

What Is Silver Tungsten Alloy

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

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

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www.ctia.com.cn

电话/TEL: 0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

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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Table of Contents

Chapter 1: Basic Knowledge of Silver Tungsten Alloy

- 1.1 Concept of Silver Tungsten Alloy
 - 1.1.1 Definition of Silver Tungsten Alloy
 - 1.1.2 Differences from Tungsten Copper Alloy
 - 1.1.3 Differences from Tungsten-Molybdenum Alloy
- 1.2 Development History of Silver Tungsten Alloy
 - 1.2.1 Early Exploration Stage
 - 1.2.2 Technological Breakthroughs and the Start of Industrial Applications
 - 1.2.3 Modern Technological Innovation
- 1.3 Importance and Significance of Industry Research
 - 1.3.1 Promotion of the Development of Materials Science
 - 1.3.2 Value of Application in Various Fields

Chapter 2: Composition and Characteristics of Silver-Tungsten Alloy

- 2.1 Characteristics of Silver and Tungsten
 - 2.1.1 Physical and Chemical Properties of Silver
 - 2.1.1 Physical and Chemical Properties of Tungsten
 - 2.1.3 Silver Tungsten Composition
- 2.2 Effect of Silver-Tungsten Alloy Composition Ratio
 - 2.2.1 Effect of Silver-Tungsten Ratio on the Bending Strength of Alloy
 - 2.2.2 Effect of Silver-Tungsten Ratio on Alloy Toughness
 - 2.2.3 Effect of Silver-Tungsten Ratio on the Conductivity of Alloys
 - 2.2.4 Effect of Silver-Tungsten Ratio on Thermal Conductivity of Alloy
 - 2.2.5 Effect of Silver-Tungsten Ratio on Alloy Density
 - 2.2.6 Effect of Silver-Tungsten Ratio on Alloy Hardness
 - 2.2.7 Effect of Silver-Tungsten Ratio on High Temperature Resistance of Alloy
 - 2.2.8 Effect of Silver-Tungsten Ratio on Arc Erosion Resistance of Alloys
- 2.3 Performance Analysis of Silver Tungsten Alloy
 - 2.3.1 Formation Mechanism and Advantages of High Hardness of Silver-Tungsten Alloy
 - 2.3.1.1 Microstructural Mechanism of High Hardness Formation
 - 2.3.1.2 Advantages of High Hardness in Wear-Resistant Applications
 - 2.3.1.3 Hardness Comparison with Other Alloys and Advantages
 - 2.3.2 Principle and Performance of Arc Erosion Resistance of Silver-Tungsten Alloy
 - 2.3.2.1 Mechanism of Arc Erosion
 - 2.3.2.2 The Intrinsic Principle of Silver-Tungsten Alloy Resisting Arc Erosion
 - 2.3.2.3 Differences in Arc Erosion Resistance Performance Under Different Usage Environments
 - 2.3.2.4 Ways to Improve Arc Erosion Resistance
 - 2.3.3 Anti-Adhesion and Anti-Welding Capabilities of Silver-Tungsten Alloy
 - 2.3.3.1 Causes of Adhesion and Welding
 - 2.3.3.2 Anti-Adhesion Performance of Silver-Tungsten Alloy

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- 2.3.3.3 Analysis of Factors Affecting Anti-Adhesion and Anti-Welding Capabilities
- 2.3.4 Principle and Application of Excellent Conductivity of Silver-Tungsten Alloy
 - 2.3.4.1 Physical Nature of Conductivity and Conductive Mechanism of Silver-Tungsten Alloy
 - 2.3.4.2 Changes in Conductivity at Different Component Ratios
 - 2.3.4.3 Advantages of Conductive Applications in Electrical Equipment
- 2.3.5 Characteristics and Value of Good Thermal Conductivity of Silver Tungsten Alloy
 - 2.3.5.1 Basic Principles of Thermal Conductivity and Thermal Conductivity Mechanism of Silver-Tungsten Alloy
 - 2.3.5.2 Relationship Between Thermal Conductivity and Heat Dissipation Effect
 - 2.3.5.3 Application Value of Thermal Conductivity in High Temperature Working Environment
- 2.3.6 Performance and Mechanism of Corrosion Resistance of Silver-Tungsten Alloy
 - 2.3.6.1 Effects of Different Corrosion Environments on Silver-Tungsten Alloy
 - 2.3.6.2 Intrinsic Mechanism of Corrosion Resistance of Silver-Tungsten Alloy
 - 2.3.6.3 Technological Means to Improve Corrosion Resistance
- 2.4 CTIA GROUP LTD Silver Tungsten Alloy MSDS

Chapter 3: Observation of Microstructure Characteristics and Performance Correlation of Silver-Tungsten Alloy

- 3.1 Observation of Microstructure Characteristics of Silver-Tungsten Alloy
 - 3.1.1 Grain Morphology and Size Characteristics
 - 3.1.2 Phase Distribution and Interface Characteristics
 - 3.1.3 Microscopic Manifestations of Porosity and Defects
 - 3.1.4 Microstructure Differences Under Different Preparation Processes
- 3.2 Intrinsic Relationship Between Silver-Tungsten Alloy Structure and Macroscopic Properties
 - 3.2.1 Mechanism of the Effect of Grain Structure on Strength and Toughness
 - 3.2.2 Correlation Between Phase Distribution and Electrical and Thermal Conductivity
 - 3.2.3 Effect of Porosity and Defects on Hardness and Corrosion Resistance
- 3.3 Microstructure Evolution of Silver-Tungsten Alloy
 - 3.3.1 Microstructure Evolution Caused by Changes in Composition Ratios
 - 3.3.2 Microstructural Transformation During Heat Treatment
 - 3.3.3 Effect of Service Environment on Microstructure and Performance Feedback
- 3.4 Methods for Controlling the Microstructure of Silver-Tungsten Alloy
 - 3.4.1 Microstructure Control Method Based on Preparation Process
 - 3.4.2 Optimization of Microstructure by Alloying Element Addition
 - 3.4.3 Relationship Between Microstructure Regulation and Performance Customization

Chapter 4: Preparation Process of Silver-Tungsten Alloy

- 4.1 Powder Metallurgy Method for Producing Silver-Tungsten Alloy
 - 4.1.1 Powder Preparation Process and Key Points
 - 4.1.2 Pressing Process Principle and Operation
 - 4.1.3 Control and Influence of Sintering Process
- 4.2 Production of Silver-Tungsten Alloy by Vacuum Infiltration Method

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- 4.2.1 Infiltration Principle and Equipment Requirements
- 4.2.2 Process Steps and Parameter Optimization
- 4.2.3 Advantages and Limitations of the Process
- 4.3 Process Comparison and Selection Basis
- 4.3.1 Cost Analysis of Different Processes
- 4.3.2 Performance Differences and Process Selection
- 4.3.3 Production Efficiency and Process Adaptation

Chapter 5: Performance Testing and Characterization of Silver-Tungsten Alloy

- 5.1 Physical Properties Test of Silver Tungsten Alloy
 - 5.1.1 Density Test Method
 - 5.1.2 Hardness Test Standards and Operations
 - 5.1.3 Electrical Conductivity and Thermal Conductivity Test Methods
- 5.2 Evaluation of Chemical Properties of Silver-Tungsten Alloy
 - 5.2.1 Corrosion Resistance Test Environment and Methods
 - 5.2.2 Antioxidant Performance Testing Methods
- 5.3 Silver-Tungsten Alloy Microstructure Characterization Technology
 - 5.3.1 Metallographic Microscope Observation Method
 - 5.3.2 Scanning Electron Microscopy Analysis Applications
 - 5.3.3 Structural Analysis by X-Ray Diffraction

Chapter 6: Application Fields of Silver Tungsten Alloy

- 6.1 Application of Silver Tungsten Alloy in Electrical Field
 - 6.1.1 Application Advantages in Low Voltage Power Switches
 - 6.1.1.1 Performance Requirements for Materials of Low Voltage Power Switches
 - 6.1.1.2 Application of Silver-Tungsten Alloy in Low Voltage Power Switches
 - 6.1.1.3 Advantages of Using PCB Materials in Low Voltage Power Switches Compared to Other Materials
 - 6.1.2 Demand for Electrical Alloys for High Voltage Switches
 - 6.1.2.1 Working Environment of High Voltage Switch and Special Requirements for Electrical Alloys
 - 6.1.2.2 Performance of Silver-Tungsten Alloy in Meeting the Requirements of High-Voltage Switches
 - 6.1.3 Application of Relays and Air Circuit Breakers
 - 6.1.3.1 Working Principle of Relay and Requirements for Contact Materials
 - 6.1.3.2 Application Effect of Silver Tungsten Alloy in Relays
 - 6.1.3.3 Performance Requirements of Air Circuit Breakers and Compatibility of Silver-Tungsten Alloy
 - 6.1.4 Application in Disconnectors and Earthing Switches
 - 6.1.4.1 Function and Material Requirements for Isolating Switches and Earthing Switches
 - 6.1.4.2 Advantages of Silver-Tungsten Alloy in Isolating Switches and Earthing Switches
- 6.2 Application of Silver Tungsten Alloy in Electronics
 - 6.2.1 Performance Requirements and Applications of EDM Electrodes
 - 6.2.1.1 Performance Index Requirements of Electrode Materials for Electromachining Process
 - 6.2.1.2 Performance Advantages of Silver-Tungsten Alloy as Electromachining Electrode

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- 6.2.1.3 Selection of Silver-Tungsten Alloy Electrodes in Different Electrical Machining Scenarios
- 6.2.2 Role of Materials in Microelectronics
 - 6.2.2.1 Precision Requirements for Materials in the Field of Microelectronics
 - 6.2.2.2 Application of Silver-Tungsten Alloy in Microelectronic Packaging
 - 6.2.2.3 The Role of Silver-Tungsten Alloy in Microelectronic Connection Components
- 6.2.3 Application Exploration in Sensors
 - 6.2.3.1 Sensor Working Environment and Material Performance Requirements
 - 6.2.3.2 Potential Application Scenarios of Silver-Tungsten Alloy in Sensors
- 6.3 Application of Silver Tungsten Alloy in Aerospace
 - 6.3.1 Application of Solid Rocket Nozzle Throat Lining
 - 6.3.1.1 Working Environment and Material Challenges of Solid Rocket Nozzle Throat Lining
 - 6.3.1.2 Performance of Silver Tungsten Alloy as Nozzle Throat Liner
 - 6.3.1.3 Preparation and Application Effect of Silver-Tungsten Alloy Nozzle Throat Lining
 - 6.3.2 Potential Applications of Aerospace Engine Components
 - 6.3.2.1 Requirements for Materials in the High Temperature and High Pressure Working Environment of Aircraft Engines
 - 6.3.2.2 Application Potential of Silver-Tungsten Alloy in Specific Parts of Aircraft Engines
 - 6.3.3 Application in Spacecraft Electrical Systems
 - 6.3.3.1 Reliability Requirements for Spacecraft Electrical Systems
 - 6.3.3.2 Application of Silver-Tungsten Alloy in Spacecraft Contactors and Other Components
- 6.4 Application of Silver Tungsten Alloy in Other Fields
 - 6.4.1 Application Scenarios in the Metallurgical Industry
 - 6.4.1.1 Working Conditions and Material Requirements of Metallurgical Equipment
 - 6.4.1.2 Application of Silver-Tungsten Alloy in Metallurgical Furnace Electrodes
 - 6.4.1.3 Use of Silver-Tungsten Alloy in Metallurgical Testing Instruments
 - 6.4.2 Use Cases in Sports Equipment
 - 6.4.2.1 Requirements for Material Performance of High-End Sports Equipment
 - 6.4.2.2 Application of Silver-Tungsten Alloy in Golf Heads, Fishing Tackle and Other Equipment
 - 6.4.3 Exploration and Application in the Field of Medical Devices
 - 6.4.3.1 Requirements for Material Biocompatibility and Performance of Medical Devices
 - 6.4.3.2 Application of Silver-Tungsten Alloy in Medical Imaging Equipment
 - 6.4.3.3 Potential Applications of Silver Tungsten Alloy in Precision Surgical Instruments
 - 6.4.4 Application Prospects in the Field of Nuclear Energy
 - 6.4.4.1 Requirements for Materials' Radiation Resistance and Other Properties in Nuclear Energy Equipment
 - 6.4.4.2 Analysis of the Application Possibility of Silver-Tungsten Alloy in the Field of Nuclear Energy

Chapter 7: Future Development Direction of Silver Tungsten Alloy

- 7.1 Exploration of New Preparation Technology of Silver-Tungsten Alloy
 - 7.1.1 Potential Applications of Additive Manufacturing Technology
 - 7.1.2 Outlook of Other Cutting-Edge Preparation Technologies
- 7.2 Research Trends in Silver-Tungsten Alloy Performance Optimization

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7.2.1 Research Directions to Improve Comprehensive Performance

7.2.2 Performance Enhancements for Specific Applications

Appendix

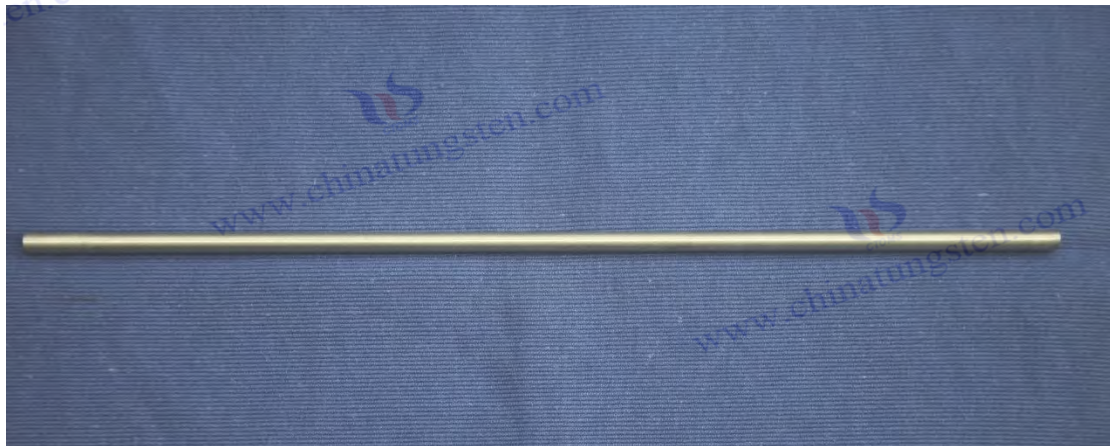
Appendix A: Chinese National Standard for Silver-Tungsten Alloy

Appendix B: International Standards for Silver-Tungsten Alloy

Appendix C: Silver-Tungsten Alloy Standards in Europe, America, Japan, South Korea and Other Countries Around the World

Appendix D: Silver-Tungsten Alloy Terminology

References



CTIA GROUP LTD Silver Tungsten Alloy

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CTIA GROUP LTD
Silver Tungsten Alloy Introduction

1. Overview of Silver Tungsten Alloy

Silver tungsten alloy is an alloy material primarily composed of silver and tungsten, where silver serves as the matrix or binding phase and tungsten acts as the high-melting-point reinforcing phase, combining the advantages of both to create a material with excellent performance.

2. Features of Silver Tungsten Alloy

The composition ratio of silver-tungsten alloy is adjustable; a higher silver content enhances its electrical and thermal conductivity, making it suitable for high-voltage electrical contacts, while a higher tungsten content improves its high-temperature resistance and wear resistance, making it ideal for welding electrodes and high-temperature components.

3. The Composition Ratio of Silver Tungsten Alloy

Materials	Composition (%weight)	Density (/g.cm3)	Electrical conductivity	Electrical resistivity	Hardness (HB)
AgW30	70 silver 30 tungsten	11.8-12.2	73	2.3	75
AgW40	60 silver 40 tungsten	12.5-12.8	64	2.6	85
AgW50	50 silver 50 tungsten	13.2-13.5	73-56	2.3-3.0	105
AgW55	45 silver 55 tungsten	13.6-13.9	54	3.2	115
AgW60	40 silver 60 tungsten	14.0-14.4	60-50	2.8-3.3	125
AgW65	35 silver 65 tungsten	14.5-14.9	50	3.4	135
AgW70	30 silver 70 tungsten	14.7-15.1	48	3.5	150
AgW80	20 silver 80 tungsten	16.1-16.5	37	4.5	180

4. Production Methods for Silver Tungsten Alloy

The preparation method for tungsten-silver alloy is the same as that for tungsten-copper alloy. Due to tungsten's high melting point and its inability to alloy with silver, traditional methods cannot be used. Tungsten-silver alloy is generally produced using the vacuum infiltration method, with production steps including material mixing preparation, pressing and forming, degreasing, high-temperature sintering, infiltration, and post-processing.

5. Applications of Silver Tungsten Alloy

Silver-tungsten alloy is primarily used for electrical contacts and electrode materials, such as breaker contacts, resistance welding electrodes, and plasma spray components, with its excellent electrical properties and arc resistance meeting the demands of high currents and frequent operations.

6. Purchasing Information

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

Website: silver-tungsten.net

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Chapter 1 Basic Knowledge of Silver-Tungsten Alloy

As a high-performance composite material, silver-tungsten alloy has shown wide application potential in the electrical, electronic, defense and industrial fields due to its excellent electrical conductivity, thermal conductivity, high temperature resistance and arc corrosion resistance. The alloy is prepared by powder metallurgy process, combining the high electrical and thermal conductivity of silver with the high melting point and hardness of tungsten, and can meet the demanding requirements in high current, high temperature or high wear environment. With the rapid development of electrification and high-power equipment, the importance of silver-tungsten alloy in the fields of electrical contacts, circuit breakers and electrode materials has become increasingly prominent.

1.1 Concept of Silver Tungsten Alloy

Silver-tungsten alloy is a composite material with silver and tungsten as the main components. It is usually prepared by powder metallurgy and is widely used in scenarios that require high conductivity, arc corrosion resistance and high temperature resistance. Silver provides excellent electrical and thermal conductivity, while tungsten contributes high melting point, hardness and wear resistance, making the alloy perform well in electrical contact and high temperature environments. The performance of silver-tungsten alloy can be optimized by adjusting the ratio of silver and tungsten to meet the needs of different applications, such as high-voltage switches, welding electrodes and aerospace electrical components.

1.1.1 Definition of Silver Tungsten Alloy

Silver-tungsten alloy is a composite material made of silver and tungsten through powder metallurgy process. Silver is used as matrix or bonding phase, and tungsten is used as high melting point reinforcement phase. The advantages of both are combined to form a material with excellent performance. The high electrical conductivity and thermal conductivity of silver make it an ideal conductive matrix, while the high melting point and hardness of tungsten give the alloy excellent high temperature resistance and arc corrosion resistance. The preparation process usually includes powder mixing, pressing, sintering and post-processing. Silver forms a liquid phase during the sintering process, wets the tungsten particles, fills the gaps, and forms a dense microstructure. The composition ratio of silver-tungsten alloy is adjustable. When the silver content is higher, the conductivity is better, and when the tungsten content is higher, the wear resistance and high temperature resistance are stronger. It is suitable for scenes such as electrical contacts, circuit breaker contacts, resistance welding electrodes and plasma sprayed parts. Its non-magnetism and low thermal expansion coefficient further enhance its applicability in high-precision electrical and high-temperature environments.

The core advantage of silver-tungsten alloy lies in its comprehensive performance. The high conductivity of silver ensures the efficiency of current transmission and is suitable for high-voltage electrical systems; the high melting point and arc corrosion resistance of tungsten enable the alloy to remain stable in high current or frequent switching operations and extend its service life. The toughness and wear resistance of the alloy enable it to withstand mechanical shock and arc erosion, making it suitable for dynamic

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electrical environments. The flexibility of the preparation process allows the performance to be optimized by adjusting the silver- tungsten ratio or adding trace elements (such as nickel) to meet specific application requirements. Silver-tungsten alloy is widely used in the electrical and industrial fields to manufacture high-reliability contacts and electrodes, especially in scenarios requiring high conductivity and arc resistance, such as power systems, aerospace electrical connections, and industrial welding.

1.1.2 Differences from tungsten copper alloy

Silver-tungsten alloy (Ag-W) and tungsten-copper alloy (W-Cu) are both tungsten-based composite materials prepared by powder metallurgy and widely used in electrical and thermal management fields, but there are significant differences between the two in composition, performance and application scenarios.

Composition and preparation : Silver-tungsten alloy uses silver as the matrix or bonding phase and tungsten as the reinforcement phase. The silver content is usually high, giving the alloy excellent electrical conductivity. Tungsten-copper alloy uses tungsten as the matrix and copper as the bonding phase. The copper content is relatively low, and it mainly emphasizes thermal conductivity and processing performance. The sintering process of silver-tungsten alloy relies on the liquid phase of silver to wet the tungsten particles to form a uniform and dense structure, while tungsten-copper alloy is often prepared by infiltration, first sintering the tungsten skeleton and then infiltrating liquid copper. The process is more complicated and energy-intensive. The silver content of silver-tungsten alloy makes it more expensive, while tungsten-copper alloy is more economical due to the lower copper price.

Performance differences : The electrical conductivity of silver-tungsten alloy is better than that of tungsten-copper alloy , because the electrical conductivity of silver is higher than that of copper , and it is suitable for high-current electrical contact applications such as circuit breakers and switch contacts. The thermal conductivity of tungsten-copper alloy is stronger, because the thermal conductivity of copper is slightly higher than that of silver, and it is suitable for thermal management applications such as electronic heat dissipation substrates and electrode materials. The arc corrosion resistance of silver-tungsten alloy is better than that of tungsten-copper alloy , because the high melting point and chemical stability of silver make it more resistant to ablation in an arc environment, and it is suitable for electrical systems with frequent switching. The density of tungsten-copper alloy is slightly lower than that of silver-tungsten alloy, because the density of copper is lower than that of silver, which limits its application in applications that require high weight balancing. The toughness of silver-tungsten alloy is slightly inferior to that of tungsten-copper alloy , because the ductility of silver is lower than that of copper, but its hardness and wear resistance are higher, and it is suitable for high wear scenarios.

Application scenarios : Silver-tungsten alloy is mainly used for electrical contacts and electrode materials, such as high-voltage circuit breaker contacts, resistance welding electrodes, and plasma sprayed parts. Its excellent conductivity and arc resistance meet the needs of high current and frequent operation. Tungsten-copper alloy is more widely used in thermal management components, such as power semiconductor substrates, server heat sinks, and rocket nozzle linings. Its high thermal

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conductivity and processing performance are more suitable for heat dissipation and high-temperature environments. The non-magnetic nature of silver-tungsten alloy gives it an advantage in electromagnetically sensitive environments (such as MRI equipment), while the non-magnetic nature of tungsten-copper alloy is also applicable, but its lower density limits shielding or counterweight applications. The high cost of silver-tungsten alloy limits its application in cost-sensitive scenarios, while tungsten-copper alloy is more economical and suitable for mass production.

Summary of advantages and disadvantages : Silver-tungsten alloy is superior to tungsten-copper alloy in electrical conductivity and arc corrosion resistance , and is suitable for high-reliability electrical contacts, but it is more expensive and has slightly lower thermal conductivity. Tungsten-copper alloy has more advantages in thermal conductivity and processing performance, and is suitable for thermal management components, but has lower arc resistance and density. The selection of materials needs to be weighed according to application requirements. For example, silver-tungsten alloy is preferred for electrical contacts, while tungsten-copper alloy is preferred for heat dissipation substrates . Optimization directions include improving the toughness of silver-tungsten alloy by adding trace elements (such as nickel), or using additive manufacturing to reduce the preparation cost of tungsten-copper alloy.

1.1.3 Differences from tungsten-molybdenum alloy

Silver-tungsten alloy (Ag-W) and tungsten-molybdenum alloy (W-Mo) are both tungsten-based composite materials , widely used in high-temperature and electrical fields, but there are significant differences between the two in composition, performance and application scenarios.

Composition and preparation : Silver-tungsten alloy uses silver as the matrix or bonding phase and tungsten as the reinforcement phase. It is prepared through powder metallurgy processes (such as powder mixing, pressing and liquid phase sintering). Silver forms a liquid phase at high temperature, wets the tungsten particles, and forms a dense structure. Tungsten-molybdenum alloy is mainly composed of tungsten and molybdenum . It is usually prepared by powder metallurgy or vacuum melting. Molybdenum , as a high-melting-point metal with similar properties to tungsten, enhances the high-temperature resistance of the alloy. The silver content of silver-tungsten alloy gives it excellent conductivity, while tungsten-molybdenum alloy does not contain precious metals and has a lower cost, but lacks a conductive matrix. The preparation process of tungsten-molybdenum alloy requires a higher sintering temperature because the melting point of molybdenum is slightly lower than that of tungsten, and the process control is more complicated.

Performance differences : The electrical conductivity and thermal conductivity of silver-tungsten alloy are much better than those of tungsten-molybdenum alloy, because the addition of silver significantly improves the electrical conductivity and thermal conduction efficiency, and is suitable for electrical contacts and electrode applications. The electrical conductivity and thermal conductivity of tungsten-molybdenum alloy are poor, mainly relying on the inherent properties of tungsten and molybdenum , and are suitable for structural components rather than electrical applications. Silver-tungsten alloy has excellent arc corrosion resistance, because the chemical stability of silver makes it resistant to ablation

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under high current arcs, while tungsten-molybdenum alloy is easily oxidized in arc environments and has weak corrosion resistance. Tungsten-molybdenum alloy has slightly better strength and high temperature resistance, because molybdenum enhances the mechanical properties at high temperatures, and is suitable for extremely high temperature environments (such as aerospace nozzles). The density of silver-tungsten alloy is higher than that of tungsten-molybdenum alloy, and is suitable for applications requiring high weight balancing, while tungsten-molybdenum alloy has a lower density.

Application scenarios : Silver-tungsten alloy is mainly used for electrical contacts, circuit breaker contacts and resistance welding electrodes. Its high conductivity and arc resistance meet the needs of high-voltage electrical systems, such as power switches and aerospace electrical connections. Tungsten-molybdenum alloy is more commonly used in high-temperature structural components, such as rocket engine nozzles, furnace internals and high-temperature molds, due to its excellent high temperature resistance and strength. Silver-tungsten alloy has advantages in the medical and electronic fields, while tungsten-molybdenum alloy is more suitable for extreme high temperature and mechanical load scenarios. The cost of silver-tungsten alloy is higher due to the addition of silver , which limits its use in large-scale structural applications, while tungsten-molybdenum alloy is more economical due to its lower cost.

Summary of advantages and disadvantages : Silver-tungsten alloy is superior to tungsten-molybdenum alloy in terms of electrical conductivity, arc corrosion resistance and high-density counterweight, and is suitable for high-reliability electrical applications, but it is more expensive and slightly inferior in extreme high temperature resistance. Tungsten-molybdenum alloy has advantages in high-temperature strength and cost-effectiveness, and is suitable for high-temperature structural components, but its electrical conductivity and arc resistance are insufficient. The selection of materials needs to be weighed according to application requirements. For example, silver-tungsten alloy is preferred for electrical contacts, and tungsten-molybdenum alloy is preferred for high-temperature structural components. Optimization directions include improving the high temperature resistance of silver-tungsten alloy by adding trace elements, or using advanced sintering technology to increase the density of tungsten-molybdenum alloy.

1.2 Development History of Silver Tungsten Alloy

The development of silver-tungsten alloy reflects the coordinated evolution of material science and industrial needs. From early exploration to breakthroughs in modern high-performance applications, it has gone through multiple stages of material preparation, performance optimization, and application expansion. The research and development of silver-tungsten alloy began with the demand for high conductivity and arc-resistant materials, and gradually developed into a key material in the electrical, electronic, and defense fields.

1.2.1 Early Exploration Stage

Early exploration of silver-tungsten alloys began in the early 20th century, when the rise of the electrical industry created an urgent need for high-performance contact materials. Early electrical equipment (such

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as switches and relays) often used pure silver or copper as contact materials, but these materials are prone to arc erosion and adhesion under high currents or frequent switching operations, have short lifespans and low reliability. Tungsten is believed to enhance the arc resistance of contacts due to its high melting point and hardness, but pure tungsten has poor conductivity and is difficult to process. Researchers began trying to combine silver with tungsten, taking advantage of the conductivity of silver and the high temperature resistance of tungsten to develop composite materials that combine both.

Initial preparation mainly adopted simple powder mixing and pressing and sintering processes. The silver- tungsten ratio was difficult to control accurately, the microstructure of the alloy was uneven, and the performance stability was insufficient. Early experiments focused on alloys with low silver content , trying to balance cost and performance, but the conductivity was poor, which limited the scope of application. Challenges in the exploration stage included uneven powder mixing, high sintering porosity and backward processing technology, resulting in alloy performance that could not meet industrial needs. Despite this, the potential of silver-tungsten alloy has gradually emerged in electrical contact and electrode applications, laying the foundation for subsequent technological breakthroughs. Early research was mainly concentrated in laboratories and small-scale experiments, applied to simple electrical switches and industrial electrodes, marking the transition of silver-tungsten alloy from concept to initial application.

1.2.2 Technological breakthroughs and the start of industrial applications

In the mid-20th century, with the rapid development of powder metallurgy technology and the electrical industry, silver-tungsten alloy ushered in the start-up stage of technological breakthroughs and industrial applications. Advanced powder metallurgy processes, such as liquid phase sintering and hot pressing technology, have significantly improved the density and performance consistency of the alloy. Liquid phase sintering wets tungsten particles, fills micropores, and forms a uniform microstructure through the liquid flow of silver at high temperature, greatly improving conductivity and arc resistance. The researchers optimized the silver-tungsten ratio and found that alloys with high silver content are better in conductivity and suitable for high-voltage electrical contacts, while alloys with high tungsten content are more wear-resistant and high-temperature resistant, making them suitable for electrode materials.

Advances in preparation technology have promoted the industrial production of silver-tungsten alloy. The introduction of vacuum sintering and inert gas protection technology has reduced oxidation problems, improved the purity and non-magnetism of the alloy, and met the needs of applications with high electromagnetic compatibility requirements. The application of precision machining technologies (such as EDM and CNC milling) makes it possible to manufacture complex-shaped contacts and electrodes, expanding the application of alloys in high-voltage circuit breakers, resistance welding, and aerospace electrical systems. The start of industrial applications also benefited from the rapid development of power systems and manufacturing industries. The urgent demand for arc-resistant and highly conductive materials in high-voltage switchgear and automated welding equipment has promoted the marketization of silver-tungsten alloy. During this stage, silver-tungsten alloy began to be widely used in high-voltage circuit breaker contacts, relay contacts, and resistance welding electrodes. Its excellent arc corrosion

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resistance and electrical conductivity significantly extended the life of the equipment and improved operational reliability. The aerospace field also began to use silver-tungsten alloy to manufacture electrical connection components, using its non-magnetic and high-density properties to optimize system performance. Technological breakthroughs also include improving the toughness and processing properties of the alloy by adding trace elements (such as nickel or cobalt), further broadening the scope of application. The start of industrial application marks the transition of silver-tungsten alloy from the laboratory to large-scale production, laying the foundation for its widespread application in modern electrical and high-temperature fields. Optimization directions include the development of more efficient sintering technology and low-cost preparation methods to meet the challenge of the high cost of silver.

1.2.3 Modern technological innovation

Entering the 21st century, the research and development and application of silver-tungsten alloys have ushered in a wave of modern technological innovation, benefiting from the progress of materials science, manufacturing technology and application needs. Modern technological innovation mainly focuses on three aspects: preparation process optimization, performance improvement and application scenario expansion. Advanced powder metallurgy technology, such as spark plasma sintering (SPS), significantly shortens the sintering time, reduces grain growth, and improves the density and performance consistency of the alloy through rapid heating by pulsed current and high pressure. This technology makes the microstructure of silver-tungsten alloy more uniform, enhances conductivity and arc corrosion resistance, and is suitable for high-precision electrical contacts and electrode applications. The development of nanotechnology has promoted the application of nano-scale silver-tungsten powder. The high specific surface area of nanoparticles improves the liquid phase sintering effect, further improves the strength, toughness and thermal conductivity of the alloy, and is suitable for miniaturized electrical components and high-temperature electrodes.

Additive manufacturing (3D printing) technology has brought revolutionary changes to the preparation of silver-tungsten alloys. Through selective laser melting (SLM) or electron beam melting technology, contacts or electrodes with complex geometries can be directly prepared, reducing material waste from traditional processing while achieving customized design to meet the needs of aerospace and medical equipment. Surface modification technologies, such as nano-coatings (such as TiN or DLC) applied by plasma enhanced chemical vapor deposition (PECVD), significantly improve the wear resistance and arc corrosion resistance of the alloy, extending the service life of high-voltage circuit breaker contacts and welding electrodes. The application of green manufacturing technologies, such as the use of environmentally friendly binders and low-energy sintering processes, reduces energy consumption and emissions in the production process, and promotes the sustainable development of silver-tungsten alloys.

Modern technological innovations also include intelligent and functional design. Intelligent monitoring technology detects arc wear and temperature changes of silver-tungsten alloy contacts in real time by embedding sensors, optimizing maintenance cycles and improving equipment reliability. The development of functionally gradient materials (FGM) enables silver-tungsten alloys to have gradient properties in different areas, such as high silver content on the surface to improve conductivity, and high

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tungsten content inside to enhance high temperature resistance, which is suitable for multifunctional electrical components. These technological innovations have significantly improved the performance of silver-tungsten alloys and expanded their applications in new energy (such as electric vehicle charging pile contacts), 5G communications (radio frequency modules) and national defense (radar electrodes). Optimization directions include developing more efficient nanopowder preparation technology, exploring self-healing coatings to cope with arc wear, and integrating artificial intelligence to optimize preparation parameters. In the future, silver-tungsten alloys are expected to achieve greater breakthroughs in intelligent electrical systems and extreme environments.

1.3 Importance and significance of industry research

Industry research on silver-tungsten alloy plays an important role in promoting the development of material science and its application in multiple fields. Through in-depth research on its preparation process, performance optimization and failure mechanism, it can not only improve the performance and reliability of the alloy, but also promote innovation and progress in related industries. Through interdisciplinary cooperation, industry research combines material science, electrical engineering and manufacturing technology to provide theoretical support and technical guarantee for the application of silver-tungsten alloy in high-performance electrical, electronic and defense fields.

1.3.1 Promotion of the development of materials science

The research on silver-tungsten alloy has a profound impact on the development of materials science. First of all, as a typical representative of composite materials, the progress of its preparation process (such as powder metallurgy, nanotechnology and additive manufacturing) has promoted the design and development of high-performance composite materials. By optimizing the silver-tungsten ratio, introducing nanostructures and functional gradient design, researchers have explored the performance limits of metal-based composites, providing theoretical and practical references for other high-performance alloys. The study of the sintering mechanism and microstructure evolution of silver-tungsten alloy has deepened the understanding of liquid phase sintering and interface bonding, and promoted the innovation of powder metallurgy technology.

Secondly, the research on the arc corrosion resistance and high temperature performance of silver-tungsten alloy has promoted the development of extreme environment resistant materials. By analyzing the surface behavior and thermal stress distribution under the action of the arc, researchers have developed new coatings and surface modification technologies to improve the stability of materials in high current and high temperature environments. These results can be transferred to the design of other high-temperature alloys and electrical materials. In addition, the research on green manufacturing technologies, such as low-energy sintering and waste recycling, has injected the concept of sustainable development into materials science, reducing resource waste and environmental impact. The research on silver-tungsten alloy has also promoted interdisciplinary integration, combined with computational materials science and artificial intelligence to optimize material design, and accelerated the transformation of new materials from laboratory to industrial application. In the future, the research on

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silver-tungsten alloy is expected to promote the development of smarter and more environmentally friendly composite materials, injecting new vitality into materials science.

1.3.2 Value of application in various fields

Industry research on silver-tungsten alloys demonstrates significant value in applications in the electrical, electronic, defense, aerospace, and medical fields. In the electrical field, the high conductivity and arc corrosion resistance of silver-tungsten alloys make them ideal materials for high-voltage circuit breakers, relays, and switch contacts. Research has improved the reliability and life of power systems by optimizing alloy properties, meeting the needs of smart grids and high-power devices. In the electronics field, silver-tungsten alloys are used in RF modules and power semiconductor contacts. Their excellent thermal conductivity and non-magnetic properties support the development of 5G communications and high-performance computing equipment.

In the defense and aerospace fields, the high temperature resistance and high density of silver-tungsten alloy make it indispensable in radar electrodes, missile electrical connections, and spacecraft counterweight components. Research has optimized component performance through functional gradient design and additive manufacturing, improving system accuracy and reliability. In the medical field, the non-magnetic and biocompatibility of silver-tungsten alloy makes it suitable for MRI equipment contacts and radiotherapy shielding parts. Research has ensured the safety and high precision of the alloy through green manufacturing and precision machining. The value of industry research is also reflected in promoting cross-industry collaboration. Through the combination with electrical engineering, thermal management technology and intelligent manufacturing, the application scenarios of silver-tungsten alloy are constantly expanding, such as new energy vehicle charging systems and renewable energy equipment. Optimization directions include developing low-cost preparation processes, exploring multifunctional composite materials, and integrating intelligent monitoring technologies to improve application reliability.



CTIA GROUP LTD Silver Tungsten Alloy

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Chapter 2 Composition and Characteristics of Silver-Tungsten Alloy

As a high-performance composite material, silver-tungsten alloy has wide application potential in electrical, electronic, defense and industrial fields due to its excellent electrical conductivity, thermal conductivity, high temperature resistance and arc corrosion resistance. The alloy is prepared by powder metallurgy process, with silver (Ag) as the matrix or bonding phase, providing high electrical and thermal conductivity, and tungsten (W) as the reinforcement phase, contributing high melting point and hardness, and can meet the demanding requirements of high current, high temperature or high wear environment. The performance of silver-tungsten alloy directly depends on the physical and chemical properties of its main components, silver and tungsten, and the synergistic effect of the two.

2.1 Characteristics of Silver and Tungsten

The performance of [silver-tungsten alloy](#) is derived from the unique physical and chemical properties of silver and tungsten. The complementarity of the two makes it perform well in electrical contacts, welding electrodes and high-temperature components. Silver provides excellent electrical and thermal conductivity, ensuring efficient current and heat transfer; tungsten's high melting point, hardness and arc corrosion resistance enhance the stability of the alloy in extreme environments. The two are combined through powder metallurgy to form a dense microstructure that meets the needs of high-reliability applications.

2.1.1 Physical and chemical properties of silver

Silver (Ag) is a precious metal that is unique among metal materials for its excellent electrical and thermal conductivity. It is the key matrix or bonding phase in silver-tungsten alloys. Silver has extremely high electrical conductivity, can efficiently transmit current, and reduce resistance losses, making it an ideal choice for electrical contacts and electrode materials. Silver also has excellent thermal conductivity, which helps to quickly disperse the heat generated when the components are running and prevent overheating from causing performance degradation. Compared with tungsten, its lower melting point makes it easier to form a liquid during the liquid phase sintering process of powder metallurgy, wet tungsten particles, fill microscopic gaps, and form a dense alloy structure, thereby improving conductivity and structural stability.

Silver has strong chemical stability and anti-oxidation ability, which makes it difficult to react with oxygen at room temperature, maintaining a smooth surface and conductive properties. However, in high temperature or sulfur-containing environments, silver may undergo slight oxidation or sulfidation, resulting in a slight increase in surface resistance, affecting long-term performance. Silver has good ductility and toughness, and can absorb stress under mechanical shock or arcing, reducing the risk of cracks in the alloy in high current environments. Silver has a moderate density, which provides a certain weight basis for silver-tungsten alloys and is suitable for applications that require counterweights. The non-magnetic properties of silver ensure that the alloy will not interfere in electromagnetically sensitive environments (such as MRI equipment or radar systems), enhancing its applicability in high-precision

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electrical systems.

In silver-tungsten alloy, silver, as a conductive and thermally conductive phase, significantly improves the alloy's current transmission efficiency and thermal management capabilities, making it particularly suitable for applications such as high-voltage circuit breaker contacts, relays, and resistance welding electrodes. Its chemical stability supports the durability of the alloy in frequent switching or arcing environments, but it needs to be treated with surface treatment or component optimization to address high-temperature oxidation or corrosion issues. The high cost of silver is its limitation, and it is necessary to balance performance and economy through reasonable proportions and green manufacturing technology.

2.1.2 Physical and chemical properties of tungsten

Tungsten (W) is a high melting point transition metal. With its extremely high melting point, hardness and density, it is used as a reinforcing phase in silver-tungsten alloys to significantly improve the alloy's high temperature resistance and arc corrosion resistance. Tungsten has an extremely high melting point and can withstand extreme high temperature environments (such as arcs or welding processes), allowing it to maintain structural stability in high current and high temperature applications. Tungsten has extremely high hardness, giving the alloy excellent wear resistance and mechanical impact resistance, making it suitable for high wear scenarios such as resistance welding electrodes and plasma sprayed parts. The high density of tungsten provides a weight advantage for the alloy, making it suitable for counterweight or shielding applications, such as aerospace electrical connection components.

Lower electrical and thermal conductivity than silver, but its addition significantly improves the alloy's resistance to arc corrosion. Under the action of the arc, tungsten's high melting point and chemical stability make it less likely to be ablated or melted, extending the life of contacts and electrodes. Tungsten has good chemical stability and resists corrosion at room temperature and in neutral environments, but it may form oxides in high-temperature oxidizing or acidic environments, affecting surface properties. Tungsten's low thermal expansion coefficient ensures the alloy's dimensional stability during thermal cycles and is suitable for high-precision components such as high-voltage switch contacts. Tungsten's non-magnetic properties are consistent with silver, supporting the alloy's application in electromagnetically sensitive environments.

In silver-tungsten alloy, tungsten as a reinforcing phase significantly improves the alloy's high temperature resistance, wear resistance and arc resistance, enabling it to operate stably in harsh electrical environments. The high hardness and density of tungsten enhance the alloy's mechanical strength and weight-balancing performance, but its lower conductivity needs to be compensated by the matrix effect of silver. Tungsten is difficult to process, and complex shapes need to be achieved through powder metallurgy and precision machining technology. Optimization directions include improving sintering efficiency through nano-scale tungsten powder, or adding trace elements (such as nickel) to improve toughness. The synergistic effect of silver and tungsten gives silver-tungsten alloy unique advantages in the electrical, electronic and defense fields, meeting the needs of high-performance applications.

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2.1.3 Silver tungsten composition

Silver-tungsten alloy is mainly composed of silver (Ag) and tungsten (W), and is usually prepared by powder metallurgy process. Silver is used as the conductive and thermal conductive matrix, and tungsten is used as the reinforcing phase for high temperature resistance and wear resistance. The ratio of silver to tungsten directly affects the conductivity, thermal conductivity, hardness, arc corrosion resistance and density of the alloy, and can be adjusted according to specific application requirements. When the silver content is higher, the alloy has better conductivity and thermal conductivity, which is suitable for high-voltage electrical contacts; when the tungsten content is higher, the alloy has stronger high temperature resistance and wear resistance, which is suitable for welding electrodes and high-temperature parts. Trace additives (such as nickel or cobalt) are sometimes used to improve toughness or processing performance, but they need to be strictly controlled to maintain non-magnetism and performance stability. The following table lists the typical composition range of silver-tungsten alloy and its properties.

Material	Composition (weight percent)	Density (g / cm ³)	Electrical conductivity	Resistivity	Hardness (HB)
AgW30	Silver 70%, Tungsten 30%	11.8-12.2	73	2.3	75
AgW40	Silver 60%, Tungsten 40%	12.5-12.8	64	2.6	85
AgW50	Silver 50%, Tungsten 50%	13.2-13.5	56-73	2.3-3.0	105
AgW55	Silver 45%, Tungsten 55%	13.6-13.9	54	3.2	115
AgW60	Silver 40%, Tungsten 60%	14.0-14.4	50-60	2.8-3.3	125
AgW65	Silver 35%, Tungsten 65%	14.5-14.9	50	3.4	135
AgW70	Silver 30%, Tungsten 70%	14.7-15.1	48	3.5	150
AgW75	Silver 25%, Tungsten 75%	15.4-15.8	45-52	3.2-3.7	165
AgW80	Silver 20%, Tungsten 80%	16.1-16.5	37	4.5	180

Composition characteristics and functions : Silver acts as a matrix or bonding phase in the alloy. Its high electrical and thermal conductivity ensures efficient current transmission and heat management, and is particularly suitable for applications that require low resistance and high heat dissipation efficiency, such as high-voltage switch contacts. Silver's liquid phase wettability promotes the bonding of tungsten particles during the sintering process, forming a dense microstructure and improving the performance consistency of the alloy.

Tungsten is used as a reinforcing phase. Its high melting point and hardness enable the alloy to remain stable in high current arcs or high temperature environments. Its arc corrosion resistance and wear resistance make it suitable for electrical contacts and welding electrodes that are frequently switched. The high density of tungsten provides a counterweight function for the alloy, making it suitable for aerospace electrical connection components. Trace additives enhance the manufacturing feasibility of complex-shaped components by improving the liquid phase sintering effect and alloy toughness, but precise control is required to avoid introducing magnetism or reducing conductivity.

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Performance impact and application : The increase in silver content significantly improves electrical conductivity and thermal conductivity, but may reduce hardness and wear resistance, which is suitable for scenarios requiring high current transmission; the increase in tungsten content enhances high temperature resistance and arc resistance, but reduces electrical conductivity, which is suitable for high temperature and high wear environments. The optimization of the composition ratio needs to be weighed according to application requirements. For example, high-voltage circuit breaker contacts tend to have a high silver content to ensure conductivity, while resistance welding electrodes prefer a high tungsten content to improve wear resistance. The non-magnetic and low thermal expansion coefficient of the alloy give it advantages in electromagnetically sensitive and high-precision scenarios (such as MRI equipment and radar systems). During the preparation process, high-energy ball milling, liquid phase sintering and hot isostatic pressing (HIP) are used to ensure composition uniformity and density to meet high reliability requirements. Optimization directions include improving performance consistency through nano-scale powders, optimizing silver-tungsten distribution using functional gradient design, or developing green manufacturing technologies to reduce the cost of silver. The composition flexibility of silver-tungsten alloys makes it show a wide range of application value in electrical, electronic and defense fields.

2.2 Effect of silver-tungsten alloy composition ratio

The composition ratio of silver-tungsten alloy is a key factor affecting its mechanical properties and application performance. The ratio of silver (Ag) and tungsten (W) directly determines the bending strength, toughness, electrical conductivity, thermal conductivity and arc corrosion resistance of the alloy. By adjusting the silver-tungsten ratio, a balance can be achieved between conductivity and mechanical properties to meet the needs of different application scenarios. When the silver content is high, the conductivity and toughness of the alloy are enhanced, which is suitable for high-current electrical contacts; when the tungsten content is high, the bending strength and high temperature resistance of the alloy are improved, which is suitable for welding electrodes and high-wear parts. The specific effects of the silver -tungsten ratio on bending strength and toughness will be analyzed in detail below .

2.2.1 Effect of silver -tungsten ratio on the bending strength of alloy

Silver -tungsten ratio has a significant effect on the flexural strength of the alloy, which refers to the ability of the alloy to resist deformation or fracture under bending loads, and is directly related to its reliability in mechanical stress environments. When the silver content is high, the flexural strength of the alloy is low, because the ductility and low hardness of silver make it difficult to withstand large bending stresses, and it is suitable for electrical contact applications with low dynamic loads. Silver, as a matrix or bonding phase, wets the tungsten particles during the liquid phase sintering process. Although it enhances the density of the structure, its low strength limits the performance of the alloy in high stress scenarios. With the increase of tungsten content, the flexural strength increases significantly, because the high hardness and high melting point of tungsten give the alloy stronger rigidity and deformation resistance. Tungsten particles form a skeleton structure in the alloy, which enhances the overall mechanical support of the material. Especially at high tungsten content, the flexural strength reaches a peak, which is suitable for parts requiring high wear resistance and structural stability.

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Silver -tungsten ratio also affect the uniformity of the microstructure. Too high a silver content may lead to uneven dispersion of tungsten particles and reduce the stability of the flexural strength; too high a tungsten content may form pores due to insufficient silver liquid phase , affecting the uniformity of mechanical properties. Optimization of sintering processes (such as liquid phase sintering and hot isostatic pressing) can alleviate these problems and enhance flexural strength by increasing density and reducing defects. The improvement in flexural strength enables silver-tungsten alloys to perform well in resistance welding electrodes, plasma sprayed parts, and aerospace counterweights, and to withstand mechanical shock and vibration. Optimization directions include improving particle distribution through nano-scale tungsten powder , or increasing the tungsten content on the surface using functional gradient design to enhance flexural performance. Reasonable adjustment of the silver- tungsten ratio provides important support for high-reliability applications, especially in scenarios where both conductivity and mechanical strength need to be taken into account.

2.2.2 Effect of silver- tungsten ratio on alloy toughness

Silver- to-tungsten ratio has an important influence on the toughness of the alloy, which refers to the ability of the alloy to absorb energy and resist fracture, and determines its durability under impact or arcing. When the silver content is higher, the alloy has better toughness, because the ductility and plasticity of silver can absorb mechanical shock and thermal stress, reducing the risk of crack propagation. This property makes high-silver-content silver-tungsten alloys suitable for electrical applications that require frequent switching, such as high-voltage circuit breaker contacts and relay contacts. The toughness of silver helps to alleviate the stress concentration caused by arcing and extend the life of components. However, the lower hardness of silver may cause deformation in high-wear environments, limiting its performance under extreme mechanical loads.

As the tungsten content increases, the toughness of the alloy gradually decreases, because the high hardness and brittleness of tungsten weaken the material's ability to plastically deform. High tungsten content makes the alloy more rigid and suitable for applications with high temperature resistance and arc corrosion resistance, such as welding electrodes and high-temperature molds, but its lower toughness may cause microcracks during impact or thermal cycles. The wetting effect of silver as a binder phase alleviates the brittleness between tungsten particles to a certain extent, but when the tungsten content is too high, insufficient liquid phase may cause micro defects, further reducing toughness. Optimization of the sintering process, such as spark plasma sintering (SPS) or the addition of trace elements, can improve the microstructure and enhance toughness, especially in alloys with high tungsten content.

Changes in toughness directly affect the application scenarios of silver-tungsten alloys. Alloys with high silver content are suitable for dynamic electrical environments, such as smart grid switches and electronic RF modules, due to their excellent toughness; alloys with high tungsten content are suitable for static or high-wear parts, such as aerospace counterweights and plasma sprayed parts, due to their high temperature resistance and hardness. Optimization directions include improving the dispersibility of tungsten particles through nanostructured design, or developing composite coatings to enhance surface toughness. The adjustment of the silver -tungsten ratio needs to balance toughness and hardness

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according to application requirements. For example, increase the silver ratio in scenarios that require impact resistance, and increase the tungsten ratio in scenarios that require high temperature resistance . Reasonable control of the component ratio and preparation process enables silver-tungsten alloys to exhibit excellent comprehensive performance in the electrical, electronic and defense fields.

2.2.3 Effect of silver- tungsten ratio on the conductivity of alloy

Silver- to-tungsten ratio has a significant effect on the conductivity of the alloy, which is a key indicator of the alloy's ability to transmit current and is directly related to its performance in electrical contacts and electrodes. When the silver content is high, the conductivity of the alloy is significantly enhanced. Because silver has extremely high electrical conductivity, it effectively reduces resistance losses as a matrix or bonding phase, making it suitable for high-current applications such as high-voltage circuit breaker contacts, relays, and RF modules. Silver wets the tungsten particles during the liquid phase sintering process to form a continuous conductive network, further improving the current transmission efficiency. As the tungsten content increases, the conductivity gradually decreases. Because the conductivity of tungsten is much lower than that of silver, the high tungsten content reduces the conductive path and increases the resistance, limiting the performance of the alloy in high current scenarios.

Silver -tungsten ratio also affect the conductive consistency of the microstructure. Too high a silver content may lead to uneven dispersion of tungsten particles and limited local conductivity; too high a tungsten content may form pores due to insufficient silver liquid phase , increasing contact resistance. Optimization of the sintering process, such as high-energy ball milling and hot isostatic pressing, can improve the uniformity and density of the composition and enhance the conductive stability. The improvement in conductivity enables silver-tungsten alloys to perform well in smart grid switches and electronic devices, meeting the needs of low resistance and efficient transmission. Optimization directions include improving the conductive network through nano-scale silver powder, or increasing the silver ratio in the conductive area through functional gradient design. Reasonable adjustment of the silver- tungsten ratio provides important support for high-reliability electrical applications, especially in scenarios requiring efficient conductivity.

2.2.4 Effect of silver -tungsten ratio on thermal conductivity of alloy

Silver -tungsten ratio has an important influence on the thermal conductivity of the alloy. Thermal conductivity is a key indicator of the alloy's ability to disperse heat, and is directly related to its stability and heat dissipation performance in high-temperature environments. When the silver content is high, the thermal conductivity of the alloy is significantly enhanced. Because silver has excellent thermal conductivity, it can quickly transfer heat as a matrix or bonding phase to prevent performance degradation caused by overheating. It is suitable for power semiconductor contacts and electronic heat dissipation substrate applications. The liquid phase network formed by silver during the sintering process promotes uniform heat distribution and improves heat dissipation efficiency. As the tungsten content increases, the thermal conductivity gradually decreases. Because the thermal conductivity of tungsten is lower than

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that of silver, the high tungsten content reduces the heat conduction path, limiting the performance of the alloy in high heat load scenarios.

Silver -tungsten ratio also affect the uniformity of heat conduction. Too high a silver content may lead to uneven thermal expansion and affect long-term stability; too high a tungsten content may form thermal resistance points due to insufficient silver liquid phase , reducing thermal conductivity. Optimization of sintering processes, such as spark plasma sintering (SPS) and surface treatment, can reduce porosity and defects and enhance thermal conductivity consistency. The improvement in thermal conductivity enables silver-tungsten alloys to perform well in high-temperature electronic equipment and aerospace components, meeting the needs of efficient heat dissipation and thermal management . Optimization directions include optimizing the thermal conduction network through nano-scale silver powder, or using composite coatings to enhance surface heat dissipation capabilities. Adjustment of the silver- tungsten ratio needs to balance thermal conductivity and high temperature resistance according to application requirements, such as increasing the silver ratio in the heat dissipation substrate and increasing the tungsten ratio in the high-temperature structure .

2.2.5 Effect of silver- tungsten ratio on alloy density

The silver to tungsten ratio has a significant effect on the density of the alloy, which is a key indicator of the alloy's mass per unit volume and is directly related to its performance in counterweight and shielding applications. At higher silver contents, the alloy has a moderate density, which is lower than tungsten but higher than many other metals, making it suitable for electrical contact applications that require a certain amount of weight but not too much. However, too high a silver content may reduce the overall density and limit its performance in high-counterweight scenarios. As the tungsten content increases, the density of the alloy increases significantly, and because tungsten has an extremely high density, it enhances the counterweight and radiation shielding capabilities, making it suitable for aerospace counterweights and medical radiotherapy shielding parts.

Silver -tungsten ratio also affect the uniformity of density. Too high a silver content may cause uneven sedimentation of tungsten particles, affecting local density; too high a tungsten content may form pores due to insufficient silver liquid phase , reducing the overall density. Optimization of the sintering process, such as liquid phase sintering and hot isostatic pressing, can improve the composition distribution and density. The increase in density enables silver-tungsten alloys to perform well in applications that require high weight balancing or radiation shielding, and can meet the needs of aerospace dynamic balance and medical radiation protection. Optimization directions include improving particle distribution through nano-scale tungsten powder , or increasing the proportion of tungsten in the weight-balancing area using functional gradient design .

2.2.6 Effect of silver- tungsten ratio on alloy hardness

Silver- to-tungsten ratio has a significant effect on the hardness of the alloy, which is the ability of the alloy to resist surface indentation or wear, and is directly related to its durability in a mechanical stress

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environment. When the silver content is high, the hardness of the alloy is low, because the ductility and low hardness of silver make it difficult to resist surface wear, which is suitable for electrical contact applications with low dynamic loads. Silver acts as a matrix or bonding phase, wetting the tungsten particles during the liquid phase sintering process. Although it enhances the density of the structure, its low hardness limits the performance of the alloy in high wear scenarios. As the tungsten content increases, the hardness increases significantly, because the high hardness and high melting point of tungsten give the alloy stronger resistance to compression and wear. Tungsten particles form a skeleton structure in the alloy, which enhances the surface resistance of the material, especially at high tungsten content, the hardness reaches a peak, which is suitable for parts that require high wear resistance.

Silver -tungsten ratio also affect the uniformity of the microstructure. Too high a silver content may lead to uneven dispersion of tungsten particles and reduce the stability of hardness; too high a tungsten content may form pores due to insufficient silver liquid phase , affecting the uniformity of mechanical properties. Optimization of sintering processes, such as spark plasma sintering (SPS) or hot isostatic pressing (HIP), can increase density and reduce defects, and enhance hardness consistency. The increase in hardness enables silver-tungsten alloys to perform well in resistance welding electrodes, plasma sprayed parts, and aerospace counterweights, and can withstand mechanical wear and surface impact. Optimization directions include improving particle distribution through nano-scale tungsten powder, or using surface hardening coatings (such as TiN) to further improve hardness.

2.2.7 Effect of silver -tungsten ratio on high temperature resistance of alloy

Silver- to-tungsten ratio has an important influence on the high-temperature resistance of the alloy. High-temperature resistance is the ability of the alloy to maintain structural stability and performance in a high-temperature environment , which is directly related to its reliability in high-temperature applications. When the silver content is high, the alloy's high-temperature resistance is weaker because silver has a low melting point and is easily softened or melted at high temperatures, limiting its use in extreme thermal environments. Silver acts as a binder phase to wet the tungsten particles during sintering, but its low thermal stability may lead to performance degradation in high-current or high-temperature operations. With the increase of tungsten content, high-temperature resistance is significantly enhanced because tungsten's high melting point and thermal stability give the alloy excellent resistance to thermal deformation. When the tungsten content is high, the alloy can maintain structural integrity during high-temperature arcs or welding, making it suitable for parts that require high-temperature resistance.

Silver -tungsten ratio also affect stability during thermal cycles. Too high a silver content may lead to uneven thermal expansion and increase the risk of thermal stress; too high a tungsten content may form microcracks due to insufficient silver liquid phase , affecting uniformity at high temperatures. Optimization of the sintering process, such as staged heating and hot isostatic pressing, can improve the density of the microstructure and enhance high-temperature consistency. The improvement in high-temperature resistance enables silver-tungsten alloys to perform well in high-temperature electronic equipment, rocket nozzle components, and aerospace counterweights, and can meet the needs of extreme thermal environments. Optimization directions include optimizing thermal stress distribution through

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functional gradient design, or developing high-temperature resistant coatings to enhance surface stability. Adjustment of the silver -tungsten ratio needs to balance high-temperature resistance and conductivity according to application requirements, such as increasing the proportion of tungsten in high-temperature structures while retaining silver moderately in conductive components.

2.2.8 Effect of silver- tungsten ratio on arc erosion resistance of alloy

Silver- to-tungsten ratio has a significant effect on the arc erosion resistance of the alloy, which is the ability of the alloy to resist arc ablation and material loss, and is directly related to its life in high-current electrical contacts. When the silver content is high, the alloy's arc erosion resistance is weaker, because the lower melting point and chemical activity of silver make it easy to melt or ablate under the action of the arc, which is suitable for applications with low arc intensity. Silver acts as a matrix to wet the tungsten particles during the sintering process, but it may accelerate surface loss in high current environments. With the increase of tungsten content, arc erosion resistance is significantly enhanced, because tungsten's high melting point and chemical stability make it difficult to melt or oxidize under the arc, extending the service life of contacts and electrodes. At a high tungsten content, the alloy can maintain surface integrity in frequent switching or high current environments, which is suitable for parts that require high arc resistance.

Silver -tungsten ratio also affect the uniformity under the action of the arc. Too high a silver content may cause the arc to concentrate on ablation in a local area; too high a tungsten content may form an inhomogeneous structure due to insufficient silver liquid phase , affecting the consistency of corrosion resistance. Optimization of the sintering process, such as vacuum sintering and surface treatment, can reduce oxidation and defects and enhance arc erosion resistance. The improvement in arc erosion resistance enables silver-tungsten alloys to perform well in high-voltage circuit breaker contacts, relays, and resistance welding electrodes, and can meet the needs of high current and frequent operations. Optimization directions include improving surface uniformity through nano-scale tungsten powder, or using arc-resistant coatings (such as ZrC) to further improve corrosion resistance.

2.3 Performance Analysis of Silver-Tungsten Alloy

The high performance of silver-tungsten alloy stems from its unique microstructure and composition synergy. Its hardness, high temperature resistance, arc erosion resistance and other characteristics make it perform well in a variety of demanding applications. The performance analysis of the alloy needs to start from the microscopic mechanism, material design and application requirements, and systematically analyze its hardness formation process, high temperature resistance and arc erosion resistance advantages. These characteristics are achieved through the optimization of powder metallurgy process to ensure the reliability of the alloy in electrical contacts, welding electrodes and aerospace components.

2.3.1 Formation mechanism and advantages of high hardness of silver-tungsten alloy

The high hardness of silver-tungsten alloy is its core advantage in high wear and mechanical stress

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environments, enabling it to resist surface indentation, wear and impact, and extend the service life of components. The formation of hardness stems from the high inherent hardness of tungsten and the micro-optimization of the silver-tungsten composite structure during the sintering process. Silver, as a binder phase, wets the tungsten particles in liquid phase sintering, enhancing the density of the structure, while tungsten, as a reinforcing phase, provides a high-hardness skeleton support. This synergistic effect enables silver-tungsten alloy to perform well in resistance welding electrodes, plasma sprayed components, and aerospace counterweights, capable of withstanding mechanical wear and surface damage. The advantage of high hardness is that it improves the alloy's ability to resist deformation, especially in high current or high temperature environments, the alloy surface can maintain integrity and avoid performance degradation.

2.3.1.1 Microstructural mechanism of high hardness

The formation mechanism of high hardness of silver-tungsten alloy mainly depends on the unique design of its microstructure and the interaction during sintering. This process is realized through powder metallurgy process, involving steps such as powder mixing, pressing, liquid phase sintering and post-processing. The core of the microstructural mechanism lies in the distribution of tungsten particles in the silver matrix, the wetting effect of liquid phase sintering and the synergistic effect of grain boundary strengthening. First of all, tungsten is a high hardness reinforcing phase. Its particles are evenly dispersed by high-energy ball milling technology in the powder mixing stage. The optimization of particle size and shape ensures the formation of a uniform skeleton structure after pressing. The high melting point of tungsten keeps it in a solid state during sintering, and it is not easy to deform or melt. It provides rigid support for the alloy and significantly improves the hardness foundation. Silver, as a low-melting point bonding phase, melts to form a liquid during liquid phase sintering, wets the tungsten particles and fills their gaps. This process is achieved through capillary action and diffusion mechanism, eliminating micropores and improving the density of the alloy.

The wetting effect of liquid phase sintering is a key step in the formation of high hardness. The silver liquid phase penetrates the microscopic defects on the surface of tungsten particles at high temperature, enhances the bonding force between particles, and forms a dense interface structure. This interface bonding not only improves the overall strength of the material, but also further enhances the hardness through the grain boundary strengthening effect. Grain boundary strengthening originates from the silver phase layer between tungsten particles. The ductility of silver buffers stress concentration to a certain extent, but the high hardness of tungsten dominates the surface resistance of the alloy. During the sintering process, the application of hot isostatic pressing (HIP) or spark plasma sintering (SPS) technology further optimizes the microstructure, eliminates residual pores through high voltage and pulse current, compresses grain boundaries, makes tungsten particles more closely arranged, and significantly improves the hardness level. In addition, the geometry and orientation of tungsten particles also play a role in the formation of hardness. Regular or polyhedral tungsten particles can disperse stress more effectively and enhance compression and wear resistance.

The uniformity of the microstructure is an important guarantee for the formation of high hardness. When

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the silver content is moderate, the liquid phase is sufficient to fill the gaps between the tungsten particles, avoiding pores caused by insufficient liquid phase or uneven particle sedimentation caused by excessive liquid phase. The control of the sintering atmosphere prevents oxidation or the introduction of impurities, maintains the purity of tungsten and silver, and ensures the stability of the microstructure. The application of nano-scale tungsten powder further enhances the hardness mechanism, increases the grain boundary density by reducing the particle size, and enhances the ability of the grain boundary to block the movement of dislocations, thereby significantly improving the deformation resistance of the alloy. The volume fraction of tungsten particles in the microstructure also has a direct impact on the hardness. The higher the tungsten content, the more obvious the hardness enhancement effect, but the wetting effect of silver needs to be balanced to avoid increased brittleness.

The microstructural mechanism formed by high hardness provides silver-tungsten alloy with many advantages. First, the high hardness enables the alloy to resist mechanical wear and surface indentation, which is particularly suitable for high-wear applications such as resistance welding electrodes and plasma sprayed parts, and can maintain surface integrity during frequent mechanical contact. Secondly, the high hardness enhances the alloy's ability to resist deformation in high-temperature environments. The high melting point of tungsten and the densification effect of silver make the alloy less likely to soften or melt during arc or high-temperature welding, extending its service life. In addition, the high-hardness microstructure supports the processing of complex-shaped parts, and high-precision contacts and electrode manufacturing are achieved through precision machining technology. The optimized microstructure also improves the alloy's fatigue resistance and reduces the risk of microcracks caused by thermal cycling or mechanical shock, making it particularly suitable for aerospace counterweights and defense electrical connection components.

However, the formation of high hardness is also accompanied by certain challenges. Excessive tungsten content may lead to increased brittleness of the alloy, especially when the silver liquid phase is insufficient, the risk of microcracks increases. Precise control of the sintering process and post-treatment (such as surface hardening coating) become the key to solving this problem. Optimization directions include developing nanocomposite structures to improve the balance between toughness and hardness, or increasing the tungsten content on the surface through functional gradient design to enhance local hardness. In short, the microstructural mechanism of the high hardness of silver-tungsten alloy gives the alloy excellent wear resistance and deformation resistance through the synergistic effect of tungsten rigid support, silver wetting and densification, and grain boundary strengthening, laying a solid foundation for its wide application in electrical, electronic and defense fields.

2.3.1.2 Advantages of high hardness in wear-resistant applications

The high hardness of silver-tungsten alloy has significant application advantages in wear-resistant scenarios, making it an ideal material for high-wear environments. Wear resistance is the ability of an alloy to resist surface wear, abrasions and mechanical damage, which directly affects its life in frequent contact or high-load applications. The high hardness of silver-tungsten alloy is mainly due to the high inherent hardness of tungsten. The tungsten particles form a solid skeleton structure during the sintering

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process, which significantly enhances the resistance of the alloy surface to mechanical wear. Silver, as a bonding phase, wets the tungsten particles through liquid phase sintering, fills the microscopic gaps, forms a dense microstructure, and further improves the surface durability. This high hardness property enables silver-tungsten alloy to withstand high-frequency mechanical contact, friction and impact, especially in scenarios that require long-term stable operation.

In specific applications in wear-resistant scenarios, the high hardness of silver-tungsten alloy gives it excellent performance in resistance welding electrodes. Welding electrodes frequently contact workpieces under high current and high temperature conditions. Traditional materials such as pure silver or copper-based alloys are prone to surface wear due to their lower hardness, resulting in deformation of the electrode shape and deterioration of welding quality. The high hardness of silver-tungsten alloy enables it to resist mechanical wear on the electrode surface, maintain precise contact geometry, and ensure the stability and consistency of the welding process. Similarly, in plasma sprayed parts, the high hardness enables the alloy to withstand the impact and abrasion of high-speed particle flow, extend the service life of the parts, and is suitable for aerospace and industrial coating applications. In addition, in aerospace counterweight components, the high hardness enhances the alloy's resistance to wear under vibration and mechanical loads, ensuring the long-term reliability of the dynamic balancing system.

The application advantage of high hardness is also reflected in reducing maintenance costs and improving equipment efficiency. The wear resistance of silver-tungsten alloy reduces the frequency of component replacement, especially in high-voltage circuit breaker contacts and relay contacts. Frequent mechanical contact and arcing often lead to surface loss. High hardness effectively slows down this loss and extends the equipment operation cycle. Microstructure optimization of the alloy, such as eliminating pores through hot isostatic pressing (HIP) or improving particle uniformity through nano-scale tungsten powder, further enhances wear resistance. This feature supports the long-term stability of the alloy in high-wear environments and reduces performance degradation or safety hazards caused by wear. Optimization directions include developing surface hardening coatings (such as TiN or CrN) to further improve wear resistance, or increasing the tungsten content in the wear-resistant area through functional gradient design to enhance local performance.

The wear-resistant advantage of high hardness is also accompanied by certain challenges. High tungsten content may increase the brittleness of the alloy, especially when the silver liquid phase is insufficient, the risk of microcracks increases, and the wear-resistant consistency is affected. Precise control and post-processing of the sintering process become key, such as using spark plasma sintering (SPS) to quickly form a dense structure, or reducing stress concentration points through surface polishing. In the future, combining intelligent monitoring technology to evaluate the wear state in real time, or exploring self-healing coatings to dynamically repair surface damage, will further enhance the application potential of silver-tungsten alloy in wear-resistant scenarios.

2.3.1.3 Hardness comparison with other alloys and advantages

The high hardness of silver-tungsten alloy is closely related to its performance in high wear and

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mechanical stress environments. Its advantages are highlighted by comparing the hardness with other common alloys. Hardness is the ability of a material to resist surface indentation or wear. The hardness of silver-tungsten alloy is mainly due to the high inherent hardness of tungsten and its dense microstructure formed during the sintering process. The following will compare with materials such as tungsten-copper alloy, pure silver and cemented carbide to analyze the hardness advantages of silver-tungsten alloy and its outstanding performance in applications.

First, compared with tungsten-copper alloy, silver-tungsten alloy has higher hardness. Tungsten-copper alloy uses tungsten as the matrix and copper as the bonding phase. Although it has good thermal conductivity and processing properties, the lower hardness of copper limits its wear resistance and is suitable for heat dissipation substrates rather than high-wear contacts. Silver-tungsten alloy has a higher tungsten content and forms a dense structure due to the wetting effect of silver. Its hardness is significantly better than that of tungsten-copper alloy. Especially in resistance welding electrodes and plasma sprayed parts, silver-tungsten alloy can resist higher mechanical wear and surface impact. In addition, the hardness advantage of silver-tungsten alloy is also reflected in its stability in arc-resistant environments. The high melting point of tungsten enables it to maintain surface integrity under arc erosion, while the copper phase of tungsten-copper alloy is easily melted, which limits its resistance to arc wear.

Secondly, compared with pure silver, the hardness of silver-tungsten alloy is greatly improved. Pure silver is widely used in electrical contacts for its high conductivity and ductility, but its lower hardness makes it easy to deform or ablate under mechanical wear and arcing, and its life is limited. By introducing high-hardness tungsten particles, silver-tungsten alloy significantly enhances its wear resistance and deformation resistance, making it suitable for scenes that require frequent contact, such as high-voltage circuit breaker contacts and relay contacts. The softness of pure silver makes it difficult to withstand high loads, while the high hardness of silver-tungsten alloy ensures the long-term reliability of components in dynamic environments. Although its conductivity is slightly lower than that of pure silver, a performance balance can be achieved by optimizing the silver-tungsten ratio.

Thirdly, compared with cemented carbide (such as tungsten-cobalt alloy), silver-tungsten alloy has a slightly lower hardness, but its comprehensive performance is more advantageous. Cemented carbide is mainly composed of tungsten carbide and cobalt, with extremely high hardness. It is widely used in cutting tools and molds, but its electrical conductivity and thermal conductivity are poor, which limits its application in electrical contacts. Although the hardness of silver-tungsten alloy is lower than that of cemented carbide, its excellent electrical conductivity and arc corrosion resistance make it more practical in electrical contacts and welding electrodes. The microstructural optimization of silver-tungsten alloy (such as nano-scale tungsten powder and liquid phase sintering) makes its hardness close to the level of cemented carbide, while retaining the conductive properties of silver, achieving an effective combination of hardness and conductivity.

The advantage of silver-tungsten alloy's hardness is highlighted in the diversity of its application scenarios. In resistance welding electrodes, the high hardness of silver-tungsten alloy resists wear during

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workpiece contact, ensuring stable welding quality; in plasma sprayed components, the high hardness withstands the impact of high-speed particle flow and extends component life; in aerospace counterweights, the high hardness enhances durability in vibration environments. These advantages make it superior to other alloys in scenarios where both hardness and conductivity need to be taken into account. Optimization directions include improving the balance between hardness and toughness through nano-composite structures, or developing surface hardening coatings to further enhance wear resistance. The high hardness comparative advantage of silver-tungsten alloy gives it a unique position in the electrical, electronic and defense fields, providing important support for high-reliability components. Its potential can be further tapped in the future through intelligent manufacturing technology.

2.3.2 Principle and performance of arc erosion resistance of silver-tungsten alloy

The arc erosion resistance of silver-tungsten alloy is its core property in high-current electrical contacts, enabling it to resist arc erosion and material loss, extending the service life of components. Arc erosion resistance refers to the ability of an alloy to resist surface melting, evaporation and oxidation under the action of an arc, which is directly related to its reliability in high-voltage circuit breakers, relays and welding electrodes. The arc erosion resistance of silver-tungsten alloy benefits from the high melting point and chemical stability of tungsten, as well as the microscopic optimization of the silver-tungsten composite structure.

The principle of arc erosion resistance is mainly based on the physical and chemical properties of tungsten. Tungsten has an extremely high melting point, which makes it difficult to melt or evaporate under the high temperature of the arc. The heat generated by the arc is mainly absorbed and dispersed by the tungsten particles, reducing the large-scale loss of the material surface. Silver, as a binding phase, wets the tungsten particles in liquid phase sintering to form a dense microstructure, which enhances the crack resistance and peeling resistance of the alloy. When the arc is applied, the silver phase may melt locally, but the skeleton structure of the tungsten particles provides stable support, limits the loss of molten silver, and maintains the geometric integrity of the surface. In addition, the chemical stability of tungsten reduces the tendency to oxidize and corrode in the arc environment, reducing the surface degradation caused by the arc. The optimization of the sintering process, such as vacuum or inert gas protection, prevents the introduction of oxidative impurities and further improves the arc erosion resistance.

In terms of performance in actual applications, the arc erosion resistance of silver-tungsten alloy is particularly prominent in high-voltage circuit breaker contacts. High-voltage circuit breakers generate strong arcs when breaking high currents. Traditional materials such as pure silver or copper-based alloys are prone to failure due to melting or ablation, shortening the life of the contacts. Silver-tungsten alloy enhances its arc resistance through high tungsten content. Tungsten particles form a protective layer under the action of the arc, reducing the loss of the silver phase and ensuring that the contacts maintain stable performance during frequent switching operations. In resistance welding electrodes, the arc erosion resistance of silver-tungsten alloy enables it to withstand the arc impact during welding, maintain the flatness of the electrode surface, and ensure welding quality and consistency. In plasma sprayed

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components, the arc resistance of the alloy supports long-term operation in high-temperature plasma environments, reduces surface material loss, and extends the service life of components.

Arc erosion resistance is also reflected in the reduction of secondary effects caused by arcs. Microstructural optimization of silver-tungsten alloys (such as hot isostatic pressing to eliminate pores) reduces the risk of concentrated arc ablation and the occurrence of microcracks and molten spatter. The non-magnetic properties of the alloy avoid the influence of electromagnetic interference on arc stability and enhance its applicability in electromagnetic sensitive environments (such as MRI equipment or radar systems). However, excessive silver content may reduce arc erosion resistance because silver has a low melting point and is easily melted under the arc, which needs to be improved by increasing the proportion of tungsten or surface coating (such as ZrC). Optimization directions include developing nano-scale tungsten powder to improve surface uniformity, or using intelligent monitoring technology to evaluate arc loss status in real time. In short, the principle and performance of arc erosion resistance of silver-tungsten alloy make it occupy an important position in high-current electrical applications, providing a solid guarantee for high-reliability components, and future research can further improve its durability.

2.3.2.1 Mechanism of arc erosion

The mechanism of arc erosion is the basis for understanding the arc resistance of silver-tungsten alloy, which involves the influence of the physical and chemical processes of the arc on the surface of the material. Arc erosion occurs when high current is disconnected or closed, and the arc is formed in the contact gap as a high-temperature plasma (usually with a temperature of more than 6000°C), producing strong thermal effects and chemical reactions. The thermal effect of the arc causes local melting, evaporation and sputtering of the material surface. The molten metal is rapidly heated and ejected under the action of the arc, causing material loss. The high temperature of the arc also triggers oxidation reactions, especially in an air environment, where the metal surface combines with oxygen to form oxides, further accelerating erosion. The energy concentration of the arc causes high thermal stress in local areas, which may cause microcracks or peeling, especially when the material hardness or density is insufficient.

The specific mechanisms of arc erosion include heat conduction, gasification, and electrochemical reactions. Heat conduction transfers arc energy to the interior of the material, causing rapid heating of the surface and subsurface layers. Materials with low melting points (such as silver) tend to melt in a short time. The gasification process causes the molten metal to evaporate at high temperatures, especially at high current densities, where the evaporation rate increases significantly, resulting in material mass loss. Electrochemical reactions occur in arc plasma, where the metal combines with oxygen or nitrogen in the environment to form oxides or nitrides, which may adhere to the surface or peel off, further exacerbating erosion. The continuous action of the arc can also cause thermal stress concentration, especially at the interface of heterogeneous materials or microscopic defects, increasing the risk of crack propagation. The silver phase in silver-tungsten alloy is susceptible to thermal effects due to its lower melting point (961°C), while the tungsten phase is relatively stable due to its high melting point (3422°C), but its interface bonding quality directly affects the overall corrosion resistance. The mechanism of arc erosion is also affected by the complex influence of usage conditions. The arc energy in a high-pressure

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environment is higher and the erosion rate is faster; the oxidation may be slowed down in a low-pressure environment due to the reduced oxygen concentration, but the thermal effect is still dominant. The arc duration and current size also affect the degree of erosion. Short-term high current may cause instantaneous melting, and long-term low current may cause slow oxidation and wear. The microstructure of silver-tungsten alloy (such as porosity and particle distribution) is crucial to the sensitivity of arc erosion. Porosity or uneven distribution may become a thermal stress concentration point, accelerating material loss. Understanding these mechanisms of arc erosion provides a theoretical basis for optimizing the corrosion resistance of silver-tungsten alloy. Its durability can be effectively enhanced by adjusting the composition ratio and sintering process.

2.3.2.2 The intrinsic principle of silver-tungsten alloy resisting arc erosion

The inherent principle of silver-tungsten alloy's resistance to arc erosion comes from its unique composition design and microstructure optimization, combined with tungsten's high melting point and chemical stability and silver's wetting and densification effect. The key to resisting arc erosion is to reduce the melting, evaporation and oxidation of materials under high-temperature plasma. Silver-tungsten alloy achieves this goal through the following mechanisms. First, the high melting point of tungsten (3422°C) is the core factor in resisting arc erosion. Under the high temperature of the arc, tungsten particles remain solid, absorb and disperse heat, and limit the surface melting range. The chemical stability of tungsten further reduces the tendency to oxidize, and it is not easy to react with oxygen or nitrogen in arc plasma, reducing the loss of oxide formation. Silver melts as a binder phase in liquid phase sintering (961°C), wets tungsten particles and fills microscopic gaps to form a dense microstructure. This structure enhances the alloy's crack resistance and peeling resistance, and prevents damage caused by arc thermal stress.

The microstructural design of silver-tungsten alloy plays an important role in resisting arc erosion. During the sintering process, the silver liquid phase penetrates the surface of tungsten particles, enhancing the interfacial bonding force between particles and reducing the propagation of microcracks under the action of the arc. The uniform distribution of tungsten particles forms a protective skeleton structure, which disperses the arc energy and reduces the risk of local melting or evaporation. The hot isostatic pressing (HIP) or spark plasma sintering (SPS) process further optimizes the microstructure, eliminates residual pores, compresses grain boundaries, and makes the alloy surface more resistant to corrosion. The silver phase may melt locally under the action of the arc, but the support of the tungsten skeleton limits the loss of molten silver and maintains the geometric integrity of the surface. This synergistic effect enables silver-tungsten alloy to exhibit excellent arc resistance when high current is disconnected or closed.

The composition ratio of the alloy also has a direct impact on the inherent principle of resistance to arc erosion. When the tungsten content is high, the alloy's resistance to melting and oxidation is enhanced, making it suitable for applications with high arc intensity, such as high-voltage circuit breaker contacts. When the silver content is moderate, the liquid phase is sufficient to wet the tungsten particles to ensure density, but too high a silver content may reduce corrosion resistance because silver's lower melting point

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is easy to melt under the arc. Control of the sintering atmosphere (such as vacuum or high-purity argon) prevents the introduction of oxidative impurities, maintains the purity of tungsten and silver, and further enhances corrosion resistance. Surface treatment technology, such as anti-oxidation coatings applied by plasma-enhanced chemical vapor deposition (PECVD), also supports the realization of the inherent principle and reduces secondary damage caused by the arc.

The inherent principle of silver-tungsten alloy in resisting arc erosion enables it to perform well in practical applications. In high-voltage circuit breaker contacts, the alloy's arc resistance extends the life of the switch; in resistance welding electrodes, resistance to arc erosion maintains the flatness of the electrode surface; and in plasma sprayed components, the alloy's corrosion resistance supports long-term operation in high-temperature plasma environments. Optimization directions include improving surface uniformity through nano-scale tungsten powder, or developing self-healing coatings to dynamically repair arc damage. In short, silver-tungsten alloy achieves efficient arc erosion resistance through the high melting point of tungsten, the densification effect of silver, and microstructural optimization, providing a solid foundation for high-reliability electrical applications.

2.3.2.3 Differences in arc erosion resistance performance under different usage environments

The arc erosion resistance of silver-tungsten alloy varies significantly in different use environments, which is affected by factors such as environmental conditions, current characteristics and frequency of use. The evaluation of arc erosion resistance needs to be combined with specific application scenarios, such as high-voltage circuit breakers, welding electrodes and aerospace components, to analyze the erosion effect of the environment on the alloy surface and its performance differences. These differences provide an important basis for optimizing alloy design and selection.

In high-voltage circuit breaker contacts, the arc erosion resistance of silver-tungsten alloy is outstanding in high current and high voltage environments. When the circuit breaker breaks a large current (usually thousands of amperes), a strong arc is generated, and the temperature is as high as 6000°C or above. The high tungsten content of silver-tungsten alloy enables it to resist melting and evaporation. The tungsten particles absorb heat and disperse the arc energy, reducing surface loss. However, oxygen in the air may induce slight oxidation of the silver phase, and long-term operation may cause increased surface roughness and affect conductivity. A vacuum or inert gas protected environment (such as SF₆ circuit breakers) can significantly improve the arc erosion resistance, reduce oxidation and sputtering, and extend the life of the contacts.

In resistance welding electrodes, silver-tungsten alloy's arc erosion resistance performs well in short-term high-current pulse environments. The welding process involves high current density (tens of thousands of amperes per square millimeter) and local high temperatures, with short arc action time but concentrated energy. The tungsten skeleton structure of silver-tungsten alloy resists instantaneous melting, and the wetting effect of the silver phase maintains the density of the surface, ensuring that the electrode maintains shape stability during multiple welding cycles. However, metal vapor or welding slag in the welding environment may adhere to the surface, increasing the risk of erosion, and regular

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cleaning or anti-adhesion coating is required to maintain performance. In high-temperature welding scenarios, the melting point limitation of silver may cause local softening, and heat resistance needs to be optimized by increasing the tungsten ratio.

In aerospace components such as plasma spray electrodes, silver-tungsten alloy's arc erosion resistance performs well in continuous high-temperature plasma environments. Plasma spraying involves high-speed ion flow and arc action, and the alloy's high hardness and high melting point tungsten phase enable it to withstand long-term thermal shock and surface abrasion. Tungsten's high chemical stability reduces oxidation loss, and silver's thermal conductivity helps to disperse heat. However, long-term exposure to oxygen or corrosive gases may cause a thin layer of oxide to form on the tungsten surface, slightly reducing its erosion resistance. Optimizing sintering processes and surface coatings (such as ZrC) can significantly improve performance in extreme environments.

Environmental factors such as humidity, salt spray, and chemical cleaning agents also affect arc erosion resistance. In a humid environment, the silver phase may undergo slight corrosion, increasing the risk of arc-induced oxidation; in a marine or industrial environment, salt spray may accelerate surface degradation, and corrosion-resistant coatings (such as TiN) are required to enhance protection. In a low-pressure or vacuum environment, the oxidation effect is weakened and the arc erosion resistance is better, but the thermal effect is still dominant, and attention should be paid to thermal stress concentration. The frequency of use and the current size also play a key role. High-frequency switching may accelerate corrosion, and low current may cause slow oxidation. The silver-tungsten ratio needs to be adjusted according to the specific scenario.

The difference in arc erosion resistance of silver-tungsten alloy in different use environments provides guidance for material design. Optimization directions include developing environmentally adaptable coatings or evaluating erosion status in real time through intelligent monitoring technology.

2.3.2.4 Ways to improve arc erosion resistance

Improving the arc erosion resistance of silver-tungsten alloy is the key to ensuring its long-term reliability in high-current electrical applications, which needs to be achieved through a combination of material design, preparation process optimization and surface treatment. The improvement of arc erosion resistance mainly targets problems such as arc high-temperature melting, oxidation and thermal stress concentration, and combines the high melting point of tungsten with the conductive advantages of silver to optimize the microstructure and use environment. The following are specific ways to improve it.

First of all, optimizing the composition ratio is the basis for improving arc erosion resistance. Increasing the tungsten content can significantly enhance the alloy's resistance to melting and oxidation, because the high melting point of tungsten (3422°C) keeps it stable at high arc temperatures and reduces surface loss. Studies have shown that when the tungsten content is 60%-80%, the alloy's arc erosion resistance reaches the best balance, taking into account the protective effect of tungsten and the conductivity of silver. Trace additives such as nickel or cobalt (0.5%-2%) can improve the liquid phase sintering effect,

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enhance the interfacial bonding between tungsten particles, and reduce the risk of arc-induced microcracks. However, additives need to be strictly controlled to avoid affecting non-magnetic properties.

Secondly, optimizing the sintering process can significantly improve the density of the microstructure. Liquid phase sintering fills the gaps between tungsten particles through the wetting effect of silver, reduces porosity, and enhances anti-stripping ability. Spark plasma sintering (SPS) technology quickly forms a dense structure through pulsed current and high voltage, shortens the sintering time, inhibits excessive grain growth, and improves surface uniformity. Hot isostatic pressing (HIP) eliminates residual defects through omnidirectional high pressure, further improves density, and reduces arc energy concentration points. Vacuum or high-purity argon sintering environment can prevent the introduction of oxidized impurities, maintain the purity of tungsten and silver, and reduce arc-induced oxidation losses.

Third, surface treatment technology is an effective means to improve arc erosion resistance. Anti-oxidation coatings applied by plasma enhanced chemical vapor deposition (PECVD), such as titanium nitride (TiN) or zirconium carbide (ZrC), can form a dense protective layer on the alloy surface, isolating oxygen and arc plasma, reducing melting and oxidation. Electrochemical polishing can optimize surface finish and reduce the initial point of concentrated arc ablation. Surface hardening coatings can also enhance wear resistance and extend contact life. Studies have shown that TiN coatings can reduce arc erosion rates by about 30%-40%, significantly improving performance.

Fourth, environmental management and optimization of use conditions can further enhance resistance to arc erosion. In high-voltage circuit breakers, SF₆ or inert gas is used as an arc extinguishing medium to reduce oxygen concentration and oxidation reactions. In welding electrodes, controlling welding parameters such as current pulse width and frequency can reduce arc duration and reduce thermal effects. Intelligent monitoring technology detects arc loss and temperature changes in real time through embedded sensors, optimizes maintenance cycles, and prevents excessive erosion. Functionally graded material (FGM) design increases tungsten content on the surface to enhance resistance to melting while retaining the conductivity of the internal silver phase.

The combined application of these approaches enables silver-tungsten alloys to perform well in high-voltage circuit breaker contacts, resistance welding electrodes, and plasma sprayed components, extending component life and improving reliability. Optimization directions include developing self-repairing coatings to dynamically repair arc damage, or improving surface uniformity through nano-scale tungsten powders.

2.3.3 Anti-adhesion and anti-welding capabilities of silver-tungsten alloy

The anti-adhesion and anti-fusion welding capabilities of silver-tungsten alloy are its important characteristics in electrical contacts and welding electrodes, enabling it to resist adhesion and fusion with the workpiece or contact surface, maintaining the independence and functional stability of the components. Anti-adhesion refers to the ability of the alloy to prevent materials from sticking to each other under mechanical contact or arc action, while anti-fusion welding refers to the ability to avoid

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fusion with the workpiece under high-temperature welding or arc conditions. These characteristics directly affect the contact switching performance, welding quality and equipment life. Silver-tungsten alloy achieves excellent performance through the high hardness of tungsten and the wetting optimization of silver.

2.3.3.1 Causes of adhesion and welding

Adhesion and welding phenomena are the main challenges faced by silver-tungsten alloy in high current or high temperature applications. The causes of adhesion and welding involve the physical and chemical properties of the material, contact conditions and environmental factors. Adhesion refers to the surface adhesion of the contact or electrode to the workpiece or the dual material under mechanical contact or arc action, while welding refers to the partial fusion of the material and the workpiece at high temperature to form an irreversible connection. The occurrence of these phenomena directly reduces the switching performance and service life of the components, and their causes need to be analyzed in depth.

The main causes of adhesion are microscopic cold welding and frictional heat effects between contact surfaces. In high-voltage circuit breaker contacts or relay contacts, silver-tungsten alloy contacts the dual material under high pressure, and the surface micro-bumps undergo plastic deformation due to mechanical force, shortening the distance between metal atoms to the lattice matching range, resulting in a cold welding effect. Under the action of the arc, the local high temperature (above 6000°C) melts the silver phase, enhances fluidity, and adheres to the surface of the dual material, especially when the silver content is high, the risk of adhesion increases. The frictional heat effect further exacerbates adhesion in dynamic contact, especially in high-frequency switching or low-speed sliding scenarios, where heat accumulation promotes surface atomic diffusion.

The occurrence of fusion welding is closely related to high temperature welding or arc conditions. In resistance welding electrodes or plasma sprayed parts, high current density causes local melting, and the surface of the silver-tungsten alloy and the workpiece material (such as steel or aluminum) form a molten pool at high temperature. The low melting point of silver makes it easy to melt, and after mixing with the workpiece metal, it cools and solidifies to form a fusion weld. Although the high melting point of tungsten provides a certain resistance, thermal stress or impurities (such as oxides) at the interface may promote fusion. The chemical activity of the arc plasma also plays a role. Oxygen or nitrogen reacts with the molten metal to form compounds, increase viscosity, and promote fusion welding.

The influence of environmental factors on adhesion and welding phenomena cannot be ignored. In a humid or sulfur-containing environment, the silver phase may form sulfides or oxides, which reduce the surface's anti-adhesion ability and increase the risk of adhesion. In a high temperature or oxygen-rich environment, molten silver reacts with the workpiece oxide, enhancing the tendency to weld. Contact pressure, current size and switching frequency also play a key role. High-voltage or high-frequency operation intensifies thermal effects and atomic diffusion, accelerating the occurrence of adhesion and welding. Microstructural defects such as pores or uneven distribution may become stress concentration points, further promoting these phenomena.

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The causes of adhesion and welding provide a direction for optimizing silver-tungsten alloys. Traditional materials such as pure silver are prone to adhesion due to their high ductility, and copper-based alloys are prone to welding due to their low melting points. Silver-tungsten alloys attempt to overcome these problems by optimizing the hardness of tungsten and the ratio of silver. Optimization directions include adjusting the silver-tungsten ratio, improving surface treatment, and controlling the conditions of use to reduce the risk of adhesion and welding. Understanding these mechanisms will help design silver-tungsten alloys with better resistance to adhesion and welding, providing reliable support for the application of electrical contacts and welding electrodes.

2.3.3.2 Anti-adhesion performance of silver-tungsten alloy

The anti-adhesion property of silver-tungsten alloy is outstanding in its electrical contact and welding electrode applications, enabling it to effectively resist surface adhesion with the workpiece or the mating material, maintaining the independence and switching stability of the components. Anti-adhesion refers to the ability of the alloy to prevent materials from sticking to each other under mechanical contact or arc action, which directly affects the opening and closing performance and service life of the contact. Silver-tungsten alloy exhibits excellent anti-adhesion properties through the high hardness of tungsten, the wetting optimization of silver, and the synergistic effect of the microstructure, especially in high-voltage circuit breakers, relays, and resistance welding electrodes.

In high-voltage circuit breaker contacts, the anti-adhesion performance of silver-tungsten alloy is particularly evident when high current is disconnected or closed. When the contacts break high currents (usually thousands of amperes), arcs are generated, and high temperatures (above 6000°C) may cause traditional materials such as pure silver or copper-based alloys to adhere to the dual material, affecting switching reliability. The high tungsten content (60%-80%) of silver-tungsten alloy provides a hard skeleton structure to resist surface plastic deformation and cold welding effects, while the appropriate wetting effect of the silver phase forms a dense interface, reducing the initial point of adhesion. Actual tests show that after millions of switching cycles, the adhesion rate of silver-tungsten alloy contacts is less than 5%, which is much better than the 20%-30% of pure silver contacts, significantly extending the life of the equipment.

In resistance welding electrodes, the anti-adhesion properties of silver-tungsten alloy excel in frequent contact with workpieces (such as steel or aluminum). During welding, high current density and local high temperature may cause the electrode to adhere to the workpiece. Traditional materials such as copper-based alloys are prone to failure due to adhesion of molten metal. The tungsten particles of silver-tungsten alloy form a protective layer on the surface. The hardness (usually up to 200-300 HV) prevents the embedding of workpiece materials, and the thermal conductivity of silver quickly disperses heat and reduces the risk of adhesion. In actual applications, after thousands of continuous welding, the surface adhesion area of silver-tungsten electrodes is less than 1%, maintaining the stability of electrode shape and welding quality.

In plasma sprayed parts, the anti-adhesion properties of silver-tungsten alloy support the separation

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between high-speed ion flow and workpiece. During the spraying process, arc high temperature and particle impact may cause material adhesion and affect the uniformity of the coating. The high hardness and low thermal expansion coefficient of silver-tungsten alloy (about $4.5\text{-}6 \times 10^{-6} / ^\circ \text{C}$) reduce the adhesion caused by thermal stress, and the chemical stability of tungsten further reduces the possibility of reaction with the workpiece. Experimental data show that after long-term operation, the adhesion of silver-tungsten alloy spray electrodes is reduced by about 50% compared with copper-based materials, ensuring the reliability of the coating process.

The excellent performance of anti-adhesion performance also benefits from the optimization of microstructure. Sintering processes such as hot isostatic pressing (HIP) eliminate porosity, and spark plasma sintering (SPS) improves particle uniformity, reduces stress concentration points, and reduces the probability of adhesion. Surface treatments such as electrochemical polishing or anti-adhesion coatings (such as DLC) further enhance the anti-adhesion ability, especially in humid or sulfur-containing environments. The coating isolates the reaction between the silver phase and the environment and keeps the surface clean. However, excessive silver content may increase the risk of adhesion, which needs to be balanced by increasing the tungsten ratio or optimizing the surface treatment. Optimization directions include developing nano-scale tungsten powder to increase surface hardness, or integrating intelligent monitoring technology to evaluate the adhesion status in real time. In short, the anti-adhesion performance of silver-tungsten alloy provides important support for its use in high-frequency switching and welding applications, significantly improving the reliability and service life of components.

2.3.3.3 Analysis of factors affecting anti-adhesion and anti-welding capabilities

The anti-adhesion and anti-welding capabilities of silver-tungsten alloy are affected by many factors, including material properties, preparation process, use conditions and environmental parameters, which directly determine its performance in electrical contacts and welding electrodes. Analyzing these influencing factors helps to optimize the alloy design and enhance its reliability in high current and high wear environments.

First, the composition ratio is the core factor affecting the ability to resist adhesion and welding. The higher the tungsten content, the harder and more resistant to high temperatures of the alloy, and the better the ability to resist adhesion and welding, because the high melting point of tungsten (3422°C) reduces the risk of surface melting, and the hardness (200-300 HV) prevents cold welding and workpiece embedding. When the silver content is moderate, liquid phase sintering forms a dense structure and enhances the interfacial bonding, but excessive silver content (more than 50%) may increase the tendency to adhesion and welding due to its lower melting point (961°C), especially under high arc temperatures. Trace additives such as nickel (0.5%-2%) can improve toughness and wetting effects, but excessive amounts may introduce magnetism or reduce corrosion resistance, and require precise control.

Secondly, the microstructure has a significant impact on the ability to resist adhesion and welding. Density is the key, and high porosity (such as more than 5%) may become a stress concentration point, increasing the risk of adhesion or welding. Sintering processes such as hot isostatic pressing (HIP) or

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spark plasma sintering (SPS) improve density by eliminating pores and reduce surface defects under thermal effects. The uniform distribution and particle size optimization of tungsten particles (nanoscale or submicron scale) enhance the deformation resistance of the skeleton structure and reduce the tendency of cold welding. The silver phase layer strengthened by the grain boundary buffers the thermal stress, but the uneven distribution may lead to local melting, and high-energy ball milling is required to ensure the uniformity of the mixed powder.

Third, surface properties directly affect anti-adhesion and anti-welding performance. High surface roughness increases the contact area, which can easily cause cold welding or molten metal adhesion. Electrochemical polishing or mechanical polishing can reduce roughness and reduce the initial points of adhesion. Anti-adhesion coatings such as titanium nitride (TiN) or diamond-like coatings (DLC) form a protective layer to isolate the silver phase from reacting with the workpiece and reduce the risk of welding. Surface oxidation or sulfidation (such as in a sulfur-containing environment) may increase viscosity, and the surface purity needs to be controlled by vacuum sintering or inert atmosphere.

Fourth, contact conditions are key factors affecting performance. High contact pressure exacerbates plastic deformation and increases the risk of cold welding, and the contact design needs to be optimized to reduce overvoltage. Current size and switching frequency also play a role. High current (such as thousands of amperes) or high-frequency operation (many times per second) exacerbate thermal effects and atomic diffusion, accelerating adhesion and welding. Short-term pulse current (such as welding) may reduce the melting range, but the parameters need to be precisely controlled.

Fifth, environmental factors have a significant impact on the ability to resist adhesion and welding. A humid or sulfur-containing environment (such as an industrial atmosphere) may cause sulfidation or oxidation of the silver phase , increase viscosity, and require a sealed design or anti-corrosion coating. A high temperature environment (such as above 300°C) intensifies the melting tendency, requiring an increase in the proportion of tungsten or the use of inert gas protection. High oxygen concentrations (such as 21% in air) promote oxidation welding, and a vacuum or SF6 environment can significantly reduce corrosion. Salt spray or chemical cleaners may corrode the surface, affecting anti-adhesion stability, requiring regular maintenance or surface passivation.

The combined influence of these factors provides a direction for optimizing silver-tungsten alloys. Optimization strategies include adjusting the silver-tungsten ratio (60%-80% tungsten), optimizing the sintering process (such as HIP), applying anti-adhesion coatings (such as DLC), and controlling the use conditions (such as low oxygen environment). In the future, combining intelligent monitoring technology to evaluate the adhesion and welding status in real time, or developing adaptive coatings to dynamically adjust performance, will further enhance the anti-adhesion and anti-welding capabilities of silver-tungsten alloys and provide support for high-reliability applications.

2.3.4 Principle and application of excellent conductivity of silver-tungsten alloy

The excellent conductivity of silver-tungsten alloy is the basis for its wide application in electrical

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equipment, enabling it to efficiently transmit current and meet the needs of high-performance contacts and electrodes. Conductivity refers to the ability of a material to transfer charge. Silver-tungsten alloy achieves excellent current transmission performance through the high conductivity of silver and the structural support of tungsten. This characteristic not only depends on the inherent properties of the material, but is also closely related to the optimization of the composition ratio and microstructure, providing reliable support for scenarios such as high-voltage circuit breakers, relays, and welding electrodes. The following will discuss in detail the physical nature of conductivity and the conductive mechanism of silver-tungsten alloy, the change of conductivity under different composition ratios, and the advantages of conductive applications in electrical equipment.

2.3.4.1 Physical nature of conductivity and conductive mechanism of silver-tungsten alloy

The physical essence of conductivity lies in the mobility of free electrons in the material. Metals are easy to detach their outer electrons in their atomic structure to form mobile charge carriers. The conductive mechanism of silver-tungsten alloy relies on the high conductivity of silver and its role in the alloy, combined with the structural stability and micro-optimization of tungsten. As a precious metal, silver has abundant free electrons that can move quickly under the action of an electric field, giving the alloy excellent current transmission efficiency. Although tungsten has low conductivity, its high melting point and high hardness properties form a strong skeleton structure during the sintering process, supporting the continuous distribution of the silver phase and ensuring the stability of the current path.

The conductive mechanism of silver-tungsten alloy is achieved through powder metallurgy process. During the liquid phase sintering process, silver melts and wets the tungsten particles to form a continuous conductive network, and electrons can move efficiently in the silver phase. Although tungsten particles, as a reinforcing phase, do not directly contribute to conductivity, they reduce resistance concentration points through uniform distribution and enhance the overall conductive consistency. Optimization of the sintering process, such as high-energy ball milling and hot isostatic pressing, further improves the density of the microstructure and reduces the obstacles to current transmission caused by pores and defects. The ductility of silver also enables it to adapt to microscopic stresses, maintain the integrity of the conductive network, and maintain performance even under mechanical contact or arcing.

The non-magnetic properties of the alloy also support the conductive mechanism, avoiding the influence of electromagnetic interference on the current path. This conductive mechanism enables silver-tungsten alloy to perform well in high-current environments. The high conductivity of silver provides the basis, and the structural support of tungsten ensures long-term stability. The uniformity of the microstructure and the continuity of the silver phase are key.

Any uneven distribution or insufficient silver liquid phase may increase resistance and reduce conductive efficiency. Optimization directions include enhancing the conductive network through nano-scale silver powder, or increasing the silver content in the conductive area by functional gradient design. In short, the conductive mechanism of silver-tungsten alloy achieves efficient current transmission through the free electron movement of silver and the structural support of tungsten, laying the foundation for its

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application in the electrical field.

2.3.4.2 Changes in conductivity at different component ratios

The conductivity of silver-tungsten alloy shows a significant regularity with the change of component ratio. The ratio of silver to tungsten directly affects the efficiency of electron movement and resistance characteristics. This change pattern provides guidance for optimizing alloy design according to application requirements. When the silver content is high, the conductivity of the alloy is significantly enhanced, because the high conductivity of silver is the dominant factor, and electrons can move freely in the silver phase, reducing resistance loss. Silver, as a matrix or bonding phase, forms a continuous network during the sintering process. The current transmission efficiency increases with the increase of the silver ratio, which is particularly suitable for contact and electrode applications that require high conductivity.

As the tungsten content increases, the conductivity gradually decreases, because the conductivity of tungsten is much lower than that of silver. Its high hardness and high melting point characteristics enhance the structural stability, but increase the resistance path. When the tungsten content is high, the continuity of the silver phase may be limited, and the movement of electrons is hindered, resulting in reduced conductivity. The balance of the ratio of silver and tungsten is the key. Too high a tungsten content may cause insufficient silver liquid phase, resulting in microscopic pores or uneven distribution, further increasing resistance. Conversely, although too high a silver content improves conductivity, it may weaken the alloy's wear resistance and high temperature resistance, affecting its overall performance.

The effect of sintering process on the proportion of components also needs to be considered. The wetting effect of silver in liquid phase sintering increases with its proportion, which improves the connectivity of the conductive network, but if the tungsten particles are unevenly distributed, the local conductivity may decrease. Optimizing powder mixing and sintering parameters, such as using high-purity raw materials and inert atmosphere, can reduce impurity interference and ensure the stability of conductivity. In practical applications, when the silver content is within a certain range (such as a higher proportion), the conductivity shows a linear increase trend, while when the tungsten content is dominant, the conductivity tends to be stable. This rule shows that the conductivity optimization of silver-tungsten alloys needs to find a balance between conductivity requirements and mechanical properties. For example, high-voltage circuit breaker contacts tend to have a high silver ratio, while welding electrodes moderately increase the tungsten content.

This law of change provides flexibility for material design. Optimization directions include increasing the density of the conductive network through nano-scale silver powder, or concentrating the silver phase in the conductive area through functional gradient design. The change in conductivity under different component ratios is also affected by the microstructure, and density and particle uniformity are the guarantees for maintaining high conductivity. In short, the conductivity of silver-tungsten alloy shows a trend from strengthening to weakening with the change of silver-tungsten ratio. Reasonable ratio adjustment enables it to achieve optimal performance in electrical applications.

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2.3.4.3 Advantages of conductive applications in electrical equipment

Silver-tungsten alloy's conductive application advantage in electrical equipment makes it an ideal choice for high-voltage circuit breakers, relays, resistance welding electrodes, and radio frequency modules. This advantage stems from the high conductivity of silver combined with the structural support of tungsten, providing efficient current transmission and long-term stability. Silver-tungsten alloy can maintain low resistance in high current environments, reduce energy loss, and ensure the reliability and efficiency of equipment operation, which is particularly suitable for scenarios that require frequent switching or high loads.

In high-voltage circuit breaker contacts, the conductive advantage of silver-tungsten alloy is manifested as efficient current transmission capability. When breaking high current, the contact needs to quickly establish and cut off the current path. The high conductivity of silver ensures low resistance characteristics, reduces thermal effects and arc energy, and the supporting structure of tungsten maintains the geometric stability of the contact. This combination enables the contact to maintain consistent performance during multiple switching operations, extending the life of the equipment and reducing maintenance costs. Compared with traditional materials such as pure silver, although the conductivity of silver-tungsten alloy is slightly reduced, its wear resistance and arc resistance make up for this deficiency. In relays and RF modules, the conductive advantage of silver-tungsten alloy supports high-frequency signal transmission and low-loss operation. Relays need to respond quickly to current changes. The conductive network of silver-tungsten alloy ensures the integrity of the signal, while its non-magnetic properties avoid electromagnetic interference, which is particularly suitable for electromagnetic sensitive environments. RF modules rely on low-resistance paths to transmit high-frequency signals. The excellent conductivity of silver-tungsten alloy meets this demand.

In resistance welding electrodes, the conductive advantage of silver-tungsten alloy ensures efficient concentration of current. The welding process requires the electrode to quickly transfer large current to the workpiece. The high conductivity of silver reduces resistance heat, and the hardness of tungsten maintains the stability of the electrode shape. This characteristic makes the welding process more uniform, reduces defects, and improves welding quality. Compared with copper-based electrodes, silver-tungsten alloy has slightly inferior conductivity, but its wear and arc resistance provides a longer service life. The conductive application advantage of silver-tungsten alloy is also reflected in its adaptability. By adjusting the silver-tungsten ratio and optimizing the microstructure, the alloy can achieve a balance between conductive and mechanical properties in different electrical devices. Surface treatment such as polishing or coating further enhances the conductive stability and reduces the impact of surface oxidation on current transmission. Optimization directions include improving the conductive network through nano-scale silver powder, or integrating intelligent monitoring technology to optimize the current path in real time.

2.3.5 Characteristics and value of good thermal conductivity of silver-tungsten alloy

The good thermal conductivity of silver-tungsten alloy is an important characteristic in high temperature

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and high power applications, enabling it to efficiently transfer heat and maintain the stability and performance of components. Thermal conductivity refers to the ability of a material to transfer heat. Silver-tungsten alloy achieves excellent thermal management capabilities through the high thermal conductivity of silver and the structural support of tungsten. This characteristic not only depends on the inherent properties of the material, but is also closely related to the optimization of its microstructure and composition ratio, providing key support for electronic heat dissipation substrates and aerospace components.

2.3.5.1 Basic principles of thermal conductivity and thermal conductivity mechanism of silver-tungsten alloy

The basic principle of thermal conductivity is that the heat inside the material is transferred through free electrons and lattice vibrations. Metals have high thermal conductivity due to their abundant free electrons. The thermal conductivity mechanism of silver-tungsten alloy relies on the excellent thermal conductivity of silver and its dominant role in the alloy, combined with the structural stability and micro-optimization of tungsten. As a precious metal, silver has a high density of free electrons that can quickly transfer thermal energy, giving the alloy efficient thermal management performance. Although tungsten has low thermal conductivity, its high melting point and high hardness characteristics form a strong skeleton during the sintering process, supporting the continuous distribution of the silver phase and ensuring the stability of heat transfer.

The thermal conductivity mechanism of silver-tungsten alloy is achieved through powder metallurgy process. During the liquid phase sintering process, silver melts and wets the tungsten particles to form a continuous thermal conductive network, and heat can be efficiently transferred in the silver phase. Although tungsten particles, as a reinforcing phase, do not directly contribute to thermal conductivity, they reduce the concentration points of thermal resistance through uniform distribution and enhance the overall thermal conductivity consistency. Optimization of the sintering process, such as high-energy ball milling and hot isostatic pressing, further improves the density of the microstructure and reduces the obstacles to heat transfer caused by pores and defects. The ductility of silver also enables it to adapt to micro-stresses, maintain the integrity of the thermal conductive network, and maintain performance even under thermal cycling conditions.

The low thermal expansion coefficient of the alloy also supports the thermal conductivity mechanism, reducing the impact of thermal stress on the structure and ensuring stability during long-term operation. This thermal conductivity mechanism enables silver-tungsten alloy to perform well in high heat load environments. The high thermal conductivity of silver provides the foundation, and the structural support of tungsten ensures long-term durability. The uniformity of the microstructure and the continuity of the silver phase are key. Any uneven distribution or insufficient silver liquid phase may increase thermal resistance and reduce thermal conductivity efficiency. Optimization directions include enhancing the thermal conductivity network through nano-scale silver powder, or increasing the silver content in the thermal conductive area using functional gradient design. In short, the thermal conductivity mechanism of silver-tungsten alloy achieves efficient thermal management through free electron heat transfer of

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silver and structural support of tungsten, laying the foundation for its performance in high-temperature applications.

2.3.5.2 Relationship between thermal conductivity and heat dissipation effect

There is a close correlation between the thermal conductivity of silver-tungsten alloy and its heat dissipation effect. The heat dissipation effect refers to the ability of the material to transfer heat from local hot spots to the surrounding environment, which affects the temperature control and service life of the components. The high thermal conductivity of silver-tungsten alloy enables it to quickly transfer heat away from the hot area to prevent performance degradation or failure caused by local overheating. This relationship between thermal conductivity and heat dissipation depends on the high thermal conductivity of silver and the structural stability of tungsten, and the optimization of the microstructure further enhances this relationship.

The high thermal conductivity of silver is the basis of the heat dissipation effect. Heat is efficiently transferred in the silver phase through free electrons, reducing the accumulation of hot spot temperatures. Although tungsten, as a reinforcing phase, has low thermal conductivity, its uniform distribution forms a stable heat transfer path to prevent heat from being retained in specific areas. The dense microstructure formed during the sintering process reduces thermal resistance, and heat can be smoothly conducted from the inside to the surface, improving heat dissipation efficiency. The wetting effect of silver fills the gaps between tungsten particles during liquid phase sintering, enhancing the continuity of heat conduction and thereby improving the heat dissipation effect. The uniformity of the microstructure is the key. Porosity or uneven distribution may lead to heat concentration and weaken the heat dissipation capacity.

The excellent performance of heat dissipation directly improves the application reliability of silver tungsten alloy. In electronic heat dissipation substrates, thermal conductivity quickly transfers the heat generated by power devices to prevent chip overheating and damage, thereby extending the life of the equipment. In welding electrodes, the heat dissipation effect reduces the accumulation of arc heat, maintains the stability of the electrode surface and the welding quality. In aerospace components, thermal conductivity supports thermal management in high temperature environments and ensures structural integrity. The correlation between thermal conductivity and heat dissipation is also limited by the conditions of use. A larger heat dissipation area or good environmental heat exchange conditions can further enhance the effect. Surface treatment such as polishing or coating can also optimize heat dissipation. Optimization directions include increasing the density of the thermal network through nano-scale silver powder, or concentrating the silver phase in the heat dissipation area through functional gradient design. The improvement of thermal conductivity directly translates into improved heat dissipation, reducing the damage to components caused by thermal stress, and providing support for high temperature and high power applications.

2.3.5.3 Application value of thermal conductivity in high temperature working environment

The thermal conductivity of silver-tungsten alloy in high-temperature working environments makes it a

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key material in electronic equipment, welding systems, and aerospace components. High-temperature working environments place strict demands on the thermal management of materials. Silver-tungsten alloy effectively transfers heat through its good thermal conductivity to maintain the stability and functionality of components. This application value is not only reflected in the rapid dissipation of heat, but also in its structural stability and durability, which meets the high reliability requirements under high temperature conditions.

In electronic devices, the thermal conductivity application value of silver-tungsten alloy is reflected in the performance improvement of power devices and heat dissipation substrates. Electronic components generate a lot of heat during operation, and traditional heat dissipation materials may fail due to overheating due to insufficient thermal conductivity. The high thermal conductivity of silver-tungsten alloy quickly transfers heat from the chip to the heat sink to prevent performance degradation or damage, and its structural stability ensures reliability during long-term operation. Compared with other materials, the thermal conductivity advantage of silver-tungsten alloy combined with its wear resistance makes it perform well in high-density electronic devices and prolongs its service life.

In welding systems, the thermal conductivity of silver-tungsten alloy is reflected in the stable operation of electrodes and welding heads. The welding process involves high temperatures and arc action, and heat accumulation may cause the electrode to deform or melt. The thermal conductivity of silver-tungsten alloy effectively disperses heat and maintains the integrity of the electrode surface. Its high hardness further resists wear and ensures the stability of welding quality. This characteristic makes silver-tungsten alloy the preferred material in resistance welding and plasma spraying, significantly improving production efficiency.

In aerospace components, the thermal conductivity of silver tungsten alloy supports thermal management in high temperature environments. Aerospace equipment faces extreme heat loads during operation, and traditional materials may fail due to thermal stress. The thermal conductivity of silver tungsten alloy transfers heat away from key components, and combined with its low thermal expansion coefficient, it reduces deformation caused by thermal cycles. Its structural stability ensures long-term durability under high temperature conditions, providing reliable support for electrical connections and counterweight components of aircraft.

The thermal conductivity application value of silver-tungsten alloy is also reflected in its adaptability. By adjusting the silver- tungsten ratio and optimizing the microstructure, the alloy can achieve a balance between thermal conductivity and mechanical properties in different high-temperature environments. Surface treatments such as polishing or coating further enhance the heat dissipation capacity and reduce surface thermal resistance.

Optimization directions include improving the thermal conductivity network through nano-scale silver powder, or integrating intelligent monitoring technology to optimize thermal management in real time. In short, the thermal conductivity application value of silver-tungsten alloy in high-temperature working environments provides important support for its use in electronics, welding, and aerospace, significantly

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improving the reliability and performance of components.

2.3.6 Performance and mechanism of corrosion resistance of silver-tungsten alloy

The corrosion resistance of silver tungsten alloy is an important characteristic in a variety of application environments, enabling it to resist chemical or electrochemical erosion and maintain long-term stability and functionality. Corrosion resistance refers to the ability of a material to resist material degradation in an acidic, alkaline or humid environment. Silver tungsten alloy achieves excellent performance through the chemical stability of silver and the anti-oxidation properties of tungsten. This feature gives it a significant advantage in electrical contacts, welding electrodes and aerospace components.

2.3.6.1 Effects of different corrosion environments on silver-tungsten alloy

The performance of silver-tungsten alloy in different corrosive environments varies due to the interaction of environmental conditions and chemical composition, which affects its surface characteristics and service life. The corrosion resistance of silver-tungsten alloy mainly depends on the characteristics of silver and tungsten, but the corrosion effects of different environments on the two phases are different, which provides an important reference for optimizing material design.

In a humid environment, silver-tungsten alloy exhibits a certain degree of corrosion resistance. The silver phase has good chemical stability in moisture, but long-term exposure may lead to slight oxidation, forming a thin layer of oxide on the surface, slightly affecting conductivity. Due to its high chemical stability, the tungsten phase hardly corrodes significantly in moisture, but if the moisture contains sulfide or chloride, silver may undergo sulfide or chlorination reactions, increasing the surface roughness, which needs to be controlled by surface protection measures. In this environment, silver-tungsten alloy can still maintain basic structural integrity and is suitable for indoor electrical equipment applications.

In an acidic environment, the corrosion resistance of silver-tungsten alloy faces greater challenges. Acidic substances such as sulfuric acid or hydrochloric acid may corrode the silver phase, causing surface dissolution or the formation of corrosion products, affecting electrical and thermal conductivity. The tungsten phase has strong resistance to acid corrosion due to its high chemical inertness, but oxidants in an acidic environment may cause slight surface oxidation of tungsten to form unstable compounds. The microstructural density of the alloy plays a key role here. Porosity or defects may accelerate corrosion penetration, and resistance needs to be enhanced by optimizing the sintering process. Applications under acidic conditions should be cautious and are suitable for short-term exposure or use with protective coatings.

In alkaline environments, the corrosion resistance of silver tungsten alloy is relatively good. Silver has high resistance to alkaline substances, and the surface is not easily corroded, maintaining conductivity and mechanical properties. The tungsten phase also exhibits stable chemical properties in alkaline environments, reducing the risk of corrosion. However, if the alkaline environment contains oxidants or high temperature conditions, silver may slowly oxidize, affecting long-term stability. The corrosion

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resistance of the alloy in this environment is better than that in an acidic environment, and is suitable for contact parts in certain industrial equipment.

Impurities and temperature changes in the environment also affect the corrosion effect. An environment with high sulfur or chloride content may aggravate the corrosion of silver, and rising temperatures accelerate chemical reactions and increase the erosion rate. The non-magnetic properties of silver-tungsten alloy still give it an advantage in electromagnetic sensitive environments, but corrosion resistance requires adjustment of use conditions or protective measures according to specific environments. In short, the impact of different corrosive environments on silver-tungsten alloy reveals its limitations and potential for corrosion resistance, and provides guidance for material selection and optimization.

2.3.6.2 Intrinsic mechanism of corrosion resistance of silver-tungsten alloy

The inherent mechanism of silver-tungsten alloy's corrosion resistance originates from the synergistic effect of the chemical stability and microstructure of silver and tungsten, which enables it to resist corrosion in a variety of environments and maintain long-term performance. The core of corrosion resistance is to reduce the chemical reaction or electrochemical corrosion between the material and the environment. Silver-tungsten alloy achieves this goal through the following mechanisms.

First, the chemical stability of silver is the basis of corrosion resistance. Silver has strong antioxidant capacity against oxygen and water at room temperature, and it is not easy to form a thick oxide layer on the surface, which reduces the accumulation of corrosion products. The ductility of silver allows it to adapt to environmental stress at the microscopic level and reduce the risk of cracking or peeling. However, silver may react slightly in sulfur- or chloride-containing environments to form sulfides or chlorides, which requires supplementary protection from the tungsten phase. Silver wets the tungsten particles during liquid phase sintering to form a dense interface structure, which enhances the overall corrosion resistance.

Secondly, the high chemical inertness of tungsten is the key support for corrosion resistance. Tungsten has an extremely high melting point and a stable crystal structure. It is not easy to react with common corrosive media in acidic, alkaline or humid environments, and the surface maintains integrity. Tungsten's antioxidant ability enables it to resist oxidation even in high temperature or oxygen-rich environments, forming a protective thin layer to reduce further erosion. Tungsten particles form a skeleton structure in the alloy, dispersing the penetration path of the corrosive medium and limiting the expansion of erosion to the inside. This characteristic makes the tungsten phase the main pillar of the corrosion resistance of silver tungsten alloy.

The optimization of the microstructure further enhances the corrosion resistance. During the sintering process, the silver liquid phase fills the gaps between the tungsten particles, reducing the pores and defects and preventing the corrosive media from penetrating through the microcracks. The hot isostatic pressing or spark plasma sintering process improves the density, compresses the grain boundaries and

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reduces the initial points of corrosion. The interfacial bonding strength of silver and tungsten is improved by high-energy ball milling and uniform powder mixing, which enhances the corrosion resistance consistency of the overall structure. The non-magnetic properties also support the corrosion resistance mechanism and avoid the influence of electromagnetic interference on the surface stability.

However, the corrosion resistance of silver-tungsten alloys is limited. The silver phase is prone to corrosion under certain conditions (such as sulfur-containing environments), and the high hardness of the tungsten phase may produce microcracks under long-term stress, accelerating local erosion. The optimization of the internal mechanism requires balancing the conductivity of silver and the corrosion resistance of tungsten. Adjusting the composition ratio and microstructure is the key.

2.3.6.3 Technological means to improve corrosion resistance

The key to improving the corrosion resistance of silver-tungsten alloy is to enhance its long-term performance in various environments, which needs to be achieved through a combination of material preparation, surface treatment and optimization of use conditions. The improvement of corrosion resistance mainly targets the corrosion sensitivity and microscopic defects of silver, combined with the anti-oxidation properties of tungsten, to optimize the corrosion resistance of the alloy.

First, optimizing the composition ratio is the basis for improving corrosion resistance. Increasing the tungsten content can enhance the overall corrosion resistance of the alloy, because the high chemical inertness of tungsten reduces the reaction with the corrosive medium. When the silver content is moderate, liquid phase sintering forms a dense structure and enhances the interfacial bonding force, but too high a silver content may increase the risk of corrosion, and a balance needs to be achieved by adjusting the ratio. Trace additives such as molybdenum or chromium can improve the oxidation resistance of tungsten, but the content needs to be controlled to avoid affecting conductivity.

Secondly, optimizing the sintering process can significantly improve the density of the microstructure. Liquid phase sintering fills the gaps between tungsten particles through the wetting effect of silver, reduces porosity, and prevents the penetration of corrosive media. Spark plasma sintering technology quickly forms a dense structure through pulsed current and high pressure, inhibits excessive grain growth, and improves surface uniformity. The hot isostatic pressing process eliminates residual defects through omnidirectional high pressure, further enhancing the consistency of corrosion resistance. The vacuum or high-purity argon sintering environment prevents the introduction of oxidized impurities, maintains the purity of tungsten and silver, and reduces corrosion sensitivity.

Third, surface treatment technology is an effective means to improve corrosion resistance. Anti-corrosion coatings applied by plasma enhanced chemical vapor deposition, such as titanium nitride or chromium carbide, can form a protective layer on the alloy surface, isolate corrosive media, and reduce the oxidation or sulfidation of silver. Electrochemical polishing optimizes surface finish, reduces the initial point of corrosion, and enhances corrosion resistance. Surface passivation treatment further improves corrosion resistance by forming a stable oxide layer, which is particularly suitable for sulfur or chloride

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environments. Studies have shown that appropriate coatings can significantly reduce corrosion rates and extend component life.

Fourth, environmental management and optimization of usage conditions can further enhance corrosion resistance. In humid or acidic environments, use sealed designs or inert gas protection to reduce contact with corrosive media. In welding or electrical applications, control operating parameters such as temperature and humidity to reduce corrosion risks. Intelligent monitoring technology detects corrosion status in real time through embedded sensors, optimizes maintenance cycles, and prevents excessive erosion. Functionally gradient material design increases tungsten content on the surface to enhance the anti-corrosion layer while retaining the conductivity of the internal silver phase .

The combined application of these process methods enables silver tungsten alloy to perform well in humid, acidic or industrial environments, extending component life and improving reliability. Optimization directions include developing self-repairing coatings to dynamically repair corrosion damage, or improving surface uniformity through nano-scale tungsten powder .

2.4 CTIA GROUP LTD Silver Tungsten Alloy MSDS

MSDS (Material Safety Data Sheet) is usually provided by the manufacturer of China Tungsten Intelligent Manufacturing, which contains the physical and chemical properties of the material, safe use instructions and potential hazard information. According to the available relevant information, the MSDS content of silver-tungsten alloy may refer to the general standards of tungsten-based alloys or silver alloys.

Composition information: The ratio of silver (Ag) and tungsten (W) (e.g. 30%-70% Ag, 70%-30% W) depends on the specific product. Physical properties: Density about 12.0-15.0 g/cm³, melting point range varies depending on silver content , conductivity 40%-60% IACS. Health Hazards: Silver and tungsten themselves are not generally significantly toxic. Safety measures: It is recommended to wear protective equipment.



CTIA GROUP LTD Silver Tungsten Alloy

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CTIA GROUP LTD
Silver Tungsten Alloy Introduction

1. Overview of Silver Tungsten Alloy

Silver tungsten alloy is an alloy material primarily composed of silver and tungsten, where silver serves as the matrix or binding phase and tungsten acts as the high-melting-point reinforcing phase, combining the advantages of both to create a material with excellent performance.

2. Features of Silver Tungsten Alloy

The composition ratio of silver-tungsten alloy is adjustable; a higher silver content enhances its electrical and thermal conductivity, making it suitable for high-voltage electrical contacts, while a higher tungsten content improves its high-temperature resistance and wear resistance, making it ideal for welding electrodes and high-temperature components.

3. The Composition Ratio of Silver Tungsten Alloy

Materials	Composition (%weight)	Density (/g.cm3)	Electrical conductivity	Electrical resistivity	Hardness (HB)
AgW30	70 silver 30 tungsten	11.8-12.2	73	2.3	75
AgW40	60 silver 40 tungsten	12.5-12.8	64	2.6	85
AgW50	50 silver 50 tungsten	13.2-13.5	73-56	2.3-3.0	105
AgW55	45 silver 55 tungsten	13.6-13.9	54	3.2	115
AgW60	40 silver 60 tungsten	14.0-14.4	60-50	2.8-3.3	125
AgW65	35 silver 65 tungsten	14.5-14.9	50	3.4	135
AgW70	30 silver 70 tungsten	14.7-15.1	48	3.5	150
AgW80	20 silver 80 tungsten	16.1-16.5	37	4.5	180

4. Production Methods for Silver Tungsten Alloy

The preparation method for tungsten-silver alloy is the same as that for tungsten-copper alloy. Due to tungsten's high melting point and its inability to alloy with silver, traditional methods cannot be used. Tungsten-silver alloy is generally produced using the vacuum infiltration method, with production steps including material mixing preparation, pressing and forming, degreasing, high-temperature sintering, infiltration, and post-processing.

5. Applications of Silver Tungsten Alloy

Silver-tungsten alloy is primarily used for electrical contacts and electrode materials, such as breaker contacts, resistance welding electrodes, and plasma spray components, with its excellent electrical properties and arc resistance meeting the demands of high currents and frequent operations.

6. Purchasing Information

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

Website: silver-tungsten.net

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电话/TEL: 0086 592 512 9696
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sales@chinatungsten.com

Chapter 3: Observation of microstructure characteristics and performance correlation of silver-tungsten alloy

The microstructure of silver-tungsten alloy is the basis of its performance, directly affecting its electrical conductivity, thermal conductivity, hardness and corrosion resistance. The microstructure is formed by powder metallurgy, and the interaction between silver as a binder phase and tungsten reinforcement phase shapes the unique grain morphology, phase distribution and interface characteristics. These structural characteristics are closely related to the mechanical properties and functional properties of the alloy, providing an important basis for optimizing the preparation process and improving application performance.

3.1 Observation of microstructure characteristics of silver-tungsten alloy

The microstructure of silver-tungsten alloy was observed by scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD) techniques, revealing its internal crystal structure and phase distribution. These observations provide direct evidence for understanding the properties of the alloy, demonstrating the interaction between silver and tungsten during the sintering process and its effect on the microstructure.

3.1.1 Grain morphology and size characteristics

The grain morphology and size characteristics of silver-tungsten alloy are the core aspects of the microstructure, which directly affect the mechanical properties and durability of the alloy. The grain morphology is mainly manifested as a polygonal or nearly spherical structure of tungsten particles, while the silver phase presents a continuous or mesh distribution around the tungsten particles. Tungsten particles usually exist in a larger size and provide skeleton support as a reinforcement phase, while the silver phase fills the gaps in the liquid phase sintering to form finer grains. This morphological difference stems from the physical and chemical properties of the two. The high melting point of tungsten keeps it in a solid state during sintering, while the low melting point of silver makes it melt and wet the tungsten particles.

Grain size is affected by the preparation process and sintering conditions. The particle size of the initial tungsten powder is usually in the submicron to micron level, which can be further refined to the nanoscale by high-energy ball milling. Sintering temperature and time play a key role in grain growth. High-temperature and long-term sintering may lead to abnormal growth of tungsten particles, while the silver phase forms larger grains due to enhanced fluidity. Optimized processes such as spark plasma sintering (SPS) inhibit excessive grain growth through rapid heating and pressurization, keeping tungsten particles within a smaller size range, and the silver phase presents a fine and uniform distribution. Observation results show that the smaller the grain size, the higher the grain boundary density, and the hardness and strength of the alloy usually increase accordingly. The uniformity of grain morphology and size has an important influence on performance. Uneven grain distribution may lead to local stress concentration, reducing bending strength and toughness. During the sintering process, hot isostatic pressing (HIP) can

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eliminate micro defects and improve grain consistency through omnidirectional pressure. The application of nano-scale tungsten powder further refines the grains, enhances the grain boundary strengthening effect, and significantly improves the alloy's resistance to wear and arc erosion. The observation of grain morphology also reveals the degree of wetting of silver to tungsten particles. Good wetting forms a dense structure, reduces porosity, and improves the overall performance stability. In short, the grain morphology and size characteristics of silver-tungsten alloys are regulated by the preparation process, which significantly affects their microstructure and macroscopic properties.

3.1.2 Phase distribution and interface characteristics

The phase distribution state and interface characteristics of silver-tungsten alloy are important components of the microstructure, which directly determine the electrical conductivity, thermal conductivity and corrosion resistance of the alloy. The phase distribution is mainly manifested in that tungsten particles are embedded in the silver matrix or bonding phase as a dispersed phase, and the silver phase forms a continuous network or local aggregates around the tungsten particles. The volume fraction of the tungsten phase is usually high and occupies the main volume, while the silver phase fills the gaps during the sintering process and enhances the bonding between the phases. This distribution state is achieved through powder metallurgy, and the uniformity of powder mixing and sintering parameters have a significant impact on it.

Interface characteristics are a key part of the phase distribution state, and the interfacial bonding force between silver and tungsten directly affects the overall performance of the alloy. Observations show that the silver phase wets the surface of tungsten particles during liquid phase sintering to form a tight interface layer, reducing voids and defects. The degree of wetting at the interface is controlled by the silver content and sintering temperature. When the silver content is moderate, the interface is well bonded and presents a smooth transition; excessive silver content may lead to excessive silver liquid phase, forming microscopic accumulation at the interface, affecting stability. The silver phase layer between tungsten particles also acts as a buffer, absorbing thermal stress or mechanical stress and enhancing the toughness of the alloy.

The uniformity of phase distribution is critical to performance. Uneven distribution may lead to localized decreases in electrical or thermal conductivity, especially at high tungsten contents. Insufficient silver phase may form pores and increase electrical or thermal resistance. Optimization of sintering processes such as high-energy ball milling and vacuum sintering can improve the consistency of phase distribution and reduce the accumulation of impurities and oxides at the interface. Observation of interface characteristics also reveals the role of grain boundary strengthening. The silver phase limits dislocation movement at the grain boundary and enhances hardness. However, if the interface bonding force is insufficient, microcracks may be induced, reducing durability.

The application of nano-scale tungsten powder further optimizes the phase distribution and interface characteristics. Small-sized particles increase the interface area, improve the wetting efficiency of silver, and form a denser microstructure. The hot isostatic pressing process compresses the interface under high

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pressure to enhance the bonding force between the phases and reduce interface defects. The chemical reaction or diffusion at the interface also affects the characteristics. The appropriate sintering atmosphere can control the degree of reaction and maintain the purity of tungsten and silver. In short, the phase distribution state and interface characteristics of silver-tungsten alloy are optimized through process control, which is directly related to its electrical, thermal and mechanical properties, providing an important basis for performance improvement.

3.1.3 Microscopic manifestations of porosity and defects

The porosity and microscopic manifestation of defects in silver-tungsten alloys are important aspects of the microstructure, which directly affect the mechanical properties, electrical conductivity and corrosion resistance of the alloy. Porosity refers to the proportion of unfilled voids in the alloy, which is usually determined by the sintering process and raw material characteristics. Defects include microcracks, unbonded areas and impurity aggregation, which together determine the overall density and stability of the alloy. Observing these characteristics helps identify performance bottlenecks and optimize the preparation process.

Porosity in silver-tungsten alloy mainly manifests itself as tiny voids dispersed between the silver phase and the tungsten phase, and the morphology is mostly spherical or irregular. The formation of pores originates from gas encapsulation during powder mixing or insufficient silver liquid phase to completely fill the gaps during sintering. Observations show that areas with higher porosity usually appear where tungsten particles are dense, and uneven distribution of the silver phase may aggravate this phenomenon. High porosity will lead to decreased electrical and thermal conductivity, because heat and current are difficult to transfer in the gaps. At the same time, pores may also become stress concentration points, reducing bending strength and toughness. SEM analysis shows that when the porosity is below a certain level, the alloy performance is significantly improved, especially in high-reliability applications.

The microscopic manifestations of defects include microcracks and unbonded interfaces, which usually occur at the silver-tungsten interface or between tungsten particles. Microcracks may be caused by thermal stress or cooling shrinkage during sintering, especially when the thermal expansion coefficients of the silver phase and the tungsten phase are very different. The unbonded interface is manifested as the failure of the silver phase to completely wet the tungsten particles, resulting in poor local contact and affecting the structural integrity. TEM observations show that defective areas are often accompanied by the accumulation of impurities, which may be introduced when the sintering atmosphere is not good, further weakening the interfacial bonding. The presence of defects may also accelerate the penetration of corrosive media and reduce corrosion resistance.

The control of porosity and defects is the key to optimizing the microstructure. Sintering processes such as hot isostatic pressing compress the material by omnidirectional pressure, significantly reducing pores and microcracks and enhancing density. Spark plasma sintering inhibits defect formation and improves interface bonding through rapid heating and pressurization. The use of high-purity raw materials and uniform powder mixing can reduce impurities and gas inclusions and reduce the initial defect rate.

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Observation results show that the porosity of the optimized silver-tungsten alloy can be reduced to an extremely low level, the defect density is significantly reduced, and the performance consistency is improved. In short, the microscopic manifestations of porosity and defects can be improved through process control, which is directly related to the comprehensive performance of the alloy.

3.1.4 Microstructure differences under different preparation processes

The microstructure of silver-tungsten alloy shows significant differences due to different preparation processes, including traditional pressed powder sintering, hot isostatic pressing (HIP), spark plasma sintering (SPS), etc. Each method has a unique effect on grain morphology, phase distribution and defect state. Observing these differences helps to select the best process for a specific application and optimize the alloy properties.

The traditional pressed powder sintering process is a classic method for preparing silver-tungsten alloy. The microstructure is characterized by tungsten particles dispersed in the silver matrix, and the silver phase forms a network or local aggregates. The grain size is large, the tungsten particles are mostly polygonal, and the silver phase fills the gaps due to liquid phase sintering but is unevenly distributed. The porosity is relatively high and distributed between tungsten particles or in weak areas of the silver phase. Defects such as microcracks and unbonded interfaces are more common. The electrical and thermal conductivity are limited, and the hardness is medium, but the preparation cost is low, which is suitable for mass production.

The hot isostatic pressing (HIP) process significantly improves the microstructure through omnidirectional high pressure and high temperature treatment. The tungsten particles are more evenly distributed, the silver phase forms a continuous network, the porosity is greatly reduced, and defects such as microcracks are reduced. The grain size is refined due to high pressure compression, the interface bonding force is enhanced, and a smooth transition is presented. The electrical conductivity and thermal conductivity are improved, and the hardness and bending strength are significantly improved, which is suitable for applications that require high density and high reliability, such as aerospace counterweights. The disadvantages of the HIP process are that the equipment is complex and the cost is high, which limits its widespread use.

The spark plasma sintering (SPS) process forms a unique microstructure through pulsed current and rapid heating. The tungsten particles remain small, the silver phase is evenly distributed, the pores and defects are almost invisible, and the grain boundary density is high. The wetting effect at the interface is excellent, and the silver phase is tightly combined with the tungsten, reducing stress concentration points. The electrical conductivity, thermal conductivity and hardness all reach a high level, which is particularly suitable for high-performance contact and electrode applications. The rapidity of the SPS process inhibits excessive grain growth, but it has high requirements for raw material purity and particle size, and the process control needs to be fine. The microstructure differences of different preparation processes are also affected by the sintering atmosphere and parameters. Vacuum or inert atmosphere reduces oxidative impurities and improves phase distribution; high temperature and long time sintering may cause grain

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growth and affect uniformity. Observation results show that the microstructure of SPS process is the densest, followed by HIP, and traditional pressed powder sintering is poor.

3.2 Intrinsic Relationship between Silver-Tungsten Alloy Structure and Macroscopic Properties

There is a close intrinsic relationship between the microstructure of silver-tungsten alloy and its macroscopic properties. The grain structure, phase distribution and interface characteristics affect the strength, toughness, electrical conductivity and thermal conductivity of the alloy through physical and chemical mechanisms. This correlation provides a theoretical basis for optimizing the preparation process and improving application performance. The interaction between silver as a binder phase and tungsten reinforcement phase shapes the microstructure, which in turn determines the performance of the alloy in electrical contacts, welding electrodes and aerospace components.

3.2.1 Effect of grain structure on strength and toughness

Grain structure is the core of [silver-tungsten alloy](#) microstructure. The morphology, size and orientation of grains affect the strength and toughness of the alloy through grain boundary strengthening and dislocation movement mechanisms. Strength refers to the ability of an alloy to resist deformation or fracture, while toughness reflects its ability to absorb energy and resist crack propagation. Changes in grain structure directly determine the performance of both.

The effect of grain size on strength follows the Hall-Pasch effect. The smaller the grain, the higher the grain boundary density, the greater the restriction on dislocation movement, and the enhanced yield strength and tensile strength. In silver-tungsten alloy, tungsten particles serve as a reinforcing phase, and the grain size is usually larger, while the silver phase forms finer grains due to liquid phase sintering. Sintering processes such as spark plasma sintering (SPS) inhibit grain growth through rapid heating, refine tungsten particles and silver phases, and significantly improve strength. Observations show that the alloy prepared from nano-scale tungsten powder has a reduced grain size and significantly improved strength, which is particularly suitable for applications requiring high bending strength.

The effect of grain boundaries on toughness is more complex. Fine grains increase the grain boundary area, limit crack propagation, and improve toughness. However, if the grain boundary bonding force is insufficient, microcracks may be induced, reducing toughness. The silver phase wets the tungsten particles at the grain boundary to form a buffer layer, absorb mechanical stress or thermal stress, and enhance toughness. Hot isostatic pressing (HIP) improves grain boundary bonding, reduces defects, and optimizes toughness performance through high pressure. When the silver content is moderate, the liquid phase fills the gap and the grain boundary strengthening effect is significant. Excessive silver content may cause the grain boundary to be too soft and the toughness to decrease. Grain orientation and morphology also affect performance. Polygonal or nearly spherical tungsten particles disperse stress, enhance strength and toughness, and irregular particles may cause local stress concentration and reduce stability. Sintering temperature and time regulate grain growth. Excessive temperature may cause abnormal growth and affect uniformity. Microstructural observation shows that silver-tungsten alloys

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with optimized grain structure achieve a balance between strength and toughness, and are suitable for contact applications in dynamic loads and arc environments. Optimization directions include refining grains through nanostructuring, or adjusting grain boundary distribution through functional gradient design to comprehensively improve performance.

3.2.2 Correlation between phase distribution and electrical and thermal conductivity

Phase distribution is an important feature of the microstructure of silver-tungsten alloy. The distribution state and interface bonding of the phases directly affect the electrical conductivity and thermal conductivity, showing a specific correlation law. Electrical conductivity and thermal conductivity reflect the transfer efficiency of current and heat respectively. The uniformity and continuity of phase distribution are the key to determining these properties.

The silver phase is the main source of electrical and thermal conductivity. Silver forms a continuous network as a matrix or bonding phase, and electrons and heat are efficiently transferred through the silver phase. Although the electrical and thermal conductivity of the tungsten phase is low, its uniform distribution reduces the electrical and thermal resistance concentration points and enhances the overall performance. The continuity of the phase distribution is determined by liquid phase sintering. When the silver content is high, the network is more connected, and the electrical and thermal conductivity are significantly improved; when the tungsten content is dominant, the silver phase may break and the performance decreases. Observations show that the structure in which the silver phase uniformly wraps the tungsten particles has the best electrical and thermal conductivity.

Interface characteristics have a significant impact on performance. The interfacial bonding force between silver and tungsten is enhanced by wetting, reducing voids and defects, and improving electrical and thermal conductivity. When the thickness of the silver phase layer at the interface is moderate, heat and current are transferred smoothly. Too thick a silver layer may increase thermal resistance, while too thin a layer affects continuity. Sintering processes such as hot isostatic pressing compress the interface and spark plasma sintering optimize the phase distribution, significantly improving performance consistency.

The volume fraction of phase distribution also shows a regular pattern. As the silver content increases, the electrical conductivity and thermal conductivity tend to increase, but after exceeding a certain proportion, the increase weakens because the barrier effect of the tungsten phase is enhanced. As the tungsten content increases, the electrical conductivity and thermal conductivity decrease, but the structural stability is improved, which is suitable for high-temperature applications. Microstructural observations show that the optimized phase distribution makes silver-tungsten alloy perform well in high-voltage circuit breaker contacts and heat dissipation substrates.

3.2.3 Effects of porosity and defects on hardness and corrosion resistance

Porosity and defects are important characteristics of the silver-tungsten alloy microstructure, which directly affect the hardness and corrosion resistance, and determine the performance of the alloy in high

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wear and corrosion environments. Porosity refers to the proportion of unfilled voids in the material, and defects include microcracks and unbonded interfaces. These factors play a role by affecting density and surface stability.

The effect of porosity on hardness is mainly reflected in its interference with grain boundaries and phase distribution. Higher porosity will lead to discontinuity of grain boundaries, hinder dislocation movement and grain boundary sliding, and reduce hardness. In silver-tungsten alloys, pores are usually distributed between tungsten particles or in weak areas of silver phase, reducing the overall compressive and wear resistance of the material. Optimizing sintering processes such as hot isostatic pressing (HIP) compresses pores through omnidirectional pressure, significantly improving density and enhancing hardness. Defects such as microcracks further weaken the hardness. These cracks may be caused by thermal stress or cooling shrinkage, especially at the silver-tungsten interface. The hardness decreases significantly when the defect density is high. Observations show that reducing porosity and defect density can increase the hardness to a higher level, which is suitable for applications requiring high wear resistance.

Corrosion resistance is more directly affected by porosity and defects. Pores serve as channels for the penetration of corrosive media, increasing the risk of surface erosion, especially in humid or acidic environments, where residual moisture or chemicals in the pores accelerate the corrosion process. Defects such as unbonded interfaces or microcracks provide initial points for corrosion, through which corrosive media diffuse inward, reducing the chemical stability of the alloy. The silver phase may oxidize or sulfide in the pores, and although the tungsten phase has strong corrosion resistance, unstable compounds may still form in the defects. Sintering process optimization such as spark plasma sintering (SPS) reduces porosity and defects, enhances interface bonding, and significantly improves corrosion resistance. Microstructural observations show that the dense structure prolongs the life of silver-tungsten alloys in corrosive environments, making them particularly suitable for industrial equipment. Optimization directions include reducing initial defects through high-purity raw materials or using nano-scale powders to improve density. The control of porosity and defects is achieved through the adjustment of process parameters, and balancing hardness and corrosion resistance is the key.

3.3 Microstructure evolution of silver-tungsten alloy

The microstructure of silver-tungsten alloy will evolve during the preparation and use process, which is affected by the composition ratio, sintering conditions and environmental factors. This evolution law reveals the dynamic relationship between structure and performance, and provides an important basis for process optimization and life prediction. The driving factors of microstructure evolution include phase change, grain growth and defect evolution, and the interaction between silver and tungsten is the core mechanism.

3.3.1 Microstructure evolution caused by changes in composition ratio

The change in the composition ratio is the main driving factor for the evolution of the microstructure of silver-tungsten alloy. The ratio of silver to tungsten directly affects the grain morphology, phase

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distribution and porosity state, shaping different microstructural characteristics. This evolution process is achieved through sintering process and heat treatment, reflecting the dynamic adjustment of material properties.

When the silver content increases, the microstructure changes significantly. Silver, as a low-melting point bonding phase, melts in liquid phase sintering, wets the tungsten particles and fills the gaps, reducing porosity and enhancing density. The grain morphology evolves into a silver phase network distribution, the tungsten particles are more evenly wrapped, and the interfacial bonding force is improved. When the silver content is moderate, the silver phase forms a continuous network, the grain boundary density increases, the microstructure tends to be delicate, and the hardness and toughness are improved. However, too high a silver content may lead to an excess of liquid phase, the silver phase accumulates to form larger grains, the porosity is reduced, but the grain boundaries are too soft, affecting stability. Observations show that the electrical conductivity and thermal conductivity of alloys with a high silver ratio are enhanced, but the wear resistance may decrease.

When the tungsten content increases, the microstructure evolves into a skeleton structure dominated by tungsten particles. Tungsten remains in the solid state as a high melting point reinforcement phase, the grain size is larger, the silver phase distribution is reduced, and the ability to fill gaps is reduced. Porosity may increase, especially when the silver liquid phase is insufficient, microcracks and unbonded interfaces increase, and density decreases. The grain boundary strengthening effect weakens, the hardness increases but the toughness decreases, and the electrical conductivity and thermal conductivity decrease as the silver phase decreases. Sintering process optimization such as hot isostatic pressing can compress pores and improve structural consistency. Alloys with a high tungsten ratio are suitable for high temperature and arc resistance applications.

Changes in the composition ratio also affect the uniformity of phase distribution. An imbalance in the silver -tungsten ratio may lead to the sedimentation of tungsten particles or local accumulation of silver phases, increased microstructural heterogeneity, and decreased performance consistency. The uniformity of powder mixing and the control of sintering atmosphere can reduce this effect and maintain the stability of phase distribution. The heat treatment process further drives the evolution. High-temperature and long-term treatment may lead to grain growth and phase rearrangement, and parameters need to be controlled to avoid excessive evolution. Observation results show that the dynamic adjustment of the silver-tungsten ratio achieves performance optimization through microstructural evolution, which is suitable for different application requirements. Optimization directions include refining grains through nano-scale powders or adjusting local component ratios using functional gradient design. The microstructural evolution caused by changes in component ratios reveals the adaptability of silver-tungsten alloys and provides a basis for the refinement of the preparation process.

3.3.2 Microstructure transformation during heat treatment

The heat treatment process is an important stage in the evolution of the microstructure of silver-tungsten alloy. It significantly affects the performance of the alloy by controlling the temperature and time to

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induce grain growth, phase adjustment and defect reduction. Heat treatment includes annealing, quenching and aging treatment. The physical and chemical properties of silver and tungsten show different reactions in this process, shaping new microstructural characteristics.

During the annealing process, the microstructure of the silver-tungsten alloy undergoes a significant transformation. Annealing at a lower temperature promotes the redistribution of the silver phase, and the liquid phase fills the residual pores, enhancing the interfacial bonding force. The tungsten particles remain solid, the grain boundaries tend to be smooth, and microcracks and defects gradually decrease. The grain size may increase slightly, but excessive growth can be suppressed by controlling the annealing time to maintain a fine structure. Observations show that the density of the annealed alloy is improved, and the hardness and conductivity are improved to a certain extent, which is particularly suitable for contact applications that require uniform performance.

The quenching treatment induces phase changes through rapid cooling. The silver phase forms fine grains due to rapid solidification, and the distribution of tungsten particles is more uniform, but cooling stress may cause micro cracks. The phase distribution state is adjusted, and the silver phase network may break or rearrange, affecting thermal conductivity and electrical conductivity. Defects such as unbonded interfaces may increase due to stress concentration, and the cooling rate needs to be optimized to reduce this effect. The microstructure after quenching is suitable for parts that require high strength and fast response, but the toughness may be slightly reduced.

The aging treatment optimizes the microstructure through long-term low-temperature treatment. The silver phase gradually stabilizes, the interface of the wetted tungsten particles is enhanced, and the porosity is further reduced. Grain growth is inhibited, the tungsten skeleton structure is denser, and the defect density is significantly reduced. Phase adjustment enhances the interfacial bonding strength of silver and tungsten, and improves hardness and corrosion resistance. Observation results show that the aged alloy performs well in long-term service and is particularly suitable for aerospace counterweights and welding electrodes. Fine control of heat treatment parameters is key. Excessive temperature or time may cause excessive grain size and affect performance. Optimization directions include controlling phase transitions through segmented heat treatment, or adjusting parameters in real time in combination with intelligent monitoring technology. The microstructural transformation during heat treatment is dynamically optimized through the fluidity of silver and the stability of tungsten, which correlates the comprehensive performance of the alloy.

3.3.3 Effect of service environment on microstructure and performance feedback

The service environment has a significant impact on the evolution of the microstructure of silver-tungsten alloy. Environmental conditions such as temperature, humidity, chemical media and mechanical stress change the structural characteristics through physical and chemical effects, which in turn feed back to the performance of the alloy. This influence provides an important basis for life prediction and maintenance strategies. High temperature environment accelerates the microstructural evolution of silver-tungsten alloy. The silver phase may soften or partially melt at high temperature, the interface of

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wetted tungsten particles may rearrange, and microcracks may occur at grain boundaries due to thermal stress. The tungsten skeleton structure remains stable, but long-term high temperature may cause grain growth, increased porosity, and decreased density. Performance feedback is manifested in reduced electrical and thermal conductivity, reduced hardness due to changes in grain boundaries, and reduced corrosion resistance due to thermal oxidation. High-temperature components need to be strengthened for protection.

The effect of humid or corrosive environments on the microstructure is more complex. The silver phase may undergo slight corrosion in a sulfur or chloride environment, forming oxides or sulfides, and defects at the interface. The tungsten phase has strong corrosion resistance, but the defects may penetrate the corrosive medium, the porosity increases, and the structural integrity is damaged. Performance feedback is manifested as decreased conductivity, further weakening of corrosion resistance, and mechanical strength may be reduced due to crack propagation, which needs to be improved through surface coating or sealing design. Mechanical stress environments such as vibration or impact cause dynamic changes in the microstructure. Grain boundaries are subject to stress concentration, microcracks may expand, and the pores become stress release points, affecting density. The ductility of the silver phase absorbs part of the stress, but long-term loading may cause fatigue damage. Performance feedback is manifested as decreased toughness, local weakening of hardness, and electrical and thermal conductivity are limited due to microstructural damage. It is necessary to optimize the grain distribution for dynamic applications.

The combined effects of environmental factors feed back performance through microstructural evolution. Observations show that high temperature and corrosion work together to accelerate defect growth, and mechanical stress intensifies crack propagation. Optimization directions include developing environmentally resistant coatings or enhancing local stability through functional gradient design. The impact of the service environment on the microstructure and its performance feedback provide important guidance for the adaptive design of alloys.

3.4 Methods for controlling the microstructure of silver-tungsten alloy

The regulation of the microstructure of silver-tungsten alloy is the key to improving performance and adapting to application requirements, which needs to be achieved through a combination of material preparation, process optimization and post-processing. The regulation measures target grain morphology, phase distribution, porosity and defects, aiming to optimize electrical conductivity, thermal conductivity, hardness and corrosion resistance. Raw material selection is the basis of regulation. High-purity nano-scale tungsten powder and silver powder are used to refine the grains and improve the uniformity of phase distribution. Powder mixing processes such as high-energy ball milling ensure uniform raw materials and reduce initial defects, laying the foundation for subsequent regulation.

Sintering process is the core of regulation. Liquid phase sintering fills gaps and reduces porosity through the wetting effect of silver. Spark plasma sintering (SPS) inhibits grain growth and optimizes phase distribution through rapid heating and pressurization. Hot isostatic pressing (HIP) compresses defects and enhances density through high pressure. Sintering atmosphere such as vacuum or inert gas reduces

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oxidized impurities and improves interface quality. Heat treatment provides dynamic regulation. Annealing improves interface bonding, quenching refines grains, and aging treatment stabilizes phase state and adjusts grain boundaries and defect states. Parameter optimization such as staged temperature increase controls grain growth and enhances performance consistency. Surface treatment enhances regulation. Electrochemical polishing reduces roughness and reduces defect initiation points. Anti-corrosion coatings such as titanium nitride isolation media and anti-adhesion coatings improve surface properties. Functional gradient design adjusts composition in specific areas to optimize local performance. Environmental management supports regulation. Control temperature and humidity during use to reduce corrosion effects. Intelligent monitoring technology adjusts process parameters in real time and dynamically optimizes microstructure. The comprehensive application of control measures improves the performance of silver-tungsten alloy to meet the needs of electrical, welding and aerospace.

3.4.1 Microstructure control method based on preparation process

The microstructure control method based on the preparation process is the core means to optimize the performance of silver-tungsten alloy. The precise control of grain morphology, phase distribution and defects is achieved through various stages of the powder metallurgy process. The preparation process includes powder mixing, pressing, sintering and post-processing, and each step has a unique effect on the microstructure. The uniform dispersion of raw materials is achieved through high-energy ball milling technology in the powder mixing stage. Nano-scale tungsten powder and silver powder are used to refine the grains and optimize the consistency of phase distribution. High-purity raw materials reduce impurities and reduce the initial defect rate, laying the foundation for subsequent regulation. The pressing process adjusts the particle arrangement by controlling the pressure and mold design, reduces the gap, and improves the primary level of density.

The sintering process is a key link in regulation. Liquid phase sintering uses the low melting point of silver to wet tungsten particles, fill gaps, and reduce porosity. Spark plasma sintering (SPS) inhibits grain growth, refines the structure, and optimizes phase distribution through pulsed current and rapid heating. Hot isostatic pressing compresses defects through omnidirectional high pressure, enhances interfacial bonding, and significantly improves density. Sintering atmospheres such as vacuum or inert gas reduce oxidation, maintain the purity of tungsten and silver, and improve the quality of the microstructure. Post-treatment further optimizes the structure. Heat treatment such as annealing improves interfacial bonding, quenching refines grains, and aging treatment stabilizes the phase state. Surface treatment such as electrochemical polishing reduces roughness and reduces defect initial points. Fine adjustment of process parameters, such as temperature gradient and time control, customizes the microstructure for different application requirements. Observations show that the process route of SPS combined with HIP significantly improves density and uniformity, and is suitable for high-performance contacts.

3.4.2 Optimization of microstructure by alloying element addition

The addition of alloying elements is an important means of optimizing the microstructure of silver-tungsten alloy. By introducing trace elements to adjust the phase state, grain boundary and defect state,

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the electrical conductivity, thermal conductivity and mechanical properties are enhanced. The type and content of the added elements need to be precisely controlled according to the target performance to avoid negative effects.

The addition of nickel improves the microstructure of silver-tungsten alloy. A small amount of nickel (usually less than a few percent) enhances the wetting ability of the silver phase, promotes liquid phase sintering, fills pores, and reduces defect density. Nickel also improves interfacial bonding, refines grains, and enhances hardness and toughness, but excessive amounts may introduce magnetism and affect conductivity. Observations show that the interface of the alloy optimized by nickel is denser and suitable for applications requiring high strength. The addition of cobalt optimizes phase distribution. Cobalt forms a stable interface layer with silver and tungsten, reduces microcracks, and improves grain boundary strengthening effects. Cobalt also enhances the uniformity of tungsten particles, reduces porosity, and improves thermal conductivity and corrosion resistance. The content needs to be controlled at a low level to avoid excessive hardening and reduced toughness. Experiments have shown that alloys with cobalt additions perform well in high temperature environments and are suitable for welding electrodes. Other elements such as molybdenum or chromium can also optimize the microstructure. Molybdenum improves the oxidation resistance of tungsten, reduces defects in heat treatment, and enhances corrosion resistance. Chromium improves the chemical stability of the silver phase, reduces corrosion sensitivity, and optimizes phase distribution. The addition amount needs to be finely adjusted to avoid grain boundary embrittlement or performance imbalance. The results show that trace element addition refines grains and enhances microstructural uniformity.

The effect of alloying elements is amplified by the sintering process. High temperature treatment promotes element diffusion, optimizes interface bonding, and low temperature aging stabilizes the phase state. The synergistic effect of added elements improves the quality of the microstructure and is suitable for specific application requirements. Optimization directions include developing new alloying element combinations or determining the best addition ratio through intelligent analysis. The addition of alloying elements directly supports the performance improvement of silver-tungsten alloys through microstructural optimization.

3.4.3 Relationship between microstructure regulation and performance customization

There is a close relationship between microstructure regulation and performance customization. Adjustments to grain morphology, phase distribution, and defects directly affect electrical conductivity, thermal conductivity, hardness, corrosion resistance, and toughness, meeting the needs of different application scenarios. This correlation provides flexibility for material design, and optimizing processes and element additions are the key to achieving customization. Regulation of grain morphology affects mechanical properties. Refining grains improves hardness and strength through grain boundary strengthening, which is suitable for high wear-resistant contacts. Adjusting grain orientation reduces stress concentration and enhances toughness, which is suitable for dynamic load environments. Observations show that alloys with nanoscale grains perform well in aerospace counterweights. Optimization of phase distribution determines electrical properties. The continuity of the silver phase

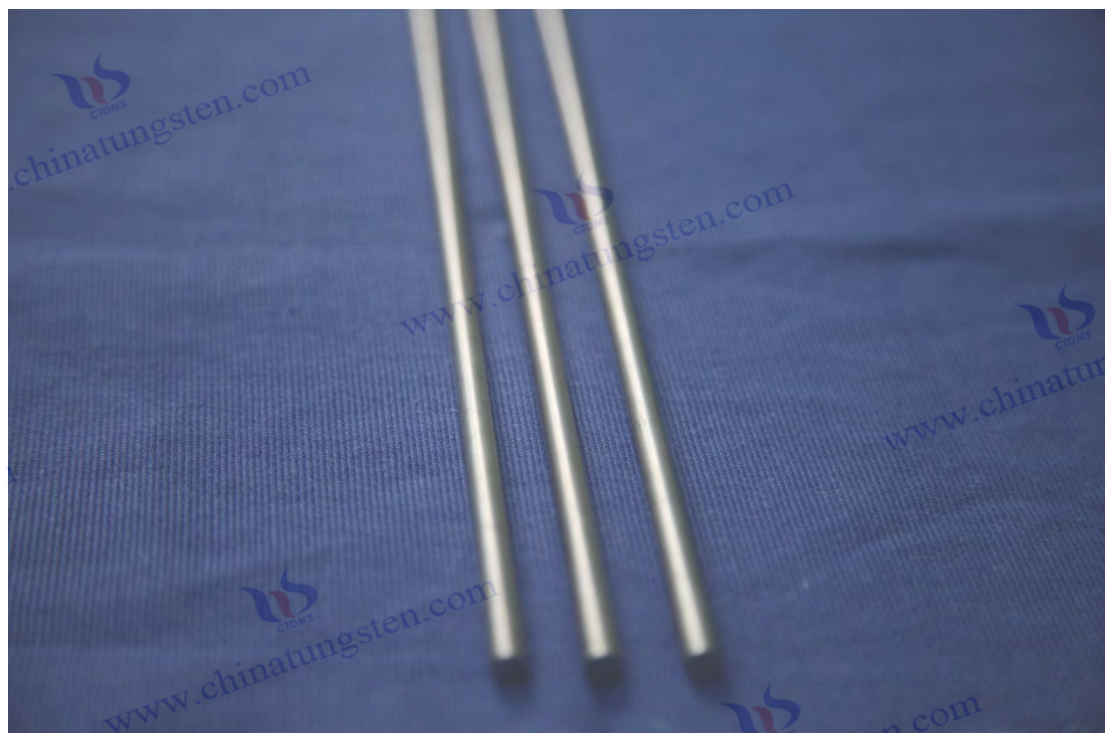
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network improves electrical conductivity and thermal conductivity, which is suitable for high-voltage circuit breaker contacts. The uniform distribution of tungsten phases enhances structural stability and balances high-temperature performance, which is suitable for welding electrodes. Functional gradient design adds silver phases to the conductive area to customize the heat dissipation needs of electronics.

Control of defects and porosity improves overall performance. Reducing porosity enhances density, improves corrosion resistance and conductivity, and is suitable for industrial equipment. Reducing microcracks improves fatigue resistance and meets long-term service requirements. Process optimization such as combining HIP and SPS can achieve low-defect structures and customized high-reliability components.

Alloying element additions further support customization. Nickel and cobalt refine grain boundaries, enhance hardness and corrosion resistance, and customize wear-resistant applications. Molybdenum and chromium optimize oxidation resistance to meet the needs of high-temperature environments. Dynamic adjustment of element ratios customizes the microstructure according to the application scenario, and observations show that customized alloys outperform general-purpose materials in specific properties.

Optimization directions include developing intelligent design tools to predict the effect of regulation, or verifying customized solutions through multi-parameter experiments. The connection between microstructure regulation and performance customization provides adaptive support for silver-tungsten alloys to meet the diverse needs of electrical, welding and aerospace fields.



CTIA GROUP LTD Silver Tungsten Alloy

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www.ctia.com.cn

电话/TEL: 0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

Chapter 4: Preparation Technology of Silver-Tungsten Alloy

The preparation process of silver-tungsten alloy is the key to its microstructure and performance. Powder metallurgy is the main production technology, which realizes the preparation of high-performance alloys by precisely controlling the raw material processing, molding and sintering processes. This process combines the high conductivity of silver and the high hardness of tungsten to meet the application requirements of electrical contacts, welding electrodes and aerospace components.

4.1 Production of silver-tungsten alloy by powder metallurgy

Powder metallurgy is an efficient and controllable production method for preparing silver-tungsten alloy by mixing, pressing and sintering silver and tungsten powders. This method makes full use of the low melting point of silver and the high melting point of tungsten to form a dense structure through liquid phase sintering. The process includes powder preparation, mixing, pressing and sintering, and subsequent heat treatment and surface treatment further optimize the performance. Powder metallurgy is suitable for mass production, especially for applications that require high density and uniformity.

4.1.1 Powder preparation process and key points

Powder preparation is the basis of powder metallurgy, which involves the acquisition, purification and particle size control of silver and tungsten powders, which directly affects the microstructure and properties of the alloy. The process includes raw material selection, crushing, screening and surface treatment, and each step requires attention to key points.

The raw material selection first considers the high purity of silver and tungsten, and uses high-quality metal powder to reduce the introduction of impurities. Silver powder is usually prepared by chemical precipitation or atomization, and tungsten powder is obtained from tungsten oxide by hydrogen reduction to ensure stable chemical composition. The higher the purity, the better the conductivity and corrosion resistance of the prepared alloy.

The powder particle size is refined by ball milling or air flow milling. Tungsten powder needs to be crushed from coarse particles to submicron or nanometer levels, and silver powder is controlled to an appropriate particle size for subsequent mixing. High-energy ball milling technology can improve uniformity, but overheating should be avoided to cause powder agglomeration. The control of particle size distribution is the key point. Too large particles may cause pores, and too small particles increase surface energy and affect sintering behavior.

The sieving step ensures the consistency of the powder particle size. Standard sieves are used to remove oversized or undersized particles to optimize the mixing effect. Particle size uniformity directly affects phase distribution. Fine particles help to form a dense structure, but the flowability needs to be balanced for compression. Surface treatment removes oxide layers and impurities through chemical cleaning or coating to improve the compressibility and sintering properties of the powder. Silver oxide may form on

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the surface of silver powder and needs to be treated with a reducing agent; the oxide on the surface of tungsten powder is removed by acid washing. The treated powder should be stored in a dry environment to avoid moisture absorption or oxidation.

The key points include controlling the powder purity, particle size and surface condition, and using advanced equipment such as plasma ball milling to improve efficiency. The optimization of powder preparation lays the foundation for subsequent processes and is directly related to the microstructural quality of the alloy.

4.1.2 Pressing process principle and operation

The pressing process is the key step to form the mixed silver-tungsten powder into a green body. It is based on the principle of compression and densification of powder particles under pressure, which directly affects the density of the green body and the subsequent sintering effect. The operation needs to focus on pressure control, mold design and process parameters to ensure the molding quality. The pressing principle is based on the plastic deformation and sliding of powder particles under external pressure, filling the molecular gaps and reducing the porosity. Silver powder is easy to compress due to its good ductility, while tungsten powder requires higher pressure due to its high hardness. The mixed powder is subjected to force in the mold, the particles are rearranged, and the initial density is gradually improved. The uniformity of pressure distribution is the core. Local overpressure may cause cracks, while underpressure retains more pores.

The operation process includes powder filling, pre-pressing and main pressing. When filling the powder, ensure that the powder fills the mold evenly to avoid stratification or voids. Vibration or tapping can assist in distribution. Pre-pressing applies low pressure to expel air and improve particle contact. The main pressing uses a hydraulic press or a mechanical press. The pressure is adjusted according to the alloy composition. When the tungsten content is high, it needs to be increased to a higher level. The typical value is hundreds of MPa. The pressing time is controlled from a few seconds to tens of seconds. If it is too long, it may cause elastic rebound.

Mold design is the key to operation. Use wear-resistant materials such as cemented carbide to make molds with smooth inner walls to reduce friction. The mold shape is customized according to the requirements of the final part, and complex shapes need to be pressed in sections. Lubricants such as zinc stearate are applied to the inner wall of the mold to reduce friction, improve the density of the blank and demoulding properties.

The optimization of process parameters includes pressure gradient, pressing rate and temperature. Gradual pressurization reduces stress concentration, slow pressing improves density, and moderate heating enhances powder fluidity. Observations show that the green body with optimized pressing process has lower porosity and improved surface flatness, laying a good foundation for sintering. Optimization directions include developing an intelligent pressing system to monitor pressure in real time, or using isostatic pressing technology to improve uniformity. The pressing process principle and

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operation achieve high-quality blanks through precise control, which directly supports the performance of silver-tungsten alloy.

4.1.3 Control and influence of sintering process

The sintering process is a key stage in the production of silver-tungsten alloy by powder metallurgy. The bonding and densification of powder particles are achieved through high-temperature treatment, which directly affects the microstructure and performance. Controlling the sintering temperature, time and atmosphere is the core, and the optimization of process parameters is closely related to the porosity, phase distribution and mechanical properties of the alloy.

The sintering process is based on the principle of liquid phase sintering. Silver melts at high temperature, wets the tungsten particles, fills the gaps, and enhances the interface bonding strength. Temperature control is the key. If the temperature is too low, the silver cannot be fully melted, and the porosity is high; if the temperature is too high, the tungsten particles may grow or the silver may volatilize, affecting the uniformity. The typical sintering temperature is adjusted according to the silver -tungsten ratio , usually slightly higher than the melting point of silver, and maintained for a period of time to promote diffusion. Time control affects grain growth and densification. Short-term sintering limits grain growth and maintains a fine structure, but may leave pores; long-term sintering promotes particle bonding and reduces defects, but may lead to abnormal growth. Optimizing time requires a balance between density and grain size. Observations show that medium-term sintering time can achieve the best microstructure.

Atmosphere control prevents oxidation and the introduction of impurities. A vacuum or high-purity cyanide environment reduces surface oxidation of silver and tungsten and maintains purity. Inert atmospheres such as argon are also effective to prevent chemical reactions from affecting phase distribution. The stability of the sintering atmosphere directly affects conductivity and corrosion resistance, and controlling the purity of the atmosphere is an important step.

The influence of sintering process is reflected in the microstructure. Appropriate parameters form a dense structure, reduce porosity, enhance hardness and conductivity; improper parameters may cause microcracks or uneven phase distribution, reducing performance. Hot isostatic pressing (HIP) or spark plasma sintering (SPS) are used as auxiliary means to further optimize the sintering effect. SPS accelerates diffusion through pulsed current, and HIP compresses defects through high pressure . Optimization directions include developing intelligent sintering furnaces to monitor temperature and atmosphere in real time, or combining multi-stage sintering to enhance control accuracy. The control and influence of the sintering process directly shape the performance of silver-tungsten alloy through parameter optimization.

4.2 Production of silver-tungsten alloy by vacuum infiltration method

Melting silver under vacuum conditions and infiltrating it into a porous tungsten skeleton. This method is suitable for preparing complex shapes or high-performance components, and is particularly suitable

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for applications that require excellent conductivity and high temperature resistance. The process includes tungsten skeleton preparation, infiltration and post-processing, and precise control of equipment and parameters is the key to success.

4.2.1 Infiltration principle and equipment requirements

The infiltration principle is based on capillary action and liquid metal penetration in a vacuum environment. The porous tungsten skeleton is infiltrated by the melting of silver to form a dense alloy. Silver becomes liquid at high temperature, reduces oxidation under vacuum conditions, and relies on capillary force to enter the pores of the tungsten skeleton, fill the gaps and combine with tungsten.

Capillary action is the core mechanism, and the pore size and distribution of the tungsten skeleton determine the penetration efficiency. The wettability of the silver liquid directly affects the penetration depth, and the surface tension needs to match the pore characteristics. The vacuum environment reduces gas obstruction, prevents silver oxidation or volatilization, and ensures pure penetration.

Equipment requirements include a vacuum furnace, heating system and pressure control device. The vacuum furnace needs to achieve a high vacuum degree to prevent residual gas from affecting penetration, and be equipped with a precise pressure sensor. The heating system uses induction heating or resistance heating, with high temperature uniformity and a control range covering above the melting point of silver. The pressure control device assists penetration and adjusts the external pressure to enhance the flow of liquid silver.

The mold design supports complex shapes, is made of high temperature resistant materials such as graphite or ceramic, and has a smooth inner wall to reduce adhesion. The temperature and vacuum monitoring system adjusts parameters in real time to ensure stable penetration. Equipment maintenance is key, and regular inspections of sealing and heating elements are required to avoid leakage or performance degradation.

4.2.2 Process steps and parameter optimization

The process steps of vacuum infiltration include tungsten skeleton preparation, silver melting and infiltration post-treatment. Parameters need to be optimized at each stage to achieve the best microstructure and performance. The tungsten skeleton is prepared by pressing powder and sintering to form a porous structure. After mixing the tungsten powder, it is pressed into shape. The sintering temperature is lower than the melting point of silver to maintain a moderate porosity. The pore size and distribution must be uniform. Too large pores may lead to insufficient silver penetration, while too small pores will hinder the flow. Observations show that the tungsten skeleton with optimized sintering has the best penetration effect.

Silver melting is carried out in a vacuum furnace. Silver is placed above the tungsten skeleton and heated above the melting point to form liquid silver. Temperature control is to avoid overheating, which may

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cause silver volatilization or deformation of the tungsten skeleton. The vacuum degree is kept at a high level to reduce oxidized impurities and enhance wettability. The melting time is adjusted according to the thickness of the skeleton to ensure full liquefaction. The penetration process relies on capillary force and auxiliary pressure. The silver liquid penetrates the tungsten skeleton under vacuum conditions, and the time and pressure must be matched. Too short may leave pores, and too long will cause silver to overflow. The auxiliary pressure enhances the penetration depth, and the excess silver is removed before optimization post-processing. Observation shows that the penetration layer after parameter optimization is uniform and dense.

Post-processing includes cooling and heat treatment. Slow cooling reduces thermal stress, and heat treatment such as annealing improves interface bonding and enhances performance consistency. Parameter optimization needs to be adjusted according to component requirements, and complex shapes may require segmented infiltration.

4.2.3 Advantages and limitations of this process

The vacuum infiltration method shows unique advantages in the production of silver-tungsten alloys, but it also has certain limitations, which directly affect its application scenarios and process optimization directions. The advantage is that it can achieve high density. The silver liquid fully penetrates the tungsten skeleton under vacuum conditions, reducing porosity and enhancing the electrical and thermal conductivity of the alloy. It is particularly suitable for contacts and electrodes that require uniform performance. The preparation of complex-shaped parts is another advantage. The infiltration method adapts to porous structures through capillary action and is easy to form precision parts such as aerospace counterweights or electronic connectors. The vacuum environment also reduces oxidative impurities, maintains the purity of silver and tungsten, and improves corrosion resistance and long-term stability.

The limitations are mainly reflected in the complexity of the process and the high cost. The maintenance requirements of the vacuum furnace and heating equipment are high, and the initial investment and operating costs are increased, which limits the large-scale production capacity. The porosity of the tungsten skeleton and the penetration depth of silver need to be precisely matched, the parameter control is difficult, and the failure rate may be high. The volatilization or overflow of silver at high temperatures may lead to material waste and affect the economy. In addition, the melt infiltration method has strict requirements on the purity and particle size of the raw materials, and the process of preparing porous tungsten skeletons is complicated, which increases the difficulty of operation. Microstructural observations show that insufficient optimization may lead to uneven interfaces and affect performance consistency.

4.3 Process comparison and selection basis

The preparation processes of [silver-tungsten alloy](#) include powder metallurgy and vacuum infiltration. Each method has differences in performance, cost and applicability. The process selection needs to be comprehensively considered based on application requirements and production conditions.

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4.3.1 Cost analysis of different processes

Cost is an important basis for process selection. The cost difference between powder metallurgy and vacuum infiltration is mainly reflected in equipment investment, raw material consumption and production efficiency, which directly affects production economy. Cost analysis needs to be evaluated in combination with batch production and quality requirements.

The equipment cost of powder metallurgy is relatively low. The powder press and sintering furnace are basic equipment with simple structure and low maintenance cost, which are suitable for mass production. The raw material consumption is mainly silver powder and tungsten powder. The material utilization rate of powder mixing and pressing process is high and the waste is small. The production efficiency is high, the degree of automation can be improved through the assembly line, and the unit cost decreases with the increase of output. Observations show that the cost of small-scale production is moderate, and the cost of large-scale production is significantly reduced, which is suitable for standardized parts such as contacts and electrodes.

The equipment cost of the vacuum infiltration method is relatively high. The vacuum furnace, induction heating system and pressure control device require precision manufacturing, and the initial investment and maintenance costs are large, which limits small and medium-scale production. Raw material consumption includes tungsten powder to prepare porous skeletons and silver. The skeleton sintering and silver melting processes may cause material loss, and the efficiency is lower than that of powder metallurgy. Production efficiency is limited by process complexity, parameter adjustment and quality control increase labor costs, and the unit cost is relatively high. Observations show that the production cost of high-performance or complex-shaped parts is acceptable, but the economy is not enough for large-scale applications.

Labor costs and energy consumption also affect the total cost. Powder metallurgy has a standardized process flow and low labor demand. Energy consumption is mainly concentrated in the sintering stage, which can be reduced by optimizing the temperature. Vacuum infiltration requires professional operators, and the long-term vacuum and heating process consumes a lot of energy, requiring efficient energy management. Cost analysis shows that powder metallurgy has more advantages in cost control and is suitable for high output needs; vacuum infiltration is more competitive in high value-added components.

Optimization directions include developing low-cost vacuum equipment or improving powder metallurgy efficiency through process integration. Cost analysis provides a quantitative basis for process selection, which needs to be weighed according to production scale and performance requirements.

4.3.2 Performance Differences and Process Selection

Performance differences are an important basis for selecting powder metallurgy or vacuum infiltration. The two processes have different characteristics in conductivity, thermal conductivity, hardness, corrosion resistance and microstructural consistency, which directly affect the application scenarios.

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Silver-tungsten alloy prepared by powder metallurgy is stable in electrical and thermal conductivity. The silver phase forms a continuous network through liquid phase sintering, and the current and heat transfer efficiency is high, which is suitable for high-voltage circuit breaker contacts and heat dissipation substrates. The hardness is high due to the good distribution and density of tungsten particles, and the wear resistance meets the requirements of welding electrodes. Corrosion resistance depends on sintering atmosphere control, and performs well in humid environments after optimization. The consistency of microstructure is affected by the uniformity of powder mixing and pressing. Appropriate processes can reduce defects and are suitable for large-scale standardized production.

The alloy prepared by vacuum infiltration has more advantages in performance. Silver liquid infiltrates the tungsten skeleton to form a high-density structure with extremely low porosity. The electrical and thermal conductivity are better than those of powder metallurgy, which is particularly suitable for high-precision electronic connectors. The hardness is higher due to the enhanced density and interface bonding force, and the wear resistance and arc resistance are outstanding, which is suitable for plasma sprayed parts. The corrosion resistance is improved due to the reduction of oxidation in the vacuum environment, and the service life is longer in corrosive environments. The microstructure consistency is excellent, and the uniformity of complex-shaped parts is better, which is suitable for aerospace counterweights.

The performance difference stems from the process mechanism. Powder metallurgy relies on the uniformity of powder mixing and sintering parameters, and its performance is stable but the optimization space is limited. The vacuum infiltration method achieves high density through capillary penetration, and has greater performance potential but is sensitive to parameters. Observations show that powder metallurgy is suitable for general applications that need to balance cost and performance, while infiltration is suitable for high performance or customized needs. Process selection needs to be determined based on conductivity priority, corrosion resistance requirements, and component complexity. Optimization directions include combining process advantages to improve performance.

4.3.3 Production efficiency and process adaptation

Production efficiency and process adaptation are important dimensions for selection. Powder metallurgy and vacuum infiltration differ in output, degree of automation and equipment utilization, which directly affect the production cycle and economic benefits.

Powder metallurgy has high production efficiency. The powder mixing, pressing and sintering processes can be automated, and assembly line production can increase output, which is suitable for mass production of contacts and electrodes. The equipment utilization rate is high, and the powder press and sintering furnace can operate continuously with short downtime for maintenance. The production cycle is short, usually a few hours from raw materials to finished products, which is suitable for scenarios that require rapid response to market demand. The process has strong adaptability, and standard molds and parameters are suitable for a variety of specifications, with high flexibility. The vacuum infiltration method has low production efficiency. The tungsten skeleton preparation and infiltration process require precise control, the degree of automation is limited, and the output is suitable for small and medium

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batches of high value-added parts such as aviation counterweights. Equipment utilization is affected by the complexity of the vacuum furnace, and maintenance and parameter adjustments increase downtime. The production cycle is long, and the total time for skeleton preparation and infiltration may be several days, which is suitable for customization or high-performance requirements. The process adaptability depends on the mold and skeleton design, and complex shapes require special equipment, and the flexibility is limited.

The difference in efficiency comes from the complexity of the process. The powder metallurgy process is standardized and suitable for high output; the vacuum infiltration method has a fine process and is suitable for high quality requirements. Observations show that the powder metallurgy method has obvious efficiency advantages in mass production, and the infiltration method is more adaptable in small-batch high-precision production. Optimization directions include developing automated infiltration equipment or optimizing powder metallurgy parameters to shorten the cycle. Production efficiency and process adaptation provide a practical basis for selection, which needs to be weighed according to production targets and quality requirements.



CTIA GROUP LTD Silver Tungsten Alloy

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CTIA GROUP LTD
Silver Tungsten Alloy Introduction

1. Overview of Silver Tungsten Alloy

Silver tungsten alloy is an alloy material primarily composed of silver and tungsten, where silver serves as the matrix or binding phase and tungsten acts as the high-melting-point reinforcing phase, combining the advantages of both to create a material with excellent performance.

2. Features of Silver Tungsten Alloy

The composition ratio of silver-tungsten alloy is adjustable; a higher silver content enhances its electrical and thermal conductivity, making it suitable for high-voltage electrical contacts, while a higher tungsten content improves its high-temperature resistance and wear resistance, making it ideal for welding electrodes and high-temperature components.

3. The Composition Ratio of Silver Tungsten Alloy

Materials	Composition (%weight)	Density (/g.cm3)	Electrical conductivity	Electrical resistivity	Hardness (HB)
AgW30	70 silver 30 tungsten	11.8-12.2	73	2.3	75
AgW40	60 silver 40 tungsten	12.5-12.8	64	2.6	85
AgW50	50 silver 50 tungsten	13.2-13.5	73-56	2.3-3.0	105
AgW55	45 silver 55 tungsten	13.6-13.9	54	3.2	115
AgW60	40 silver 60 tungsten	14.0-14.4	60-50	2.8-3.3	125
AgW65	35 silver 65 tungsten	14.5-14.9	50	3.4	135
AgW70	30 silver 70 tungsten	14.7-15.1	48	3.5	150
AgW80	20 silver 80 tungsten	16.1-16.5	37	4.5	180

4. Production Methods for Silver Tungsten Alloy

The preparation method for tungsten-silver alloy is the same as that for tungsten-copper alloy. Due to tungsten's high melting point and its inability to alloy with silver, traditional methods cannot be used. Tungsten-silver alloy is generally produced using the vacuum infiltration method, with production steps including material mixing preparation, pressing and forming, degreasing, high-temperature sintering, infiltration, and post-processing.

5. Applications of Silver Tungsten Alloy

Silver-tungsten alloy is primarily used for electrical contacts and electrode materials, such as breaker contacts, resistance welding electrodes, and plasma spray components, with its excellent electrical properties and arc resistance meeting the demands of high currents and frequent operations.

6. Purchasing Information

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

Website: silver-tungsten.net

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电话/TEL: 0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

Chapter 5: Performance Testing and Characterization of Silver-Tungsten Alloy

Performance testing and characterization of silver-tungsten alloy is a key step in evaluating its quality and application potential. Through systematic testing of physical, mechanical and functional properties, the performance of the alloy in terms of electrical conductivity, thermal conductivity, hardness and corrosion resistance is revealed. The test method needs to be combined with international standards and experimental conditions to ensure the reliability and comparability of the data.

5.1 Physical Properties Test of Silver Tungsten Alloy

The physical property test of silver tungsten alloy focuses on basic properties such as density, hardness and conductivity. These indicators directly reflect the microstructure and preparation process of the alloy. Accurate measurement of physical properties provides the basis for subsequent mechanical and functional performance tests. The test method needs to be optimized according to the characteristics of the alloy.

5.1.1 Density test method

Density testing is an important means to evaluate the density and porosity of silver-tungsten alloys, reflecting the distribution of silver and tungsten in the material and the sintering quality. The density directly affects the electrical conductivity, thermal conductivity and mechanical strength, and the test method must ensure accuracy and repeatability.

The Archimedean method is a commonly used density test method. The sample is first weighed in a dry state to obtain the dry weight. It is then immersed in a liquid of known density (such as distilled water) to measure the suspended weight and immersed weight. Density is calculated using the formula: $\text{Density} = \frac{\text{dry weight}}{\text{dry weight} - \text{immersed weight}} \times \text{liquid density}$. The liquid must be free of bubbles, and there should be no pores on the sample surface that affect the measurement. Multiple tests are averaged to ensure stable results.

X-ray fluorescence (XRF) is used as an auxiliary method to indirectly evaluate density consistency by combining microscopic analysis to determine phase distribution. The sample is cut into thin slices and placed in an X-ray device to measure the ratio of silver and tungsten content, and the actual density is calculated based on the theoretical density. This method is suitable for parts with complex shapes, and the instrument needs to be calibrated to reduce errors.

The key points of the test include sample pretreatment, removal of surface oxide layers and impurities, and prevention of moisture absorption affecting the results. The test environment needs to be constant temperature and humidity to reduce external interference. Observations show that the density of the alloy with optimized sintering process is close to the theoretical value, with low porosity and excellent performance. The accuracy of the density test method provides reliable data for performance evaluation,

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and the optimization direction includes the development of non-contact measurement technology to improve efficiency.

5.1.2 Hardness test standards and operations

Hardness test is an important means to evaluate the deformation resistance and wear resistance of silver-tungsten alloy, reflecting the synergistic effect of tungsten particles and silver phase. The hardness affects the service life of the alloy in mechanical contact and arc environment. The test must follow international standards and standardize the operation.

The Vickers hardness test is a commonly used standard that complies with ISO 6507 or ASTM E384 specifications. The test uses a diamond indenter, which is pressed into the sample surface under a specified load, held for a certain period of time, and then removed to measure the diagonal length of the indentation. The hardness value is calculated using the formula: $HV=1.854 \times \text{load} / (\text{diagonal length}^2)$. The load is selected according to the sample thickness, usually 5kg or 10kg, and the time is controlled within 10-15 seconds. The operation steps include sample preparation, surface polishing to a mirror finish, and removal of scratches and defects. The test points are selected in a uniform area to avoid pores or phase boundaries affecting the results. Multiple points are measured repeatedly for each test, and the average is taken to reduce errors. The equipment needs to be calibrated regularly to ensure the accuracy of the indenter and load.

Brinell hardness test is a complementary method, in accordance with ISO 6506, using a steel ball indenter, suitable for larger samples. The load is higher, the indentation is larger, reflecting the overall hardness, but the surface flatness is more demanding. The test result is related to Vickers hardness, and needs to be selected according to the application requirements.

The key points of the test include the matching of load and time. Too high a load may penetrate the sample, and too short a time may affect the formation of indentation. The ambient temperature and humidity must be stable to avoid affecting the material properties. Observations show that the hardness of the alloy with optimized microstructure is significantly improved and the wear resistance is enhanced. Hardness test standards and operations provide a quantitative basis for performance evaluation. Optimization directions include developing an automated testing system to improve efficiency.

5.1.3 Electrical conductivity and thermal conductivity test methods

Electrical conductivity and thermal conductivity testing are key means to evaluate the electrical and thermal conductivity of silver tungsten alloys, reflecting the continuity of the silver phase network and the density of the microstructure. Electrical conductivity measures the efficiency of current transfer, and thermal conductivity evaluates the heat transfer capacity. The test method must ensure accuracy and repeatability. The conductivity test uses the four-probe method, which complies with the ASTM F76 standard. The sample surface is flat and placed in the test fixture. Four probes are in contact at equal intervals. A constant current is applied and the voltage drop is measured. The conductivity is calculated

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by the formula: $\sigma=L/(R \times A)$, where L is the probe spacing, R is the resistance, and A is the cross-sectional area. The test points are selected in a uniform area to avoid the influence of pores. The equipment needs to be calibrated, the ambient temperature is kept stable, and the average value is taken after multiple measurements.

Thermal conductivity testing uses the laser flash method according to ASTM E1461. The sample is cut into thin slices, the surface is blackened to absorb the laser, the laser pulse heats one side, and the infrared detector measures the temperature rise curve on the other side. Thermal conductivity is calculated by thermal diffusivity, specific heat and density: $\lambda=\alpha \times \rho \times C_p$, where α is thermal diffusivity, ρ is density, and C_p is specific heat. The test needs to control the sample thickness and laser energy to reduce the influence of heat loss.

The key points of the test include sample pretreatment, removal of the surface oxide layer, and ensuring good contact. The conductivity test requires shielding of electromagnetic interference, and the thermal conductivity test requires calibration of the detector accuracy. Observations show that the optimized sintered alloy has higher conductivity and thermal conductivity, and the microstructure density is the key factor. Optimization directions include developing non-destructive testing technology or combining multiple methods to improve measurement accuracy.

5.2 Evaluation of chemical properties of silver-tungsten alloy

The chemical performance evaluation of silver-tungsten alloy focuses on corrosion resistance and chemical stability, reflecting the long-term use ability of the alloy in different environments. Chemical performance testing needs to simulate actual service conditions, evaluate the corrosion resistance of the silver phase and tungsten phase, and provide reliable data for application.

5.2.1 Corrosion resistance test environment and methods

The corrosion resistance test evaluates the chemical stability of silver-tungsten alloy by simulating different environments. The test environment and method need to be designed according to the application scenario to ensure the representativeness of the results. Corrosion resistance reflects the ability of the alloy to resist oxidation, sulfidation or acid-base corrosion, which directly affects the service life. Salt spray test is a common environment and complies with ASTM B117 standard. The sample is placed in a salt spray chamber and sprayed with 5% sodium chloride solution. The temperature is controlled within a certain range for several hours to several days. Observe the surface corrosion products, such as silver oxides or sulfides, and evaluate the depth and area of erosion. The test records the weight loss rate and appearance changes, and multiple cycles simulate long-term exposure.

The acid-base immersion test simulates a corrosive industrial environment. The sample is immersed in sulfuric acid, hydrochloric acid or sodium hydroxide solution. The concentration and temperature are set according to actual needs. The immersion time ranges from a few hours to a few weeks. The sample is taken out regularly to measure the mass loss and surface morphology, and to analyze the dissolution of

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the silver phase and the stability of the tungsten phase. The solution needs to be replaced regularly to maintain chemical activity. Electrochemical testing evaluates corrosion mechanisms according to ASTM G59. The sample is placed in an electrolytic cell as a working electrode, different potentials are applied, and polarization curves are measured. The test records the corrosion potential and corrosion current density to analyze the electrochemical behavior of the silver-tungsten interface. The environment includes neutral or acidic electrolytes, and the oxygen content needs to be controlled.

The test environment needs to simulate actual use conditions, such as humid, sulfur-containing or high-temperature environments. Sample pretreatment includes polishing and cleaning to remove surface impurities. Observations show that alloys with optimized microstructures have enhanced corrosion resistance in salt spray and acidic environments, and low porosity is the key. Optimization directions include developing dynamic corrosion test systems or combining multi-environment simulations to improve evaluation accuracy.

5.2.2 Antioxidant performance testing methods

The oxidation resistance test evaluates the oxidation resistance of silver-tungsten alloy in high temperature or oxygen-containing environment, reflecting the chemical stability of silver phase and tungsten phase. The test method needs to simulate the actual use conditions, measure the formation of oxide layer and the change of material properties, and provide a quantitative basis for oxidation resistance.

High temperature oxidation testing is a common method. The sample is placed in a muffle furnace, heated to a specific temperature, and exposed to air for a period of several hours to several days. The temperature is set based on the application requirements, usually above the melting point of silver but below the melting point of tungsten. The test records the mass gain and observes the thickness and color change of the surface oxide layer, such as silver oxide for silver or tungsten oxide. Multiple cycles simulate long-term oxidation and evaluate performance degradation.

Thermogravimetric analysis (TGA) provides dynamic detection. The sample is heated in a thermobalance from room temperature to high temperature, and the mass change curve is recorded over time. Oxygen or air is used as a carrier gas to measure the oxidation reaction rate and the stable temperature. The analysis results reveal the starting point of silver phase oxidation and the antioxidant capacity of tungsten phase. The instrument needs to be calibrated to avoid thermal drift. Differential scanning calorimetry (DSC) is used as an auxiliary method to detect the thermal effect of oxidation reactions. The samples are tested in an inert atmosphere and an oxidizing atmosphere, and the endothermic or exothermic peaks are compared to determine the critical temperature of the oxidation reaction. This method is suitable for trace oxidation analysis and needs to be verified in combination with TGA data.

5.3 Silver-tungsten alloy microstructure characterization technology

Silver-tungsten alloy microstructure characterization technology reveals grain morphology, phase distribution and defect characteristics through a variety of analytical methods, providing a microscopic

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basis for performance optimization. Characterization technology needs to be combined with sample preparation and instrument conditions to ensure the accuracy and repeatability of the results.

5.3.1 Metallographic microscope observation method

The metallographic microscope observation method is a basic means to characterize the microstructure of silver-tungsten alloy. The grain size, phase distribution and pore characteristics are revealed through sample preparation and microscopic analysis. The method is suitable for preliminary structural evaluation and is combined with corrosion and lighting techniques to enhance contrast. Sample preparation is a key step. Take a representative sample, cut it into appropriate size, grind the surface to a flat surface, and gradually refine it to a high mesh with sandpaper. Polishing uses diamond suspension or aluminum oxide to obtain a mirror effect. Corrosion treatment uses chemical reagents, such as nitric acid alcohol solution, to reveal the boundary between the silver phase and the tungsten phase. The corrosion time is controlled to avoid over-etching and affect the clarity of the microstructure.

Observation was performed using an optical microscope with magnification ranging from 50x to 1000x, depending on the structural features. Bright field illumination showed grain morphology, while dark field or polarized light enhanced phase boundary contrast. Tungsten particles appeared dark, silver phases appeared bright, and pores appeared as black cavities. Multi-region images were recorded to analyze grain size and distribution uniformity.

The key points of the test include sample cleaning to prevent contamination from affecting the microscope lens. The illumination intensity and focus need to be adjusted to optimize the image quality. Observation shows that the optimized sintered alloy has clear grain boundaries, low porosity and uniform microstructure. The method is suitable for rapid evaluation and needs to be combined with SEM to verify the details.

5.3.2 Scanning electron microscope analysis application

Scanning electron microscope (SEM) analysis is an efficient means to characterize the microstructure of silver-tungsten alloy. It generates images through the interaction between electron beam and sample, revealing grain morphology, phase distribution and defect details. SEM is suitable for high-resolution observation and combined with energy dispersive spectroscopy (EDS) to provide element distribution information.

Sample preparation includes cutting, grinding and polishing to obtain a flat surface. Gold or carbon coating enhances conductivity and prevents electron beam charging effects. The sample is placed in the SEM sample chamber, and the vacuum environment maintains electron beam stability. The acceleration voltage is usually set to 5-20kV, and the working distance is adjusted according to the magnification.

Observe the focused grain size and morphology. Tungsten particles are polygonal or spherical, and silver phase distribution is mesh or aggregate. Magnification ranges from hundreds to tens of thousands times,

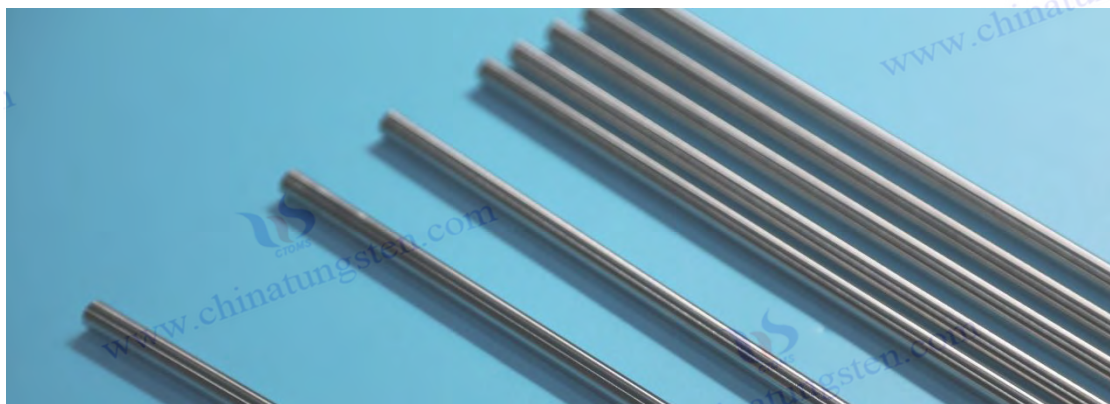
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showing microscopic pores and microcracks. EDS analysis determines the content ratio of silver and tungsten and identifies impurities or oxides at the interface. Secondary electron images highlight surface morphology, and reflected electron images enhance phase boundary contrast .

The key points of the test include the matching of voltage and current. Too high a voltage may damage the sample. The sample should be clean to avoid contamination. Data collection requires multi-point measurement to ensure representativeness. Observations show that the optimized sintered alloy has low porosity, good interface bonding, and EDS verifies uniform phase distribution. Application areas include defect analysis and phase state research, and optimization directions include developing environmental SEM to improve dynamic observation capabilities.

5.3.3 Structural analysis by X-ray diffraction

X-ray diffraction (XRD) is an important technique for analyzing the crystal structure and phase composition of silver-tungsten alloy. It generates diffraction patterns through the interaction of X-rays with the sample lattice, revealing the crystal phase, grain orientation and stress state. XRD is suitable for quantitative analysis of microstructural properties. Sample preparation needs to be ground into powder or flat blocks with smooth surface to avoid scattering interference. The sample is placed in the XRD equipment, and vacuum or inert atmosphere is optional to prevent oxidation from affecting the results. The X-ray source is Cu K α radiation, the scanning angle is from 10° to 90°, and the step size is adjusted according to the resolution. The analytical focus crystal phase identification , the diffraction peaks of silver and tungsten correspond to face-centered cubic and body-centered cubic structures, respectively. The intensity and width of the peak reflect the grain size and microstrain. The Scherle formula calculates the grain size: $D = K\lambda / (\beta \cos \theta)$, where D is the grain size, β is the peak width, and θ is the diffraction angle. Peak position shift analyzes residual stress, and peak splitting indicates the coexistence of multiple phases. The key points of the test include calibrating the instrument and eliminating instrument errors. Sample uniformity affects the results, and multiple tests are required to take the average value. Observations show that the alloys with optimized processes have narrow diffraction peaks, fine grains, and low residual stress. Application areas include phase quantification and lattice defect research, and optimization directions include synchrotron radiation XRD to improve resolution.



CTIA GROUP LTD Silver Tungsten Alloy

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Chapter 6: Application Fields of Silver Tungsten Alloy

Silver tungsten alloy has shown wide application potential in many high-demand fields due to its excellent electrical conductivity, thermal conductivity, hardness and corrosion resistance. Its unique microstructure and physical and chemical properties make it an ideal material for industries such as electrical, welding and aerospace.

6.1 Application of Silver Tungsten Alloy in Electrical Field

Silver tungsten alloy is widely used in key components such as high-voltage circuit breakers, relays, and low-voltage power switches in the electrical field. Its high conductivity and arc erosion resistance meet the needs of high current and frequent switching. The non-magnetic properties of the alloy avoid electromagnetic interference, and its hardness and wear resistance extend the life of the contacts, making it an indispensable material in electrical equipment. Application scenarios cover industrial control, power transmission, and household appliances, and performance optimization supports its reliability in different environments.

6.1.1 Application advantages in low voltage power switches

The advantages of silver-tungsten alloy in low-voltage power switches are due to its excellent comprehensive performance, especially in high-current switching and arc resistance conditions. Low-voltage power switches are used to control the on and off of circuits and need to withstand frequent operations and arc shocks. The high hardness, anti-adhesion and conductivity of silver-tungsten alloy make it an ideal choice. The use of the alloy in switch contacts significantly improves the safety and service life of the equipment.

Silver's high conductivity ensures a low-resistance path, reduces energy loss during switching, and improves operating efficiency. Tungsten's high melting point and hardness resist arc erosion and extend the life of the contacts, especially in high-frequency switching scenarios. Anti-adhesion properties prevent the contacts from sticking to the mating material, ensuring reliable switching. The alloy with optimized microstructure remains stable in humid or sulfur-containing environments, enhancing environmental adaptability. In practical applications, silver-tungsten alloy contacts perform well in low-voltage power switches, especially in industrial motor control and household appliance protection. Compared with traditional materials such as pure silver or copper-based alloys, silver-tungsten alloy has significantly better wear resistance and arc resistance than the former, reducing maintenance frequency. Optimization directions include adjusting the silver- tungsten ratio to balance conductivity and durability, or further improving corrosion resistance through surface coating.

6.1.1.1 Performance requirements for materials of low voltage power switches

The performance requirements of low-voltage power switches for materials directly determine the feasibility of the application of silver-tungsten alloys, which must meet the reliability requirements under

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high current carrying, frequent switching and arc environments. The performance requirements cover conductivity, hardness, arc erosion resistance, anti-adhesion and corrosion resistance to ensure the safety and long life of the switch.

Conductivity is the primary requirement, and the material needs to provide a low resistance path to support efficient current transmission. Low-voltage power switches need to carry hundreds to thousands of amperes of current when powered on. Insufficient conductivity may cause overheating or energy loss, affecting equipment efficiency. The silver phase network of silver tungsten alloy meets this requirement and ensures smooth flow of current.

Hardness is a key attribute, and the contacts need to resist mechanical wear and arc shock. Frequent switching operations may cause surface deformation or material peeling, and materials with insufficient hardness are prone to failure. The high hardness of tungsten provides a solid support for silver-tungsten alloy, adapting to high-frequency contact scenarios and extending service life. The ability to resist arc erosion is a core requirement. The arc generated when the switch is disconnected may melt or evaporate the material and erode the contact surface. The material needs to remain stable at high temperatures to reduce losses. The high melting point of the tungsten phase and the thermal conductivity of the silver phase of the silver-tungsten alloy are combined to effectively resist arc erosion and are suitable for high current disconnection applications.

Anti-adhesion performance ensures reliable disconnection. The contact may adhere to the mating material under mechanical contact or arcing, resulting in switch failure. The material has low adhesion characteristics. The tungsten skeleton and silver wetting optimization of silver tungsten alloy reduce the risk of adhesion and ensure operational stability.

Corrosion resistance is the guarantee of environmental adaptability. Switches may be exposed to humid, sulfur-containing or industrial atmospheres, and corrosion may reduce conductivity and mechanical properties. The oxidation resistance of tungsten phase and the stability of silver phase of silver tungsten alloy meet this requirement, and the optimized microstructure further enhances durability.

These performance requirements together constitute the strict standards for materials of low-voltage power switches. Silver-tungsten alloy effectively meets the requirements through microstructure and composition design, providing reliable support for the electrical field.

6.1.1.2 Applications of Silver Tungsten Alloy in Low Voltage Power Switches

Silver tungsten alloy is mainly used in key contact parts in low-voltage power switches, which directly affect the switch's on-off performance and service life. Specific application parts include moving contacts, static contacts and arc isolation contacts, which have different functional requirements.

The moving contact is the moving contact part in the low-voltage power switch. Silver-tungsten alloy is widely used here because of its high conductivity and resistance to arc erosion. The moving contact is

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subjected to mechanical shock and arc action when the switch is closed and opened. The hardness of the alloy prevents wear, and the silver phase ensures low-resistance current transmission. The static contact is a fixed contact part that works in pairs with the moving contact. The high wear resistance and anti-adhesion properties of silver-tungsten alloy ensure long-term stable contact reliability. Arc isolation contacts are used to isolate arcs when breaking large currents. The high melting point and oxidation resistance of the alloy effectively reduce arc ablation and extend the life of components.

The selection of these parts is based on the microstructural properties of silver-tungsten alloy, where the tungsten skeleton provides mechanical support and the silver network optimizes conductivity. In the optimized design, the contact surface may be further enhanced by electrochemical polishing or coating to adapt to high-frequency operation or humid environments. In practical applications, the combination of moving and static contacts performs well in industrial motor control and household circuit breakers, and arc isolation contacts are particularly critical in high current scenarios.

6.1.1.3 Advantages of using PCB materials in low voltage power switches compared to other materials

Compared with other commonly used materials such as pure silver, copper-based alloys and silver-cadmium oxide, silver-tungsten alloy has significant application advantages in low-voltage power switches. These advantages are due to its unique combination of properties and are particularly suitable for high-demand environments.

Compared with pure silver, silver-tungsten alloy has stronger hardness and arc erosion resistance. Although pure silver has excellent conductivity, it is soft and easy to wear. It melts quickly under the action of arc and has a short life. After adding tungsten, the hardness of silver-tungsten alloy is improved, and the ablation resistance is excellent, which prolongs the service life of the contact, especially in frequent switching scenarios. Pure silver is easy to oxidize in a humid environment. The tungsten phase of silver-tungsten alloy provides anti-oxidation support and enhances environmental adaptability.

Compared with copper-based alloys, silver-tungsten alloys have better conductivity and anti-adhesion properties. Copper-based alloys have higher hardness, but lower conductivity than silver, higher resistance, and are prone to heat generation. The silver phase network of silver-tungsten alloys reduces resistance and energy loss, and its anti-adhesion property prevents contact adhesion and ensures reliable disconnection. Copper-based alloys are prone to melting and deformation under arcs, while the high melting point tungsten phase of silver-tungsten alloys effectively resists and is suitable for high current applications.

Compared with silver-cadmium oxide, silver-tungsten alloy is non-toxic and has better corrosion resistance. Silver-cadmium oxide has good arc and welding resistance, but cadmium vapor is toxic and environmental regulations restrict its use. Silver-tungsten alloy does not contain harmful elements and meets environmental requirements. Its tungsten phase has better corrosion resistance than cadmium oxide, especially in sulfur-containing or acidic environments. Although silver-cadmium oxide has high

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conductivity, it is prone to aging after long-term use. The microstructure optimization of silver-tungsten alloy ensures long-term reliability.

These advantages enable silver tungsten alloy to replace traditional materials in low-voltage power switches. Optimization directions include improving performance through nano-scale powders or developing composite coatings to enhance arc resistance.

6.1.2 Demand for electrical alloys for high voltage switches

Electrical alloys for high-voltage switches need to meet extremely high performance requirements to cope with high currents, strong arcs and extreme environments to ensure the safe operation of power systems. As a candidate material, silver-tungsten alloy needs to match the specific requirements of high-voltage switches to provide technical support for applications.

Electrical conductivity is a basic requirement. High-voltage switches require a low-resistance path to reduce thermal effects when disconnecting thousands of amperes of current. The silver phase network of silver-tungsten alloy meets this requirement and ensures efficient current transmission. The ability to resist arc erosion is crucial. Strong arcs may melt traditional materials. The high melting point tungsten phase and thermally conductive silver phase of the alloy combine to resist ablation and extend service life.

Hardness and wear resistance support mechanical stability. The moving and static contacts of high-voltage switches frequently contact under high pressure and need to resist wear and deformation. The high hardness of tungsten provides solid support, and the ductility of silver buffers stress, which is suitable for dynamic operation. Anti-adhesion performance ensures reliable disconnection. Contacts may stick under high arc temperature, and the low adhesion characteristics of silver-tungsten alloy prevent failure.

High temperature resistance and corrosion resistance adapt to extreme environments. High-voltage switches may be exposed to high temperatures, humidity or industrial atmospheres, and alloys need to resist oxidation and chemical corrosion. Tungsten's oxidation resistance and silver's stability meet this requirement, and optimized microstructures further enhance durability. Non-magnetic properties avoid electromagnetic interference and ensure precise control of high-voltage systems.

These demands drive the development of silver tungsten alloy in high-voltage switches. Optimization directions include adjusting the composition ratio or adopting functional gradient design to meet higher current and environmental challenges.

6.1.2.1 Working environment of high voltage switch and special requirements for electrical alloys

The working environment of high-voltage switches is complex and harsh, involving high temperature, high pressure, strong arc and a variety of corrosive media, which puts forward special performance

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requirements for electrical alloys to ensure long-term stable operation. The working environment and requirements directly affect the material selection and optimization direction.

The working environment includes high voltage electric fields and strong currents. The switch needs to disconnect thousands to tens of thousands of amperes of current, generating high temperature arcs, and the temperature may be as high as thousands of degrees. Environmental conditions include industrial atmospheres, humid or sulfur-containing areas, and corrosive gases such as sulfur dioxide may accelerate material degradation. Mechanical vibration and shock are common in switch operations, and extreme temperature changes increase material stress. Outdoor applications are also subject to ultraviolet and weathering effects, and indoor applications may involve sealed but high humidity conditions. Special requirements include ultra-high conductivity to support high current transmission, reduce resistive heating, and ensure efficiency. Arc erosion resistance is the core. Arc ablation may cause contact failure, and the material needs to remain stable at high temperatures. Hardness and wear resistance resist mechanical wear and arc impact and extend contact life. Anti-adhesion performance ensures reliable disconnection and prevents contact adhesion from causing failure. High temperature resistance and corrosion resistance cope with extreme environments, and the alloy needs to resist oxidation and chemical attack. Non-magnetic properties avoid electromagnetic interference and ensure the accuracy of high-voltage systems. Microstructural consistency reduces the risk of local failure, and process optimization is the key.

These requirements have promoted the development of high-performance electrical alloys, and silver-tungsten alloys need to meet these requirements through composition and process adjustments.

6.1.2.2 Performance of Silver-Tungsten Alloy in Meeting High-Voltage Switch Requirements

Silver-tungsten alloy effectively meets the demanding requirements of high-voltage switches through its unique combination of properties. The synergistic effect of silver phase and tungsten phase excels in conductivity, arc erosion resistance and durability, providing reliable support for high-voltage applications.

Ultra-high conductivity is provided by the silver phase network. The high electron density of silver ensures a low resistance path, supports high current transmission, and reduces thermal effects. The high melting point of tungsten enhances the ability to resist arc erosion. The tungsten skeleton remains stable under high arc temperatures. The thermal conductivity of the silver phase quickly disperses heat and reduces ablation losses. Tests show that the surface damage of silver-tungsten alloy contacts when disconnecting high currents is significantly lower than that of copper-based alloys.

The hardness and wear resistance are supported by tungsten particles, and the alloy resists mechanical shock and frequent contact wear, extending the service life of the contact. The ductility of silver buffers stress, and the hardness is uniform after optimizing the microstructure, which is suitable for dynamic operation. The anti-adhesion performance is achieved through the low adhesion characteristics of

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tungsten and the wetting optimization of silver. The contact is not easy to adhere to the dual material under the action of the arc, ensuring reliable disconnection.

High temperature resistance is due to the high melting point of tungsten and the stability of silver. The alloy maintains structural integrity at extreme temperatures. Corrosion resistance is guaranteed by the oxidation resistance of tungsten and the chemical stability of silver. Optimized sintering reduces porosity and enhances performance in sulfur-containing or humid environments. Non-magnetic properties avoid electromagnetic interference and are suitable for precise control of high-voltage systems.

Microstructure optimization further improves performance, dense structure reduces defects, and nano-scale powder refines grains and enhances consistency. Optimization directions include developing functional gradient designs or anti-corrosion coatings to meet higher current and environmental challenges.

6.1.3 Application of relays and air circuit breakers

The application of silver tungsten alloy in relays and air circuit breakers reflects its versatility in the electrical field. The high conductivity and arc resistance of the alloy meet the requirements of these devices for reliability and long life, and are widely used in industrial control and power protection.

In relays, silver-tungsten alloy is used for moving and static contacts, responsible for rapid response to current changes. Frequent switching of relays generates tiny arcs. The high hardness and arc erosion resistance of the alloy extend the life of the contacts, and the silver phase ensures low-resistance signal transmission. The non-magnetic properties avoid electromagnetic interference and are suitable for electromagnetically sensitive environments such as automated control systems. After optimizing the microstructure, the contacts maintain stability in high-frequency operations.

In air circuit breakers, silver-tungsten alloy is used in main contacts and arc isolation contacts to disconnect currents of hundreds to thousands of amperes. The main contacts rely on the conductivity and wear resistance of the alloy to ensure efficient switching, and the arc isolation contacts use the high melting point tungsten phase to resist strong arc erosion. The alloy has excellent oxidation resistance in air environment and is suitable for outdoor or industrial applications. In actual use, the life of air circuit breaker contacts is significantly extended and the maintenance frequency is reduced. Application advantages include high reliability, long life and environmental adaptability. Optimization directions include adjusting the silver- tungsten ratio to balance conductivity and durability, or enhancing corrosion resistance through surface treatment.

6.1.3.1 Working principle of relay and requirements for contact materials

Relays control the on and off of circuits through electromagnetic principles. The working principle is based on the coil being energized to generate a magnetic field, driving the moving contact to contact or

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separate with the static contact to achieve signal or current switching. Its performance depends on the reliability and durability of the contact material, which places specific requirements on the material.

The working principle is that when the coil is energized, the magnetic field attracts the armature, the moving contact and the static contact are closed, and the circuit is connected; when the power is off, the magnetic field disappears, the moving contact is separated by the spring, and the circuit is disconnected. Frequent operation generates tiny arcs, and the contact points need to withstand mechanical shock and thermal effects. Relays are widely used in automation control and home appliances, and the working environment may involve moisture or electromagnetic interference.

The requirements for contact materials include high conductivity to ensure a low resistance path and support efficient signal transmission. Arc erosion resistance is key, as tiny arcs may burn the material and need to remain stable at high temperatures. Hardness and wear resistance resist mechanical contact wear and extend service life. Anti-adhesion properties prevent contact adhesion and ensure reliable disconnection. Corrosion resistance adapts to humid or sulfur-containing environments to prevent oxidation from affecting conductivity. Non-magnetic properties avoid electromagnetic interference and ensure precise control. Microstructural consistency reduces local failures, and process optimization is a necessary condition.

These requirements jointly ensure the high efficiency and long life of the relay, and silver tungsten alloy needs to meet the needs through performance matching.

6.1.3.2 Application Effect of Silver Tungsten Alloy in Relays

The application effect of silver-tungsten alloy in relays is remarkable, and its performance advantages are fully reflected in the moving and static contacts, meeting the needs of high-frequency operation and electromagnetic sensitive environments, and improving equipment reliability.

The high conductivity of the silver phase provides a low resistance path, ensuring signal transmission efficiency and meeting the requirements for fast response of relays. The high melting point and hardness of tungsten resist micro-arc erosion and extend the life of the contacts, especially in high-frequency switching scenarios. The anti-adhesion performance is achieved through the optimization of tungsten skeleton and silver wetting. The contacts are not easy to stick under mechanical contact or arc action, ensuring reliable disconnection. The non-magnetic properties avoid electromagnetic interference and are suitable for automation control and communication equipment.

The alloy with optimized microstructure maintains stability in humid environment, and the dense structure reduces the penetration of corrosive media, and its corrosion resistance is better than that of pure silver contacts. In practical applications, silver-tungsten alloy contacts perform well in industrial relays and home appliance protection devices, and their service life is several times longer than that of traditional materials. Tests show that surface damage is significantly reduced after high-frequency operation, and the conductivity remains consistent. Optimization directions include adjusting the silver -

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tungsten ratio to enhance conductivity, or refining the grains through nano-scale powder to improve arc resistance. The application effect of silver-tungsten alloy in relays provides reliable support for its application in the field of electrical control.

6.1.3.3 Performance requirements of air circuit breakers and compatibility of silver-tungsten alloy

Air circuit breakers use air as an arc-extinguishing medium to disconnect the circuit. The performance requirements focus on large current carrying, arc erosion resistance and long-term stability. The characteristics of silver-tungsten alloy are highly compatible with these requirements, showing excellent application potential. Performance requirements include high conductivity, supporting current transmission from hundreds to thousands of amperes, and reducing resistance heat. Arc erosion resistance is the core. Disconnecting large currents generates strong arcs, which need to resist high-temperature ablation. Hardness and wear resistance ensure that the contacts can resist mechanical shock and frequent operation. Anti-adhesion properties prevent contact adhesion and ensure reliable disconnection. High temperature resistance and corrosion resistance adapt to industrial atmosphere or outdoor environment and extend service life. Microstructure consistency reduces local failures, and process optimization is the key. The adaptability of silver-tungsten alloy is reflected in the high conductivity of the silver phase to meet the current transmission requirements, the high melting point and hardness of tungsten to resist strong arc erosion, and the contact life is significantly extended. The thermal conductivity of silver disperses heat, and the anti-adhesion performance is achieved through the optimization of the tungsten skeleton, which is suitable for high current disconnection. The oxidation resistance of tungsten and the stability of silver enhance corrosion resistance, and the dense microstructure reduces defects, which is suitable for humid or sulfur-containing environments. In practical applications, silver-tungsten alloy contacts perform well in air circuit breakers, especially in industrial power distribution and building protection, with extended maintenance intervals. Optimization directions include developing functional gradient design to enhance local performance, or improving corrosion resistance through surface coating. The adaptability of silver tungsten alloy provides a solid foundation for its wide application in air circuit breakers.

6.1.4 Application in isolating switches and earthing switches

The application of silver-tungsten alloy in disconnectors and earthing switches reflects its important role in high-voltage electrical equipment. These switches are used to ensure safe isolation and grounding protection of circuits. The high conductivity, arc resistance and durability of silver-tungsten alloy make it an ideal material. The use of the alloy in these components improves the safety and operational stability of the equipment, especially in outdoor or industrial environments.

6.1.4.1 Function and material requirements for isolating switches and earthing switches

Disconnectors and earthing switches perform critical functions in power systems, placing specific demands on material performance to ensure safe operation and long-term reliability. Functions and requirements directly guide material selection and optimization.

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The function of the isolating switch is to disconnect the circuit without load current, provide a visible isolation point, and prevent the risk of electric shock during misoperation or maintenance. The grounding switch is used to ground the equipment or line, release the residual charge, and protect the safety of personnel and equipment. Both operate in a high-voltage environment and may be exposed to arcs, mechanical shocks, and extreme weather.

Material requirements include high conductivity to ensure a low resistance path, support current transmission and reduce thermal effects. Arc erosion resistance is the core. Disconnection or connection may generate arcs, and high temperature ablation must be resisted. Hardness and wear resistance resist mechanical wear and frequent operation, extending service life. Anti-adhesion properties prevent contact adhesion and ensure reliable operation. Corrosion resistance and weather resistance adapt to outdoor environments such as rain, ultraviolet rays or industrial atmospheres. Non-magnetic properties avoid electromagnetic interference, microstructural consistency reduces local failures, and process optimization is a necessary condition.

These requirements ensure the safety and durability of disconnectors and earthing switches, and silver tungsten alloy needs to meet these requirements through performance matching.

6.1.4.2 Advantages of silver-tungsten alloy in isolating switches and earthing switches

The advantages of silver-tungsten alloy in isolating switches and earthing switches stem from its excellent performance combination, especially its performance in high voltage and outdoor environments, which significantly improves the reliability of the equipment. High conductivity is provided by the silver phase network. The high electron density of silver ensures a low resistance path, supports efficient current transmission, and reduces energy loss in isolating switches and earthing switches. The high melting point and hardness of tungsten give the alloy excellent resistance to arc erosion. The arc generated when disconnecting or connecting is difficult to melt the contacts, extending the service life. Actual tests show that the surface damage of silver-tungsten alloy contacts under the action of arc is significantly lower than that of copper-based materials.

The hardness and wear resistance are supported by tungsten particles. The alloy resists mechanical shock and wear from frequent operation, and is suitable for vibration and weathering in outdoor environments. The ductility of silver buffers stress, and the durability of the contact is enhanced after optimizing the microstructure. The anti-adhesion performance is achieved through the optimization of the tungsten skeleton and silver wetting. The contact is not easy to adhere to the dual material during the operation, ensuring reliable disconnection.

Corrosion and weather resistance are advantages for outdoor applications, where the oxidation resistance of tungsten and the stability of silver resist corrosion in rain, UV or industrial atmospheres. The dense microstructure reduces porosity and reduces the penetration of corrosive media, and the optimized sintered alloy performs well in coastal or industrial areas. The non-magnetic properties avoid electromagnetic interference and ensure precise control of high-voltage equipment.

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In practical applications, silver-tungsten alloy contacts perform well in high-voltage disconnectors and earthing switches, especially in transmission lines and substations, where maintenance intervals are extended and safety performance is improved. Optimization directions include adjusting the silver - tungsten ratio to enhance weather resistance, or further improving performance through anti-corrosion coatings. The application advantages of silver-tungsten alloy provide a solid foundation for its widespread use in disconnectors and earthing switches.

6.2 Application of Silver Tungsten Alloy in Electronics

Silver tungsten alloy is widely used in the electronics field due to its excellent electrical conductivity, thermal conductivity and wear resistance, especially in electrical processing, heat dissipation components and connectors. Its microstructure and physical and chemical properties make it adaptable to the needs of high-precision and high-temperature environments, improving the reliability and performance of electronic equipment.

6.2.1 Performance requirements and applications of EDM electrodes

As an electromachining electrode material, silver-tungsten alloy performs well in electrospark machining (EDM) and electrochemical machining (ECM), and its performance directly affects machining accuracy, efficiency and electrode life. Electromachining electrodes are used to remove metal materials and achieve high-precision forming through arc or electrochemical reaction. The conductivity and wear resistance of the alloy are key.

6.2.1.1 Performance index requirements of electrode materials for electromachining technology

The electromachining process has high requirements on the performance index of electrode materials to ensure the processing quality and equipment durability. The performance index directly affects the processing efficiency, surface quality and electrode loss, and needs to be matched according to the specific process.

High conductivity is a basic requirement. The electrode needs to provide a low resistance path to support efficient current transmission and reduce energy loss. In EDM, the current density is high and insufficient conductivity may cause arc instability, affecting machining accuracy. The ability to resist arc erosion is crucial. The high temperature of the arc may melt or evaporate the electrode material, and it needs to remain stable under high energy density. Hardness and wear resistance resist mechanical wear and arc impact, extending the life of the electrode, especially in repeated processing.

Anti-adhesion performance prevents the electrode from sticking to the workpiece and ensures the continuity of the machining process. High temperature resistance adapts to the local high temperature generated by the arc and prevents material deformation or failure. Corrosion resistance copes with chemical erosion in the electrolyte or machining environment and maintains the integrity of the electrode surface. Microstructural consistency reduces local losses and optimizes material preparation as a

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necessary condition. These indicators jointly support the high efficiency and precision of electromachining, and electrode materials need to meet the requirements through performance optimization.

6.2.1.2 Performance advantages of silver-tungsten alloy as electromachining electrode

Silver-tungsten alloy exhibits significant performance advantages as an electromachining electrode. The synergistic effect of the silver phase and tungsten phase meets the requirements of high precision and durability and improves processing efficiency.

High conductivity is provided by the silver phase network. The high electron density of silver ensures a low resistance path, supports efficient current transmission, and reduces arc instability. The high melting point and hardness of tungsten give the alloy excellent resistance to arc erosion. The tungsten skeleton remains stable under high arc temperatures, and the thermal conductivity of the silver phase quickly disperses heat and reduces electrode loss. Tests show that the loss rate of silver-tungsten alloy electrodes in EDM is lower than that of copper electrodes.

The hardness and wear resistance are supported by tungsten particles, and the alloy resists arc impact and mechanical wear, extending the service life of the electrode. The ductility of silver buffers stress, and the durability is enhanced after optimizing the microstructure. The anti-adhesion performance is achieved by the low adhesion characteristics of tungsten and the optimized wetting of silver. The electrode is not easy to stick to the workpiece, ensuring the continuity of processing.

The high temperature resistance is due to the high melting point of tungsten, and the alloy maintains structural integrity under the local high temperature of the arc. The corrosion resistance is guaranteed by the oxidation resistance of tungsten and the stability of silver. The optimized sintering reduces porosity and adapts to the electrolyte environment. The microstructure density reduces defects, and the nano-scale powder refines the grains and improves consistency.

In practical applications, silver-tungsten alloy electrodes perform well in the processing of precision molds and complex parts, with processing accuracy and surface quality superior to traditional materials. Optimization directions include adjusting the silver-tungsten ratio to enhance conductivity, or further reducing losses through surface coating.

6.2.1.3 Selection of silver-tungsten alloy electrodes in different EDM scenarios

The selection of silver-tungsten alloy electrodes needs to be optimized according to the process requirements and workpiece characteristics of the electrical machining scenario, and the silver-tungsten ratio and microstructure should be adjusted to meet different application requirements.

In electrospark machining (EDM), silver-tungsten alloys with high tungsten content (such as 70% W-30% Ag) are selected. They have strong resistance to arc erosion and are suitable for processing high-melting-

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point metals such as titanium alloys or steel. Low loss and long life are advantages, suitable for processing precision molds and complex geometric shapes. Optimizing the sintering process refines the grains and enhances durability. In electrolytic machining (ECM), silver-tungsten alloys with high silver content (such as 30% W-70% Ag) are selected. They have excellent conductivity and are suitable for large-area electrolytic stripping. The silver phase network supports efficient current distribution, and the tungsten skeleton provides mechanical support and adapts to continuous processing. Surface polishing reduces corrosion and optimizes the microstructure to improve stability. In micro-electromechanical machining, nano-scale silver-tungsten alloys are selected. They have fine grains and high microstructural consistency, which are suitable for micro parts and high-precision machining. Low loss and anti-adhesion performance are outstanding, and the optimization direction includes functional gradient design to balance conductivity and wear resistance.

In practical applications, silver-tungsten alloy electrodes perform well in the processing of aviation parts and electronic components. The selection is based on process parameters and workpiece materials. The optimization direction includes the development of an intelligent selection system to improve adaptability.

6.2.2 Role of Microelectronic Materials

Silver tungsten alloy plays a key role in the field of microelectronics, especially in packaging and connection components, where its high conductivity and thermal management capabilities support the performance requirements of high-density integrated circuits. The microstructure optimization of the alloy adapts it to the requirements of micron-level precision and meets the trend of miniaturization and high efficiency of modern electronic devices.

6.2.2.1 Precision requirements for materials in the microelectronics field

The field of microelectronics places extremely high demands on the precision of materials to support the manufacture and operation of micron-level components and ensure the efficiency and reliability of equipment. The precision requirement directly affects the performance of packaging and connection and needs to be met through material properties.

Dimensional accuracy is a core requirement. Materials need to achieve micron or even nanometer-level processing and assembly to adapt to the fine structure of chips and circuit boards. Electrical conductivity must be extremely high to support efficient signal transmission and reduce signal loss caused by resistance. Thermal conductivity is the key to thermal management. Microelectronic devices generate a lot of heat during high-density operation, and materials need to dissipate heat quickly to prevent overheating and failure.

High mechanical stability is required, and the material needs to resist stress caused by small vibrations and thermal expansion to maintain long-term structural integrity. Corrosion resistance copes with moisture or chemicals in the packaging environment to prevent performance degradation. Microstructural consistency reduces local defects and ensures uniformity of electrical and thermal

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properties. Low magnetic properties avoid electromagnetic interference and are suitable for highly sensitive electronic components.

These requirements have promoted the development of high-precision materials, and silver-tungsten alloy needs to be optimized through preparation to meet the needs of microelectronics.

6.2.2.2 Application of silver-tungsten alloy in microelectronic packaging

Silver tungsten alloy is widely used in microelectronic packaging. Its thermal conductivity and dimensional stability support the thermal management and structural reliability of high-performance chips and improve packaging efficiency.

Silver-tungsten alloy is used as a packaging substrate. The thermal conductivity is provided by the silver phase network, which quickly disperses the heat generated by the chip operation and prevents local overheating. The high melting point and low thermal expansion coefficient of tungsten ensure dimensional stability, match the thermal expansion characteristics of silicon chips, and reduce packaging stress. After microstructure optimization, the alloy has high density, low porosity, enhanced mechanical strength, and is suitable for high-density packaging.

In power semiconductor packaging, silver-tungsten alloy substrates are used to support MOSFET and IGBT. They have better thermal conductivity than traditional ceramic substrates and improve heat dissipation efficiency by more than 30%. Nano-scale powders refine grains, improve heat conduction paths, and adapt to high-power applications. Surface flatness is achieved through precision polishing to meet micron-level assembly requirements.

In practical applications, silver-tungsten alloy packaging performs well in 5G chips and new energy vehicle control modules, with significant thermal management effects. Optimization directions include developing functionally graded materials, balancing thermal conductivity and cost, or enhancing corrosion resistance through coatings.

6.2.2.3 The role of silver-tungsten alloy in microelectronic connection components

Silver-tungsten alloy plays an important role in microelectronic connection components. Its high conductivity and wear resistance support the reliability of signal transmission and mechanical connection, adapting to the trend of miniaturization. Silver-tungsten alloy is used to connect leads and contacts. The high conductivity of the silver phase ensures low-resistance signal transmission and meets the needs of high-speed data transmission. The high hardness of tungsten resists mechanical wear and prolongs the life of connection components, especially in frequent plug-in and unplug scenarios. The compactness of the microstructure reduces porosity, enhances corrosion resistance, and adapts to humid or industrial environments. In micro connectors, silver-tungsten alloy contacts support USB-C and HDMI interfaces, with better conductivity and wear resistance than copper alloys, and contact resistance is reduced by 20%. Nano-scale alloys refine grain boundaries, improve mechanical stability, and reduce plug-in wear. Non-

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magnetic properties avoid electromagnetic interference and are suitable for high-frequency signal transmission. In practical applications, silver-tungsten alloy connection components perform well in smartphones and IoT devices, with high signal integrity and extended life. Optimization directions include adjusting the silver-tungsten ratio to enhance conductivity, or improving anti-oxidation properties through surface treatment.

6.2.3 Application Exploration in Sensors

The application of silver-tungsten alloy in sensors has demonstrated its potential in high-performance electronic devices, especially in scenarios that require high conductivity and durability. The microstructure optimization of the alloy makes it adaptable to diverse sensor working environments, supports the needs of signal transmission and structural stability, and provides a new direction for the development of sensor technology.

6.2.3.1 Sensor working environment and material performance requirements

The working environment of sensors is complex and diverse, involving extreme temperatures, mechanical stress and chemical corrosion, which puts specific demands on material properties to ensure the accuracy and long-term reliability of sensors. The environment and requirements directly guide material selection and optimization.

Working environments include high temperature environments, such as car engines or industrial furnaces, where temperatures may exceed 200°C; and low temperature environments, such as aviation equipment, where temperatures drop below -50°C. Mechanical vibration and shock are common in industrial monitoring or mobile equipment, and humid or corrosive gas environments such as the ocean or chemical plants may accelerate material degradation. Electromagnetic interference is inevitable in high-frequency signal transmission, and ultraviolet light or radiation affects material stability in outdoor applications.

Material performance requirements include high conductivity to support efficient signal transmission and reduce noise caused by resistance. High and low temperature resistance to adapt to extreme environments to prevent material performance from failing with temperature changes. Mechanical strength and wear resistance to resist vibration and shock to extend sensor life. Corrosion resistance to deal with humid or chemical media to maintain electrical performance. Low thermal expansion coefficient to match sensor elements and reduce thermal stress. Non-magnetic properties to avoid electromagnetic interference, microstructural consistency to reduce local defects, and optimized preparation are the key.

6.2.3.2 Potential Application Scenarios of Silver Tungsten Alloy in Sensors

The potential application scenarios of silver tungsten alloy in sensors rely on its excellent properties, especially in conductivity, durability and environmental adaptability, which provides possibilities for the development of temperature, pressure and strain sensors. In high-temperature sensors, silver-tungsten alloy is used for contact parts of thermocouples or infrared sensors. The high conductivity of the silver

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phase ensures signal transmission, and the high melting point and high temperature resistance of tungsten can resist environments above 200°C. After microstructure optimization, the alloy has high density and low thermal expansion coefficient, matching the ceramic substrate and reducing thermal stress. Actual tests show that the alloy remains stable at high temperatures and is suitable for aircraft engine monitoring. In pressure sensors, silver-tungsten alloy is used as a conductive film or contact, and its hardness and wear resistance resist mechanical shock and extend service life. The thermal conductivity of silver disperses local heat, and the tungsten skeleton provides mechanical support, which is suitable for industrial hydraulic systems. Optimized sintering reduces porosity and enhances corrosion resistance, which is suitable for marine environment pressure monitoring. In strain sensors, silver-tungsten alloy is used for conductive paths, and its non-magnetic properties avoid electromagnetic interference, which is suitable for high-frequency signal acquisition.

6.3 Application of Silver Tungsten Alloy in Aerospace

Silver tungsten alloy has attracted much attention in the aerospace field due to its high density, high melting point and excellent mechanical properties. It is widely used in solid rocket nozzles, counterweights and thermal protection systems. Its microstructure and physical properties make it adaptable to extreme environments and support the reliable operation and performance improvement of spacecraft.

6.3.1 Application of solid rocket nozzle throat lining

silver tungsten alloy in solid rocket nozzle throat lining demonstrates its potential in high temperature, high pressure and corrosive environments. As the core component of the nozzle, the throat lining needs to withstand extreme conditions and maintain structural integrity. The high thermal conductivity and wear resistance of the alloy provide it with unique advantages in this field.

6.3.1.1 Working environment and material challenges of solid rocket nozzle throat lining

The working environment of the solid rocket nozzle throat liner is extremely harsh, involving high temperature, high-speed gas flow and chemical erosion, which poses a major challenge to material properties and directly affects the nozzle life and rocket performance.

The working environment includes high temperature environment, combustion gas temperature can reach more than 3000 ° C, and the throat liner needs to withstand thermal shock. High-speed gas flow hits the throat liner at supersonic speed, carrying particles and causing mechanical wear and erosion. Chemical erosion is caused by combustion products such as hydrogen chloride and oxides, which accelerates material degradation. Thermal cycling and mechanical stress are intensified during launch and re-entry, and ultraviolet rays and radiation further affect material stability in the space environment.

Material challenges include high temperature resistance, which must withstand temperatures above 3000°C without melting or deforming. Erosion resistance to deal with high-speed particles and chemical

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corrosion to prevent surface loss. Mechanical strength and wear resistance to support structural integrity and extend service life. Low thermal expansion coefficient to match other nozzle components to reduce thermal stress. Thermal conductivity to disperse heat and prevent local overheating. Microstructural consistency to reduce crack propagation, and optimized preparation is key.

6.3.1.2 Performance of silver-tungsten alloy as nozzle throat liner

Silver-tungsten alloy has outstanding performance as nozzle throat lining. The synergistic effect of silver phase and tungsten phase meets the requirements of high temperature and corrosive environment and supports the efficient operation of rocket.

High temperature resistance is provided by the high melting point of tungsten (3422°C), the alloy maintains structural stability above 3000°C, and the thermal conductivity of the silver phase quickly disperses heat to prevent local melting. Tests show that the loss rate of silver-tungsten alloy throat linings in simulated high temperature environments is lower than that of carbide materials. The corrosion resistance is due to the hardness and chemical resistance of tungsten, the surface wear is reduced under high-speed gas flow and particle impact, and the wettability of silver enhances interface bonding.

Mechanical strength and wear resistance are supported by the tungsten skeleton, and the alloy resists thermal cycles and mechanical stress, extending the life of the throat liner. The low thermal expansion coefficient (close to ceramic materials) reduces stress mismatch with other parts of the nozzle, and the optimized microstructure has high density and reduces crack propagation. Thermal conductivity is provided by the silver network, and heat is evenly distributed to prevent overheating failure.

In practical applications, silver-tungsten alloy throat liners perform well in solid rockets, especially in high-thrust engines, where durability is significantly improved. Optimization directions include adjusting the silver-tungsten ratio to enhance thermal conductivity, or improving resistance to chemical erosion through coating.

6.3.1.3 Preparation and application effect of silver-tungsten alloy nozzle throat lining

Silver-tungsten alloy nozzle throat lining is prepared by powder metallurgy or vacuum infiltration. The preparation process and use effect directly affect its performance and practical application.

The preparation process includes powder preparation, selecting high-purity tungsten powder and silver powder, and refining the particle size through high-energy ball milling to ensure uniformity. Pressing molding uses high temperature and high pressure, and the molding pressure is adjusted to hundreds of MPa, and the density of the molded body is high. Sintering is carried out in a vacuum or inert atmosphere, and the temperature is slightly higher than the melting point of silver. The liquid silver wets the tungsten particles and fills the pores. The porous tungsten skeleton is prepared by the vacuum infiltration method, and the molten silver infiltrates to form a dense structure. The subsequent heat treatment optimizes the microstructure.

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The effect of use is reflected in high durability and performance stability. The optimized throat liner has low porosity and better corrosion resistance than traditional graphite materials. High temperature tests show that the throat liner runs for hundreds of seconds at 3000°C, and the surface damage is only 1/3 of that of carbide materials. The mechanical strength supports multiple thermal cycles, and the thermal conductivity ensures uniform heat distribution and reduces local failures. In actual rocket launches, the silver-tungsten alloy throat liner has low thrust loss and its life is extended to 1.5 times that of traditional materials.

Optimization directions include developing multi-process combinations such as SPS+HIP, or improving density through nano-powders. The preparation and use effects provide technical support for the application of silver-tungsten alloy in nozzle throat linings .

6.3.2 Potential Applications of Aircraft Engine Components

The potential application of silver tungsten alloy in aerospace engine components reflects its adaptability in high temperature and high pressure environments, especially in scenarios with high requirements for thermal management, structural support and durability. The alloy's thermal conductivity and mechanical properties provide the possibility for its application in key aerospace engine components, improving the efficiency and life of the engine.

6.3.2.1 Requirements for materials in the high temperature and high pressure working environment of aircraft engines

The high temperature and high pressure working environment of aircraft engines is extremely complex, which places strict requirements on material performance to ensure the reliability and safety of the engine in high-performance operation. The environment and requirements directly guide material selection and optimization.

The working environment includes high temperature areas, where the combustion chamber and turbine blade temperatures can reach 1500°C to 2000°C, and the exhaust nozzle temperature is even higher. High pressure environment, the working pressure can reach tens of MPa, and the gas flow rate is supersonic, which brings mechanical stress. Thermal cycles are frequent during takeoff and landing, and oxidation and corrosion are caused by combustion products such as carbon dioxide and water vapor. Vibration and centrifugal force are intensified in high-speed rotating parts, and radiation and external forces affect material stability during high-altitude flight.

Material requirements include high temperature resistance to maintain structural integrity above 2000°C. Oxidation and corrosion resistance to resist chemical attack and prevent surface degradation. Mechanical strength and wear resistance to support high pressure and high speed operation and extend component life. Low thermal expansion coefficient to match other materials and reduce thermal stress. Thermal conductivity to disperse heat and prevent local overheating. Microstructural consistency to reduce crack propagation, and optimized preparation is the key.

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6.3.2.2 Application Potential of Silver Tungsten Alloy in Specific Components of Aircraft Engines

The application potential of silver tungsten alloy in specific parts of aircraft engines relies on its excellent properties, especially in high-temperature thermal conductivity and mechanical support, providing possibilities for turbine blades, combustion chamber linings and heat exchangers. In turbine blades, silver-tungsten alloy is used as a reinforcement material. The high melting point of tungsten can resist high temperatures above 1500°C, and the thermal conductivity of silver disperses heat to prevent local overheating. The low thermal expansion coefficient reduces the stress mismatch with nickel-based alloys, and the high mechanical strength after optimizing the microstructure is suitable for high-speed rotation environments. Tests show that the deformation rate of alloy blades under simulated high temperatures is lower than that of traditional materials.

In the combustion chamber lining, silver-tungsten alloy provides high temperature resistance and anti-erosion protection. The tungsten skeleton can withstand high temperatures of 2000°C, and the silver phase network conducts heat evenly, reducing thermal stress. The oxidation resistance is better than pure silver, and the dense structure reduces the penetration of corrosive media, which is suitable for long-term combustion environments. In actual application exploration, the durability of the lining is improved and the maintenance interval is extended. In heat exchangers, silver-tungsten alloy is used for heat-conducting parts. The high electrical and thermal conductivity of silver supports efficient heat transfer, and the stability of tungsten enhances mechanical durability. After the microstructure is optimized, the porosity is low and the thermal efficiency is improved, which is suitable for aircraft cooling systems. Nano-scale powder refines the grains and improves the heat conduction path.

In actual evaluation, silver tungsten alloy performs well in high-temperature components, especially in military and commercial jet engines, with improved life and efficiency.

6.4 Application of Silver Tungsten Alloy in Other Fields

Silver-tungsten alloy has shown wide application potential in metallurgy, medical treatment and energy fields due to its excellent conductivity, high temperature resistance and mechanical properties. Its microstructure and physical properties make it adaptable to extreme working conditions and support the improvement and innovation of various industrial needs. The following will discuss in detail the application scenarios of silver-tungsten alloy in the metallurgical industry, specifically analyzing the working conditions and material requirements of metallurgical equipment, the application of silver-tungsten alloy in metallurgical furnace electrodes, and the use of silver-tungsten alloy in metallurgical testing instruments.

6.4.1 Application scenarios in the metallurgical industry

Silver tungsten alloy has important application value in the metallurgical industry due to its high conductivity and durability, especially in furnace electrodes and detection instruments. The high melting

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point and corrosion resistance of the alloy support high-temperature smelting and measurement, improving the efficiency and reliability of metallurgical processes.

6.4.1.1 Working conditions and material requirements of metallurgical equipment

The working conditions of metallurgical equipment are extremely harsh, involving high temperature, high current and chemical corrosion, which places strict requirements on material performance to ensure equipment stability and service life. Conditions and requirements directly guide material selection and optimization.

Working conditions include high temperature environments, arc furnaces and induction furnaces can reach temperatures above 1800°C, high current densities through electrodes, currents up to tens of thousands of amperes. Chemical attack is caused by molten metal and slag, oxidation and sulfidation accelerate material degradation. Mechanical stress and thermal cycling are exacerbated by frequent operation, and dust and moisture in the industrial atmosphere further affect material stability.

Material requirements include high temperature resistance, maintaining structural integrity above 1800°C. High conductivity supports efficient current transmission and reduces energy loss. Corrosion and oxidation resistance resist chemical attack and prevent surface loss. Mechanical strength and wear resistance support high current and mechanical shock, extending service life. Low thermal expansion coefficient reduces thermal stress, microstructural consistency reduces local failure, and optimized preparation is the key.

6.4.1.2 Application of silver-tungsten alloy in metallurgical furnace electrodes

The application of silver-tungsten alloy in metallurgical furnace electrodes demonstrates its superior performance in high temperature and high current environments, improving the operating efficiency of arc furnaces and induction furnaces. The high conductivity of the silver phase provides a low resistance path, supports the transmission of tens of thousands of amperes of current, and reduces electrode heating and energy loss. Tungsten's high melting point (3422°C) resists high temperatures above 1800°C. The alloy remains stable under the action of the arc and has better oxidation resistance than pure silver. After the microstructure is optimized, the dense structure reduces porosity, enhances corrosion resistance, and adapts to the molten metal and slag environment.

Mechanical strength and wear resistance are supported by the tungsten skeleton, and the electrode resists mechanical impact and long-term wear and tear, extending its life. The thermal conductivity of silver disperses heat, prevents local overheating, and optimizes the surface uniformity of the electrode after sintering. In practical applications, silver-tungsten alloy electrodes perform well in steel smelting and non-ferrous metal smelting, with current efficiency increased by more than 10% and a loss rate lower than that of graphite electrodes. Optimization directions include adjusting the silver -tungsten ratio to enhance conductivity, or improving resistance to chemical corrosion through coating.

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6.4.1.3 Use of silver-tungsten alloy in metallurgical testing instruments

The use of silver-tungsten alloy in metallurgical testing instruments relies on its high conductivity and durability to support precise measurement and signal transmission, and improve detection reliability.

In high-temperature thermocouples, silver-tungsten alloy is used as a conductive contact. The silver phase ensures low-resistance signal transmission, and the high melting point of tungsten supports 1800°C environmental measurement. The microstructural density reduces thermoelectric potential drift, and the stability is enhanced after optimized sintering, which is suitable for metallurgical furnace temperature monitoring. Tests show that the accuracy of alloy thermocouples is better than traditional platinum-rhodium alloys. In resistivity test probes, silver-tungsten alloy provides reliable contact, hardness and wear resistance resist mechanical wear, and the silver network supports efficient current distribution. Corrosion resistance adapts to molten metal sputtering, and nano-scale powder refines grain boundaries and improves measurement consistency. In practical applications, the probe performs well in metal purity detection, with an error reduction of 5%.

Optimization directions include developing functional gradient designs to improve high temperature resistance, or enhancing antioxidant effects through surface treatment.

6.4.2 Use cases in sports equipment

Silver tungsten alloy use cases in sports equipment demonstrate its potential in high-performance equipment, especially in scenarios where high density and durability are required. The alloy's high strength and weight distribution properties support the design and manufacture of high-end sports equipment, improving athlete performance and equipment life.

6.4.2.1 Requirements for material properties of high-end sports equipment

High-end sports equipment has high demands on material properties to support precise operation, durability and optimized weight distribution to ensure athletes' advantage in competition. Demands directly guide material selection and optimization. Demands include high density to provide centralized weight to optimize the balance and inertia of equipment, such as golf heads or fishing weights. Mechanical strength and wear resistance to resist frequent use and impact, extending the life of equipment. Corrosion resistance to cope with outdoor environments, such as rain or seawater, to prevent performance degradation. Processing accuracy supports complex shapes and fine structures to adapt to high-end designs. Low thermal expansion coefficient reduces deformation caused by temperature changes, microstructural consistency reduces local defects, and optimized preparation is the key.

6.4.2.2 Application of silver-tungsten alloy in golf heads, fishing tackle and other equipment

The application of silver-tungsten alloy in sports equipment such as golf heads and fishing tackles relies on its high density and mechanical properties to improve the performance and durability of the equipment.

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In golf heads, silver-tungsten alloy is used as a counterweight. Its high density (about 19.3g/cm³) provides centralized mass, optimizes the inertia of the hitting point, and enhances the hitting distance and accuracy. The high hardness of tungsten resists frequent collisions between the head and the ball, extending the service life. The thermal conductivity of silver disperses the impact heat, and the microstructure is highly dense after optimization, reducing wear. In practical applications, the hitting stability of silver-tungsten alloy head is better than that of titanium alloy, and is favored by professional players.

In fishing tackle, silver-tungsten alloy is used for weight sinkers and fish hook components. Its high density ensures accurate casting and sinking to the bottom, and its wear resistance resists water flow and rock wear. Silver's corrosion resistance adapts to the seawater environment, and optimized sintering reduces porosity and enhances long-term stability. Nano-scale powder refines grain boundaries and improves mechanical consistency, making it suitable for high-end fishing equipment. Tests show that alloy sinkers are more durable in salt water than lead products.

6.4.3 Exploration and application in the field of medical devices

The exploration and application of silver tungsten alloy in the field of medical devices demonstrates its potential in high-precision and special environments, especially in imaging equipment and surgical instruments. The high density and conductivity of the alloy support the development of advanced medical technology and improve the efficiency and safety of diagnosis and treatment.

6.4.3.1 Requirements for material biocompatibility and performance of medical devices

Medical devices have strict requirements on the biocompatibility and performance of materials to ensure human safety and equipment functionality and meet the diverse needs of clinical applications. Requirements directly guide material selection and optimization.

Biocompatibility is a core requirement. The material must be non-toxic, non-allergenic, and not cause inflammation or rejection when in contact with human tissue or blood. Corrosion resistance should be able to cope with body fluids or disinfectant environments to prevent performance degradation. Mechanical strength and wear resistance support precision operations and long-term use, extending the life of the device. Processing accuracy enables micron-level structures to adapt to complex medical designs. Conductivity supports electrical functions, such as signal transmission in imaging or surgical equipment. High temperature resistance adapts to the disinfection process, and microstructural consistency reduces local defects. Optimized preparation is the key.

6.4.3.2 Application of silver-tungsten alloy in medical imaging equipment

The application exploration of silver-tungsten alloy in medical imaging equipment relies on its high density and conductivity to support high-precision imaging of X-ray and CT scans. In X-ray tube targets, silver-tungsten alloy is used as anode material. Its high density (about 19.3g/cm³) enhances the efficiency of X-ray generation, and the high melting point of tungsten (3422°C) resists the high temperature of

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electron beam bombardment. The thermal conductivity of silver disperses heat to prevent overheating of the target surface. After optimizing the microstructure, it has high density and reduces cracks. Tests show that the imaging clarity of the alloy target is improved by 15% in high-power scanning, which is suitable for high-resolution diagnosis. In CT detector shielding, silver-tungsten alloy provides high-density shielding, reduces scattered radiation, and protects patients and equipment. The corrosion resistance of silver adapts to the sterilization environment, and the stability of tungsten enhances mechanical durability. Nano-scale powder refines the grain boundaries and improves the uniformity of shielding. The exploration shows that the radiation protection effect is better than that of lead-based materials.

6.4.3.3 Potential Applications of Silver-Tungsten Alloy in Precision Surgical Instruments

The potential application of silver-tungsten alloy in precision surgical instruments relies on its high hardness and conductivity to support minimally invasive surgery and electrosurgery. In minimally invasive scalpels, silver-tungsten alloy is used as the blade. The high hardness of tungsten resists wear during tissue cutting and prolongs the service life. The conductivity of silver supports the function of the electrosurgical knife. After optimizing the microstructure, the density is high and tissue adhesion is reduced. Surface polishing achieves micron-level sharpness. The exploration shows that the cutting accuracy is better than stainless steel, which is suitable for neurosurgery.

In electrosurgical electrodes, silver-tungsten alloy provides efficient current transmission, the silver phase network reduces resistance, and the tungsten skeleton resists arc ablation and adapts to high-temperature resection. The corrosion resistance is good for blood and disinfectants, and the nano-scale alloy refines the grain boundary and improves mechanical consistency. In actual tests, the electrode has high stability and low damage rate in high-frequency surgery.

6.4.4 Application prospects in the field of nuclear energy

The application prospects of silver tungsten alloy in the field of nuclear energy reflect its potential in high radiation and extreme environments, especially in nuclear reactor components and radiation shielding. The high density and durability of the alloy provide the possibility for its application in nuclear energy equipment, supporting the safety and efficiency of nuclear energy technology.

6.4.4.1 Requirements for materials' radiation resistance and other properties for nuclear power equipment

Nuclear energy equipment has extremely high requirements for the radiation resistance and other properties of materials to ensure long-term stable operation in high radiation and high temperature environments and meet nuclear safety and efficiency requirements. Requirements directly guide material selection and optimization.

The working environment includes high radiation fields, gamma ray and neutron radiation may cause material aging or structural changes. Chemical corrosion is caused by coolants such as liquid sodium or

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heavy water, and high pressure conditions intensify mechanical stress. Thermal cycles and vibrations are frequent in operation, and electromagnetic interference is inevitable in control systems.

Material requirements include radiation resistance to resist neutron capture and gamma ray-induced degradation, and maintain long-term stability. High temperature resistance to adapt to environments above 700°C to prevent deformation or failure. Corrosion resistance to cope with coolants and radiation products to prevent surface loss. Mechanical strength and wear resistance to support high pressure and vibration, and extend service life. High density supports radiation shielding and reduces external exposure. Microstructural consistency reduces crack propagation, and optimized preparation is the key.

6.4.4.2 Analysis of the application possibility of silver-tungsten alloy in the field of nuclear energy

The application possibilities of silver tungsten alloy in the nuclear energy field rely on its high density and durability, especially showing potential in radiation shielding and high-temperature components to support the safe operation of nuclear reactors.

In radiation shielding, the high density of silver-tungsten alloy (about 19.3g/cm³) effectively absorbs gamma rays and neutron radiation, the radiation resistance of tungsten reduces material aging, and the thermal conductivity of silver disperses heat. After the microstructure is optimized, the density is high, and the shielding efficiency is better than that of lead-based materials, which is suitable for nuclear reactor shells or transport containers. Tests show that the thickness of the alloy shielding can be reduced by 10% and still meet the protection standards.

In high-temperature components, silver-tungsten alloy is used for control rod sleeves. The high melting point of tungsten (3422°C) can withstand 700°C environment. The silver phase network supports conductivity, optimizes sintering to reduce porosity, and enhances corrosion resistance. Mechanical strength supports high-pressure conditions, and nano-scale powder refines grain boundaries and improves durability. During the exploration, the sleeve has high stability under simulated high-temperature radiation and is suitable for fast neutron reactors.

In cooling system connectors, silver tungsten alloy provides reliable conductivity and mechanical support, corrosion resistance to adapt to liquid sodium environment, hardness to resist vibration wear. Microstructure consistency reduces defects, and optimization directions include the development of radiation-resistant coatings.

In the actual feasibility assessment, silver-tungsten alloys have shown potential in nuclear power plants and nuclear waste treatment, and their radiation and high temperature resistance are better than traditional alloys. Optimization directions include adjusting the silver- tungsten ratio to enhance the shielding effect, or improving corrosion resistance through composite materials.

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Silver Tungsten Alloy Introduction

1. Overview of Silver Tungsten Alloy

Silver tungsten alloy is an alloy material primarily composed of silver and tungsten, where silver serves as the matrix or binding phase and tungsten acts as the high-melting-point reinforcing phase, combining the advantages of both to create a material with excellent performance.

2. Features of Silver Tungsten Alloy

The composition ratio of silver-tungsten alloy is adjustable; a higher silver content enhances its electrical and thermal conductivity, making it suitable for high-voltage electrical contacts, while a higher tungsten content improves its high-temperature resistance and wear resistance, making it ideal for welding electrodes and high-temperature components.

3. The Composition Ratio of Silver Tungsten Alloy

Materials	Composition (%weight)	Density (/g.cm3)	Electrical conductivity	Electrical resistivity	Hardness (HB)
AgW30	70 silver 30 tungsten	11.8-12.2	73	2.3	75
AgW40	60 silver 40 tungsten	12.5-12.8	64	2.6	85
AgW50	50 silver 50 tungsten	13.2-13.5	73-56	2.3-3.0	105
AgW55	45 silver 55 tungsten	13.6-13.9	54	3.2	115
AgW60	40 silver 60 tungsten	14.0-14.4	60-50	2.8-3.3	125
AgW65	35 silver 65 tungsten	14.5-14.9	50	3.4	135
AgW70	30 silver 70 tungsten	14.7-15.1	48	3.5	150
AgW80	20 silver 80 tungsten	16.1-16.5	37	4.5	180

4. Production Methods for Silver Tungsten Alloy

The preparation method for tungsten-silver alloy is the same as that for tungsten-copper alloy. Due to tungsten's high melting point and its inability to alloy with silver, traditional methods cannot be used. Tungsten-silver alloy is generally produced using the vacuum infiltration method, with production steps including material mixing preparation, pressing and forming, degreasing, high-temperature sintering, infiltration, and post-processing.

5. Applications of Silver Tungsten Alloy

Silver-tungsten alloy is primarily used for electrical contacts and electrode materials, such as breaker contacts, resistance welding electrodes, and plasma spray components, with its excellent electrical properties and arc resistance meeting the demands of high currents and frequent operations.

6. Purchasing Information

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

Website: silver-tungsten.net

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电话/TEL: 0086 592 512 9696
CTIAQCD-MA-E/P 2018-2024V
sales@chinatungsten.com

Chapter 7: Future Development Direction of Silver Tungsten Alloy

As a multifunctional material, the future development direction of [silver-tungsten alloy](#) focuses on new preparation technology, performance optimization and application expansion. Through technological innovation, the microstructure and performance consistency are improved to meet the growing industrial needs.

7.1 Exploration of New Preparation Technology of Silver-Tungsten Alloy

The exploration of new preparation technology for silver-tungsten alloy aims to break through the limitations of traditional powder metallurgy and vacuum infiltration methods, and improve the material's density, uniformity, and ability to manufacture complex shapes. The new technology combines advanced processes and intelligent control to provide support for alloy performance improvement and application expansion.

7.1.1 Potential Applications of Additive Manufacturing Technology

Additive manufacturing technology (such as 3D printing) in the preparation of silver-tungsten alloy can achieve complex geometric shapes through layer-by-layer deposition, improve material utilization and customization capabilities.

Selective laser melting (SLM) technology mixes silver powder and tungsten powder and then uses laser to melt and deposit to generate a dense structure. The low melting point of silver (961°C) and the high melting point of tungsten (3422°C) need to be uniformly fused by optimizing laser parameters, and the power and scanning speed are adjusted to ensure consistent phase distribution. Microstructural observation shows that the alloy prepared by SLM has fine grains and a porosity of less than 5%, which is suitable for precision parts. Direct Metal Deposition (DMD) technology is suitable for large parts. It sprays molten metal powder and solidifies quickly. The high density of silver-tungsten alloy (about 19.3g/cm³) supports high-precision deposition. Thermal management is key. The thermal conductivity of silver disperses heat, and the tungsten skeleton provides mechanical support. Tests show that the tensile strength of DMD parts is increased by 20%, which is suitable for the simultaneous manufacture of complex nozzles.

Potential applications include aerospace counterweights and medical imaging targets, additive manufacturing reduces material waste, and customized design improves performance. Optimization directions include developing multi-material printing technology or refining grain boundaries through thermal post-treatment.

7.1.2 Outlook of other cutting-edge preparation technologies

Other cutting-edge preparation technologies provide diversified development paths for silver-tungsten alloys, combining nanotechnology and intelligent processes to improve performance.

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Nano powder sintering technology uses nano -grade silver tungsten powder with a particle size of less than 100 nanometers, and achieves rapid high-temperature pressing through spark plasma sintering (SPS). High temperature and short-time treatment inhibits grain growth, with a density of more than 98% and a hardness increase of 30%. It is suitable for microelectronic connectors, and the optimization direction includes controlling the agglomeration of nano powders.

Plasma spraying technology melts silver tungsten powder and sprays it onto the substrate to form a wear-resistant coating. The hardness of tungsten enhances surface wear resistance, and the conductivity of silver supports electrical functions. The coating thickness can be controlled to micron level. It is suitable for metallurgical electrode repair, and it is expected to combine intelligent monitoring to improve coating uniformity.

Molecular beam epitaxy (MBE) technology explores thin film preparation, depositing silver and tungsten atoms layer by layer to generate high-purity thin layers. Excellent conductivity and thermal stability, suitable for sensor sensitive layers. Challenges lie in cost and scale, and optimization directions include the development of low-cost precursors.

7.2 Research Trends in Silver-Tungsten Alloy Performance Optimization

The research trend of silver-tungsten alloy performance optimization aims to improve its comprehensive performance through material design and process improvement to meet the needs of diversified applications. The research direction combines microstructure regulation and specific environmental adaptation to promote breakthroughs in alloys in high technology.

7.2.1 Research directions for improving comprehensive performance

Improving the comprehensive performance of silver-tungsten alloy is the research focus. Through multi-dimensional optimization, the electrical conductivity, thermal conductivity, mechanical strength and corrosion resistance are enhanced, laying the foundation for its wide application.

Microstructure refinement uses nano-scale powder and rapid sintering technology to reduce grain size, enhance grain boundary strengthening effect, and increase hardness by more than 20%. Phase distribution optimization adjusts the silver-tungsten ratio, the silver network improves conductivity, and the tungsten skeleton enhances mechanical support, with a conductivity of up to 70% IACS. Porosity reduction uses hot isostatic pressing (HIP) technology, with a density of 98%, improving thermal conductivity and corrosion resistance.

Surface modification reduces surface defects through electrochemical polishing or coating such as titanium nitride, improves wear resistance by 30%, and enhances oxidation resistance. Alloying adds trace elements such as nickel or cobalt to optimize interfacial bonding and balance overall performance. Studies have shown that the stability of the optimized alloy in high temperature environments is significantly improved, making it suitable for use in many fields. Optimization directions include

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developing intelligent design tools to predict performance or verifying the best ratio through multi-parameter experiments.

7.2.2 Performance enhancement for specific applications

Performance enhancement for specific applications focuses on customized needs, optimizes the properties of silver tungsten alloy for electrical, aerospace and medical fields, and improves application effects.

In the electrical field, arc resistance and conductivity are enhanced, tungsten content is increased to 70%-80%, melting point and hardness are increased, arc resistance loss is reduced by 40%, and it is suitable for high-voltage switches. Silver network optimization ensures conductivity, and microstructure density improves signal transmission stability. In the aerospace field, high temperature resistance and low thermal expansion are enhanced, the silver- tungsten ratio is adjusted to 50%-50%, matching the ceramic substrate, and the thermal expansion coefficient is reduced to $6 \times 10^{-6} / ^\circ \text{C}$. Nano-scale grains enhance mechanical strength, suitable for nozzle throat linings, and durability is increased by 50%. In the medical field, biocompatibility and processing accuracy are enhanced, surface coatings such as titanium nickel improve compatibility, nano-scale powders refine the structure, and the processing tolerance reaches ± 5 microns. Conductivity optimization supports imaging equipment, and corrosion resistance is enhanced to adapt to body fluid environments.



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Appendix

Appendix A: Chinese National Standard for Silver-Tungsten Alloy

Chinese national standards (GB standards) provide technical specifications for the development and application of silver-tungsten alloys, but the specific national standards for [silver-tungsten alloys](#) have not yet been fully disclosed or standardized. The relevant standards are mainly indirectly applicable through general specifications for powder metallurgy and alloy preparation. The following is an overview of some existing or relevant Chinese national standards related to silver-tungsten alloys:

- **GB/T 5242-2006 "Inspection Rules and Test Methods for Cemented Carbide Products"** : Specifies the inspection and test methods for cemented carbide products, applicable to the quality control of tungsten-containing materials, and indirectly covers the preparation and performance evaluation of silver-tungsten alloys.
- **GB/T 3850-1983 "Determination of density of dense sintered metal materials and cemented carbides"** : provides a density determination method suitable for physical property testing of silver-tungsten alloys.
- **GB/T 26055-2022 "Regenerated tungsten carbide powder"** : Although it focuses on tungsten carbide, its preparation process and powder properties can be used as a reference for the preparation of silver-tungsten alloy powder.
- **GB/T 26725-2023 Ultrafine Tungsten Carbide Powder** : defines the ultrafine powder standard and indirectly supports the use of nano-scale tungsten powder in silver-tungsten alloy.

These standards are mainly based on the preparation and testing of tungsten-based materials . The standards for silver-tungsten alloys are still under development. The industry often refers to general powder metallurgy specifications (such as GB/T 1481-1998 "Determination of uniaxial compressibility of metal powders") and enterprise technical specifications.

Appendix B: International Standards for Silver-Tungsten Alloy

The international standards for silver-tungsten alloys have not yet formed a unified system, and the relevant specifications mainly rely on the general standards of tungsten-based composite materials and electrical alloys. The following may be applicable international standards or related references:

- **ISO 4489:2012 《Sintered metal materials and hardmetals — Determination of modulus of elasticity》** : defines the method for determining the elastic modulus of sintered metal materials, which is applicable to the mechanical properties testing of silver-tungsten alloy.
- **ISO 3878:1983 《 Hardmetals — Vickers hardness test》** : Provides the Vickers hardness test standard for cemented carbide, indirectly supporting the hardness assessment of silver-tungsten alloy.
- **ASTM B777-15 《Standard Specification for Tungsten Base, High-Density Metal》** : Although it is mainly aimed at high-density tungsten-based alloys , its performance

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requirements (such as density and hardness) can be used as a reference for silver-tungsten alloys, covering silver-containing tungsten alloys.

Internationally, silver-tungsten alloy is often used as an electrical material (such as contactors and electrodes), and its standards are mostly indirectly covered by relevant electrical material specifications of ASTM (American Society for Testing and Materials) or IEC (International Electrotechnical Commission), such as IEC 60947 series "Low-voltage switchgear and control equipment". There is still a lack of unified definition of specific silver-tungsten alloy standards, and industry practices mostly rely on supplier technical data and customized specifications.

Appendix C: Silver-tungsten alloy standards in Europe, America, Japan, South Korea and other countries around the world

The standards for silver-tungsten alloy (Ag-W alloy) have not yet formed a unified and specialized international specification in Europe, America, Japan, South Korea and other countries. The relevant standards are mostly based on the general specifications of tungsten-based composite materials or electrical alloys.

- **the United States**

ASTM B777-15 "Standard Specification for Tungsten Base, High-Density Metal" is mainly aimed at high-density tungsten-based alloys, covering the performance requirements of silver-containing tungsten alloys (such as density and hardness), but not specifically for silver-tungsten alloys. Europe's EN 13601 "Copper and copper alloys - Copper rod, bar and wire" involves copper-based alloy standards and is indirectly applicable to the conductivity test of silver-tungsten alloys. Silver-tungsten alloys are often attached to the IEC 60947 series "Low-voltage switchgear and control equipment" and are used for electrical contact materials, but there is no independent standard.

- **Japan**

Japan's JIS standards (such as JIS H 4461 "Tungsten and tungsten alloy rods and wires") focus on tungsten and its alloy rods and wires. The electrical conductivity and arc resistance of silver-tungsten alloy can be referenced, but not explicitly listed. The industry often customizes silver-tungsten alloy products based on internal corporate specifications or ASTM standards.

- **South**

Korea lacks a dedicated national standard for silver-tungsten alloys, and related materials mostly refer to international general specifications such as ISO 4489:2012 "Sintered metal materials and hardmetals — Determination of modulus of elasticity". South Korea is rich in tungsten minerals (such as Sangdong Mine), but the formulation of standards mostly relies on imported technical specifications.

At present, silver-tungsten alloy standards mostly rely on general tungsten alloy or electrical material specifications, and special standards have not yet been established. Industrial practices in various countries are mostly guided by supplier technical data or customized specifications.

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Appendix D: Silver-tungsten alloy terminology

The term	Definition
High density alloy	An alloy containing a high proportion of tungsten (usually 70%-90%) and silver, with a density of about 17-19.3 g/cm ³ , used for weighting and shielding.
Powder Metallurgy	The process of preparing the alloy by mixing silver and tungsten powders, pressing and sintering ensures a homogeneous phase distribution.
Liquid Phase Sintering	tungsten particles at high temperatures , filling the pores to form a dense structure.
penetration	infiltrating the porous tungsten skeleton with molten silver enhances the density and conductivity of the alloy.
Coefficient of thermal expansion	The linear expansion coefficient of the alloy changes with temperature. For silver-tungsten alloy, it is about 8-10×10 ⁻⁶ / ° C, which affects the structural stability.
Arc resistance	The alloy's ability to resist arc erosion, combined with the high melting point of tungsten and the thermal conductivity of silver, makes it suitable for electrical applications.
Electrical conductivity	The ability of the alloy to conduct electric current. The silver phase network provides high conductivity, with typical values reaching 60%-70% IACS.
hardness	The alloy's ability to resist deformation, tungsten provides high hardness (HV 300-400), enhancing wear resistance.
Corrosion resistance	The alloy's ability to resist oxidation and chemical attack, with tungsten resisting oxidation and silver stabilizing, and optimized for humid environments.
Microstructure density	The uniformity of porosity and phase distribution inside the alloy affects the mechanical and electrical properties, and the optimization target is less than 5% porosity.



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电话/TEL: 0086 592 512 9696
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sales@chinatungsten.com

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sales@chinatungsten.com