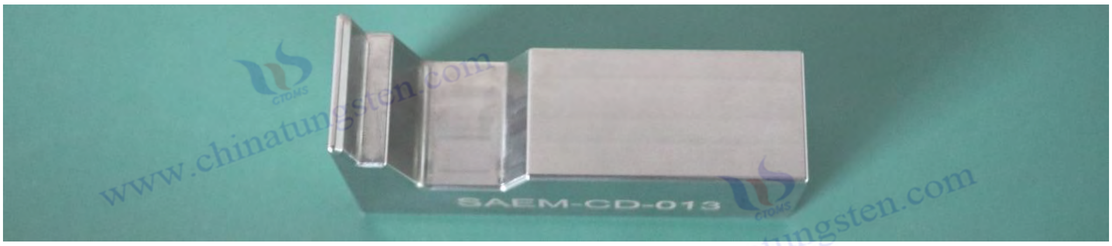
Appendix D Glossary of Tungsten Alloy Rivet Bucking Bar Terms

Chinese terminology	Brief explanation
Tungsten alloy rivet top bar	A rod-shaped tool made of tungsten alloy is used to support the tail of the rivet during the riveting process and promote uniform deformation.
High-density tungsten alloy	tungsten content have high density and are used in support tools that require concentrated mass.
binder phase	tungsten particles in the alloy provide toughness and machinability.
Liquid phase sintering	tungsten particles during sintering to promote densification.
pseudo-alloys	two non-solid substances , such as tungsten-copper alloys , are prepared by melt infiltration.
Cold isostatic pressing	A method for uniformly pressing and molding powder blanks using a liquid medium.
Hot isostatic pressing	A post-processing technique that eliminates porosity and increases density under high temperature and high pressure.
recrystallization annealing	High-temperature annealing is a heat treatment that eliminates processing stress and restores plasticity.
work hardening	Cold working increases dislocation density, thereby improving hardness and strength.
Texture	The preferential distribution of crystal orientation caused by deformation processing affects anisotropy.
Vickers hardness	The hardness index measured by diamond indenter indentation is applicable to tungsten alloy mandrels.
Impact toughness	The material's ability to absorb impact energy, resisting fracture when supported by a top rod .
Fatigue strength	The ability of a material to resist damage under cyclic loading is related to high-frequency riveting of the mandrel .
Surface smoothness	The top bar has a low surface roughness, which reduces rivet adhesion and friction.
passivation layer	A protective oxide layer, formed naturally or artificially on the surface, enhances corrosion resistance.
Stress corrosion	Cracking caused by the combined effects of stress and corrosive media requires attention to the wet load on the top bar .
coefficient of thermal expansion	The dimensional expansion rate of the material when the temperature changes, and the matching rivets during hot riveting of the mandrel .
fracture toughness	The material's ability to resist crack propagation is evaluated under top bar overload .



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