Encyclopedia of Composite Rare-Earth Tungsten Electrode

中钨智造科技有限公司

CTIA GROUP LTD

CTIA GROUP LTD

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

INTRODUCTION TO CTIA GROUP

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

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

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

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

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Composite Rare-Earth Tungsten Electrode Introduction

1. Overview of Composite Rare-Earth Tungsten Electrode

The composite rare-earth tungsten electrode is a high-performance welding electrode made from high-purity tungsten as the base material, with multiple rare-earth oxides (such as lanthanum oxide, yttrium oxide, cerium oxide, etc.) added in combination. Compared with traditional single rare-earth tungsten electrodes, it demonstrates superior electron emission performance, high-temperature stability, burn resistance, and arc ignition capability, making it widely used in high-precision, high-strength, and long-duration continuous welding applications.

2. Performance Parameters (Reference Values) of Composite Rare-Earth Tungsten Electrode

Item	Typical Value	Remarks
Tungsten Purity	≥99.95%	Base tungsten content
Rare-Earth Oxide Content	1.5%–3.0%	Composite ratio customizable
Operating Current Range	DC 5A–500A / AC 20A–350A	Depends on electrode diameter
Maximum Temperature Resistance	2600°C	Instantaneous arc temperature
Service Life Improvement	1.5–3 times	Compared to pure tungsten or single rare-earth tungsten electrodes

3. Applications of Composite Rare-Earth Tungsten Electrode

Aerospace Manufacturing: Welding of titanium alloys, nickel-based alloys, and other high-temperature alloys

Nuclear and Power Equipment: Welding of high-temperature pipelines and heat-resistant steel structures

Precision Machining: Welding of stainless steel, copper, aluminum, and their alloys

Automotive and Rail Transit: Welding of critical load-bearing components

Electronics and Vacuum Devices: High-vacuum arc welding and micro-welding processes

4. Packaging and Supply Specifications

Diameter: Ø1.0mm, 1.6mm, 2.4mm, 3.2mm, 4.0mm, etc. (customizable)

Length: 150mm, 175mm, etc. (customizable)

Packaging: Plastic box or vacuum-sealed packaging, 10 pieces/box (Standard)

5. Procurement Information

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Chapter 1 Introduction

1.1 Concept and definition of composite rare-earth tungsten electrode

Composite rare-earth tungsten electrode is a kind of high-purity tungsten as the matrix, doped with a variety of rare earth oxides (such as lanthanum oxide La_2O_3, cerium oxide CeO_2, yttrium oxide Y_2O_3, zirconia ZrO_2, etc.) advanced electrode materials that optimize performance. Its core lies in the "composite" design, that is, through the synergy of multiple rare earth oxides, the electrode significantly improves the electron emission capacity, arc stability, high temperature resistance and service life of the electrode. Compared with traditional pure tungsten electrodes or single rare earth tungsten electrodes, composite rare-earth tungsten electrodes exhibit better comprehensive performance in applications such as welding, cutting, and melting, making them indispensable key materials for modern industry.

From the technical definition, composite rare-earth tungsten electrode refers to a non-melting electrode material prepared by powder metallurgy, chemical doping or solution spraying by doping 1%~4% mass fraction of rare earth oxides in a tungsten matrix. It is mainly used in inert gas shielded welding (TIG welding), plasma welding, cutting, thermal spraying and electric light sources. According to the type and quantity of rare earth oxides, they can be divided into binary composites (such as cerium-lanthanum-tungsten electrodes), ternary composites (such as cerium-lanthanum-yttrium-tungsten electrodes) and multi-composite electrodes. International standards (such as ISO 6848:2015) classify it as a non-melting electrode, and common models include WL series (lanthanum tungsten), WC series (cerium tungsten), WY series (yttrium tungsten), and customized multi-composite models.

The development of composite rare-earth tungsten electrodes stems from the limitations of traditional tungsten electrodes. Pure tungsten electrodes have a melting point of up to 3410°C and excellent corrosion resistance, but their electron escape work is high (about 4.5eV), resulting in difficult arcing, unstable arcing, and fast electrode loss. Early thorium tungsten electrodes (containing ThO_2) improved performance by reducing the operating function, but the radioactivity of thorium posed a threat to the environment and operator health. By introducing non-radioactive rare earth oxides, the composite rare-earth tungsten electrode not only retains the high melting point and stability of tungsten, but also significantly reduces the electron escape work (up to 2.0~2.5eV), improves the arc stability (stability index can reach more than 95%), and extends the service life (23 times longer than pure tungsten electrode).

In terms of microstructure, the tungsten matrix of the composite rare-earth tungsten electrode is distributed with fine rare earth oxide particles, which enhance the mechanical strength and toughness of the material by inhibiting grain growth and refining the grain structure. For example, cerium oxide reduces the working function and promotes electron emission; Lanthanum oxide improves arc stability; yttrium oxide enhances high temperature mechanical properties; Zirconia improves antioxidant properties. The synergistic effect of these rare earth elements allows the electrode to remain stable at high current densities (>100A/mm²) by optimizing grain boundary properties, reducing high-temperature volatilization, and inhibiting crack propagation.

In terms of preparation process, composite rare-earth tungsten electrodes can be prepared by mechanical mixing or chemical doping. The mechanical mixing method physically mixes tungsten powder with rare earth oxide powder, which is simple but slightly less uniform. Chemical doping methods achieve atomic-level doping through solution spraying or co-precipitation technology for better uniformity. Process selection affects the uniformity of rare earth distribution and the stability of electrode properties, such as chemical doping can control the size of rare earth oxide particles at the nanometer level, significantly improving the durability of the electrode.

The concept of composite rare-earth tungsten electrodes also covers its expansion in emerging fields. For example, it is combined with tungsten carbide or tungsten nitride to form composite materials suitable for new energy battery electrodes, or used as catalyst carriers for electrochemical reactions. These expanded applications exemplify its versatility, driving the transition from traditional welding materials to high-tech sectors. Additionally, its eco-friendly properties (non-radioactive, REACH compliant) make it an ideal alternative to thorium tungsten electrodes, meeting the global demand for sustainable materials.

In terms of performance indicators, the typical specifications of composite rare-earth tungsten electrodes include a diameter of 1.0~10.0mm, a length of 150~175mm, and the surface can be polished, oxidized or coated. Its key parameters include: electron escape power < 2.5eV, arc stability $> 95\%$, arc life of 500~1000 hours (depending on process conditions). These characteristics make it widely used in high-precision welding, aerospace, and new energy fields.

1.2 Development history, technical background and research status of composite rare-earth tungsten electrodes

The development process of composite rare-earth tungsten electrodes is closely related to the evolution of welding technology, material science and environmental protection requirements. In the early 20th century, tungsten was used as an electrode material due to its high melting point and chemical stability, but the inadequate performance of pure tungsten electrodes limited their application. In 1913, thorium tungsten electrode (containing 1%~2% ThO_2) was introduced, which significantly improved the arcing performance by reducing the working function and was widely used in TIG welding. However, the radioactivity of thorium has gradually attracted attention, especially in the context of increasingly stringent environmental regulations.

In 1973, Wang Juzhen's team at the Shanghai Bulb Factory in China successfully developed a cerium tungsten electrode (containing CeO_2), which was a pioneering breakthrough in rare earth tungsten electrodes. Cerium-tungsten electrodes quickly replaced some thorium-tungsten electrode applications with non-radioactivity, low operating function (approx. 2.7eV) and excellent arc stability, and were included in the ISO 6848 standard. In the 80s of the 20th century, with the advancement of powder metallurgy technology, binary composite rare-earth tungsten electrodes (such as cerium-lanthanum combinations) began to appear. Beijing Tungsten Molybdenum Material Factory and other institutions have achieved uniform distribution of rare earth elements and improved the comprehensive performance of electrodes by optimizing the doping process.

In the 90s, the development of ternary composite rare-earth tungsten electrodes (such as cerium, lanthanum, lanthanum and yttrium combinations) became a hot topic. The technical background includes the wide application of scanning electron microscopy (SEM), X-ray diffraction (XRD), and transmission electron microscopy (TEM) to help reveal the microscopic distribution of rare earth oxides in tungsten substrates. For example, studies have shown that rare earth oxide particles can form a stable second phase, inhibit the coarsening of tungsten grains at high temperatures, and extend electrode life. During the same period, the "multi-composite rare-earth tungsten electrode Industrialization Technology" project supported by China's 863 plan promoted large-scale production, covering hydrogen reduction, cold isostatic pressing and vacuum sintering.

In the 21st century, the application fields of composite rare-earth tungsten electrodes have expanded from traditional welding to plasma cutting, thermal spraying and new energy batteries. After 2000, the global demand for green materials drove the popularity of radioactive electrodes. The technical background includes the introduction of nanotechnology, the use of rare earth nanopowders to improve the doping uniformity, and the particle size is controlled in the range of 50~100nm. In addition, automated production equipment (e.g., spray-doped dryers, medium-frequency induction sintering furnaces) significantly improve yield and consistency.

In the 2010s, research focused on performance optimization and defect control. For example, the sintering stratification mechanism revealed the influence of temperature gradient on the distribution of rare earths, and optimized the sintering parameters (1450~1800°C, vacuum $<10^{-3}$Pa). International standards such as AWS A5.12/A5.12M further regulate the composition, performance testing and quality control requirements of electrodes. During the same period, the stability of the rare earth supply chain became a concern, and the Global Critical Minerals Outlook report highlighted the strategic importance of rare earth resources.

As of 2025, the research status of composite rare-earth tungsten electrodes shows a multidisciplinary trend. Hotspots include:

Emerging Applications: In lithium-ion batteries, fuel cells, and photovoltaic equipment, composite rare-earth tungsten electrodes are used as cathodes or conductive coating materials to improve energy density and cycle life.
Green Manufacturing: The process of extracting rare earths from coal waste reduces reliance on virgin minerals, aligning with the concept of a circular economy.
Intelligent Production: AI-assisted process optimization and 3D printing technology are used for customized electrode production, improving the manufacturing accuracy of complex structures.
Performance Testing: Arc life test (> 1000 hours), accelerated aging experiment, and microstructure analysis (SEM/TEM) provide reliable data for performance evaluation.

Challenges include scarcity of rare earth resources, high processing costs, and international trade barriers, but opportunities lie in policy support (e.g., China's rare earth management regulations) and growing market demand. According to the global market forecast, the annual consumption of composite rare-earth tungsten electrodes has exceeded 1,600 tons, and the average annual growth

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rate is expected to reach 5.8% in 2025~2030.

1.3 The importance of composite rare-earth tungsten electrodes in modern industry

The importance of composite rare-earth tungsten electrodes in modern industry stems from their excellent performance, multi-field applications, and contribution to green manufacturing. As a green alternative to thorium tungsten electrodes, it eliminates radioactive risks and complies with global environmental regulations (e.g., REACH, RoHS), promoting sustainability in the welding industry.

In the field of welding, composite rare-earth tungsten electrodes are the core materials of TIG welding and plasma welding. Its low operating function and high arc stability (>95%) ensure high-quality welds and are widely used in aerospace (titanium and stainless steel welding), automotive manufacturing (aluminum alloy lightweight welding) and nuclear power (reactor pipeline welding). For example, in the aviation sector, electrodes support defect-free welding of complex components, meeting stringent safety standards; In the automotive industry, it helps the precision welding of electric vehicle battery components to improve production efficiency.

In the field of new energy, composite rare-earth tungsten electrodes are used as electrode materials or conductive coatings for lithium-ion batteries, fuel cells and photovoltaic equipment. For example, in lithium battery production, its high conductivity and corrosion resistance improve the cycle life of electrodes (>5000 cycles). In the photovoltaic industry, plasma electrodes for silicon wafer cutting improve cutting accuracy and durability.

In the electronics industry, composite rare-earth tungsten electrodes are used in cathodes and filaments in semiconductor devices, providing stable electron emission and supporting the high-precision requirements of chip manufacturing. In addition, in the field of thermal spraying, its high temperature resistance (>3000°C) and oxidation resistance are used to spray wear-resistant coatings and extend the life of mechanical components.

In the military and medical fields, composite rare-earth tungsten electrodes support high-precision welding, such as the manufacture of armor-piercing shells and medical implants. Its high melting point and chemical stability ensure reliability under extreme conditions.

In terms of economic benefits, composite rare-earth tungsten electrodes significantly save production costs by extending the life (500~1000 hours) and reducing maintenance costs. For example, in TIG welding, the arc burning time is more than 2 times longer than that of pure tungsten electrodes, reducing the frequency of replacement. Global market analysis shows that its demand in high-end manufacturing has driven market growth at an average annual rate of more than 5%.

Strategically, the scarcity of rare earth resources and the irreplaceability of composite rare-earth tungsten electrodes make them key materials and attract policy attention. The EU's Critical Raw Materials Act and China's Rare Earth Management Regulations emphasize the safeguarding of rare earth supply chains, promoting the research and development of recycling technologies and alternative processes. By 2025, the market size of composite rare-earth tungsten electrodes is expected to exceed $1 billion, becoming an important pillar supporting the high-tech industry.

Chapter 2 Material Composition and Classification of Composite Rare-Earth Tungsten Electrodes

2.1 Basic characteristics of tungsten-based materials and limitations of pure tungsten electrodes

Tungsten-based materials are widely used in electrode manufacturing due to their unique physical and chemical properties, becoming the core matrix of composite rare-earth tungsten electrodes. Tungsten is a refractory metal with an extremely high melting point, excellent thermal and chemical stability, making it ideal for non-melting electrodes. Its essential properties include high density, good conductivity, and very low vapor pressure, which make it excellent in high-temperature, high-current welding environments.

Tungsten has a melting point of 3410°C, the highest of any metal, which ensures that the electrode does not melt or deform significantly at arc temperatures. Tungsten has a density of 19.25 g/cm³, which gives it excellent mechanical strength and resistance to wear and tear. Additionally, tungsten has an electrical conductivity of about 30% of copper, which is lower than common conductive materials but sufficient to support high-current welding. Its chemical stability manifests as inertness to acid, alkali and oxidizing environments at room temperature, making it suitable for use in demanding industrial environments. Tungsten has a low coefficient of thermal expansion of only

4.5×10^{-6}/°C, which reduces the risk of thermal stress cracking at high temperatures.

However, pure tungsten electrodes have significant limitations in practical applications. First, pure tungsten has high electron escape work, resulting in poor arcing performance. In TIG welding, pure tungsten electrodes require higher voltages to initiate arcs, increasing energy consumption and potentially leading to arc instability. Secondly, the arc stability of pure tungsten electrode is insufficient, especially in high current or AC welding, the arc is easy to drift, affecting the quality of the weld. In addition, the grain coarsening of pure tungsten electrodes at high temperatures can lead to brittleness of the material and shorten its service life. In high-temperature environments, oxides may also form on the surface of tungsten, leading to electrode contamination and reduced performance.

Another limitation of pure tungsten electrodes is their lower electron emission capabilities. During the welding process, the efficiency of electron emission directly affects the stability and energy concentration of the arc. The high working function of pure tungsten electrodes makes it difficult to maintain a stable arc under low current conditions, limiting their application in precision welding. In addition, the wear resistance and burnout resistance of pure tungsten electrodes are limited, especially in long-term high-intensity welding, where the electrode tip is prone to ablation and needs to be replaced frequently, increasing production costs.

These limitations have led researchers to explore optimization of tungsten electrode performance through doping modifications. In the early days, thorium oxides were used as dopants to improve electron emission, but their radioactivity problems drove the development of non-toxic rare earth oxides. Composite rare-earth tungsten electrodes overcome the shortcomings of pure tungsten electrodes by introducing a variety of rare earth oxides, becoming the mainstream choice of modern welding technology.

2.2 Types and functions of rare earth oxides

Rare earth oxides are the key additives for composite rare-earth tungsten electrodes, and their type and action directly determine the performance optimization degree of the electrode. Commonly used rare earth oxides include lanthanum oxide (La_2O_3), cerium oxide (CeO_2), yttrium oxide (Y_2O_3), and zirconia (ZrO_2), which reduce the working function, improve microstructure, and enhance high-temperature stability. Significantly improve electrode performance.

Lanthanum oxide (La_2O_3) is known for its excellent electron emission capabilities and arc stability. The addition of lanthanum oxide reduces the electron escape work of the tungsten matrix, so that the electrode can trigger a stable arc at a lower voltage. This is particularly important for AC and precision welding, as it reduces arc start time and improves weld consistency. Lanthanum oxide also inhibits the growth of tungsten grains at high temperatures by forming stable second-phase particles, enhancing the embrittlement resistance of electrodes. In addition, lanthanum oxide has a low evaporation rate at high temperatures, reducing the loss of electrode material.

Cerium oxide (CeO_2) is another widely used rare earth oxide known for its low working function and high electron emission efficiency. The addition of cerium oxide allows the electrode to arc quickly in both DC and AC welding, especially suitable for low-current precision welding. The cerium oxide particles are evenly distributed in the tungsten matrix, which improves the electrical and thermal conductivity of the electrode, while reducing the temperature gradient in the arc concentration area and reducing burnout loss. In addition, cerium oxide significantly contributes to the anti-fouling ability of the electrode surface, reducing the interference of impurities on the arc during the welding process.

Yttrium oxide (Y_2O_3) mainly enhances the high-temperature mechanical properties and oxidation resistance of electrodes. Yttrium oxide is extremely thermally stable and can maintain structural integrity in high-temperature arcing environments and reduce ablation at the electrode tip. The addition of yttrium oxide also refines the grain structure of tungsten, improving the toughness and fatigue resistance of the electrode. This makes yttrium-containing electrodes particularly suitable for high-current, long-term continuous welding, such as in the manufacture of aerospace components.

Zirconia (ZrO_2) is used in composite electrodes due to its excellent oxidation and corrosion resistance. Zirconia forms a stable protective layer at high temperatures, preventing the tungsten matrix from reacting with oxygen or other reactive gases, thereby extending electrode life. Zirconia also improves the thermal shock resistance of the electrode, making it suitable for use in complex environments such as plasma cutting. Additionally, the addition of zirconia optimizes arc stability, especially in high-frequency welding.

Other rare earth oxides, such as neodymium oxide (Nd_2O_3) and samarium oxide (Sm_2O_3), are also explored in specific applications. These oxides provide additional performance optimization by adjusting the electrode's microstructure and electron emission characteristics. For example, neodymium oxide further reduces the working function, while samarium oxide enhances the electrode's resistance to high-temperature oxidation.

The mechanism of action of rare earth oxides lies in their interaction with the tungsten matrix. At high temperatures, rare earth oxide particles migrate to the electrode surface, forming an emission point with low working function and promoting electron escape. At the same time, these particles inhibit grain boundary slippage through the pinning effect, enhancing the high-temperature strength of the material. For example, the combination of cerium oxide and lanthanum oxide balances arcing performance and lifetime, while the combination of yttrium oxide and zirconia optimizes high-temperature stability and corrosion resistance.

2.3 Classification standards for composite rare-earth tungsten electrodes

The classification of composite rare-earth tungsten electrodes is based on the type, quantity, and application characteristics of rare earth oxides, aiming to meet different welding needs and industrial standards. The classification standards mainly include the following aspects:

According to the type of rare earth oxide: According to the type of rare earth oxide added, the electrode can be divided into single rare earth electrode (such as cerium tungsten, lanthanum tungsten) and composite rare earth electrode. Composite rare earth electrodes are further subdivided into binary composites (such as cerium-lanthanum-tungsten electrodes), ternary composites (such as cerium-lanthanum-yttrium-tungsten electrodes), and multi-composites (containing more than three rare earth oxides). The performance of a single rare earth electrode is relatively simple, while the composite electrode achieves more comprehensive performance optimization through the synergy of rare earth elements.

According to rare earth content: The total content of rare earth oxides is usually between 1%~4%, and is divided into low rare earth (1%~2%), medium rare earth (2%~3%) and high rare earth (3%~4%) electrodes according to different contents. Low rare earth electrodes are suitable for low-current precision welding, while high rare earth electrodes are used for high-current, heavy-duty welding.

By application: According to the main application, electrodes can be divided into welding (such as TIG welding, plasma welding), cutting (plasma cutting), spraying (thermal spraying), and electric light source (filament, cathode). For example, the electrode for welding emphasizes arc stability, and the electrode for cutting focuses on high temperature resistance.

According to international standards: According to ISO 6848:2015 and AWS A5.12 standards, composite rare-earth tungsten electrodes are graded by rare earth type and performance. For example, models such as WL20 (containing 2% lanthanum oxide) and WC20 (containing 2% cerium oxide) specify the type and content of rare earths, while composite electrodes may be represented by customized numbers, such as WLaCeY (ternary composite).

According to the processing process: according to the preparation method, it can be divided into mechanical mixed electrode and chemical doped electrode. The cost of the electrode of the mechanical hybrid method is low, but the uniformity is slightly worse. Chemically doped electrodes offer higher uniformity of rare earth distribution and are suitable for high-performance applications. The classification criteria are developed with the balance between performance optimization and production costs in mind. For example, binary composite electrodes strike a good balance between performance and cost, and are widely used in industrial welding; Ternary or multi-composite electrodes are designed for high-precision, demanding environments, such as aerospace and nuclear power.

2.4 Common models and specifications of composite rare-earth tungsten electrodes

The models and specifications of composite rare-earth tungsten electrodes are formulated according to international standards and market demand, and common models include WL, WC, WY series and customized composite models. The following are the main models and their specifications:

WL series (lanthanum tungsten electrode): contains lanthanum oxide, usually expressed as WL10 (1% La_2O_3), WL15 (1.5% La_2O_3), WL20 (2% La_2O_3). It is suitable for TIG welding and plasma welding, with excellent arc initiation performance and arc stability, with a diameter range of

1.0~10.0mm and a length of 150~175mm.

WC series (cerium tungsten electrode): Contains cerium oxide, the common model is WC20 (2% CeO_2). It is suitable for low-current precision welding and AC welding, with a diameter of 1.0~6.4mm and a length of 150mm, and the surface is usually polished to reduce contamination.

WY series (yttrium tungsten electrode): contains yttrium oxide, model such as WY20 (2% Y_2O_3), mainly used for high-current DC welding, excellent high temperature resistance, diameter 2.0~8.0mm, length 150~175mm.

Composite models: such as WLaCe (containing lanthanum oxide and cerium oxide), WLaCeY (containing lanthanum oxide, cerium oxide and yttrium oxide). These models are customized products, the rare earth content is adjusted according to the application needs, usually between 1.5%~3.5%, and the diameter and length can be customized according to customer requirements.

Specifications: Electrode diameters range from 0.5mm (micro welding) to 12.0mm (heavy industry welding), and lengths include 150mm, 175mm, and customized lengths. The surface treatment includes polishing, oxidation, and coating, and the end shape can be pointed, flat, or spherical to meet the needs of different welding processes.

The choice of model depends on the type of welding, current range, and material properties. For example, WL20 is suitable for AC welding of aluminum alloys, WC20 is used for low-current welding of stainless steel, and WLaCeY is used for high-load welding of high-strength steel. The diversity of specifications ensures the electrode's wide applicability in aerospace, automotive manufacturing, nuclear power, and more.

2.5 Analysis of the influence of composite rare-earth tungsten electrode material composition on performance

The performance of composite rare-earth tungsten electrodes is affected by the material composition, including the type, content, distribution uniformity of rare earth oxides, and their interaction with the tungsten matrix. The following is an analysis of its impact from multiple perspectives:

Rare earth oxide types: Different rare earth oxides contribute differently to electrode performance. Lanthanum oxide mainly reduces the working function and improves arc stability. cerium oxide enhances arc initiation and anti-pollution ability; Yttrium oxide improves high-temperature strength and burn resistance; Zirconia improves antioxidant properties. Binary or ternary composites optimize the combined performance through synergistic action, such as WLaCe electrodes that combine low operating functions and long-life characteristics.

Rare earth content: Increased rare earth oxide content usually reduces the working function and improves electron emission efficiency, but too high a content (>4%) may lead to a decrease in matrix strength and sintering defects. The low content of 1%~2% is suitable for precision welding, 2%~3% is the general range, and 3%~4% is used for high-load welding. Optimizing content requires balancing performance and cost.

Distribution Uniformity: The uniform distribution of rare earth oxides is crucial for performance. The chemical doping method can achieve nanoscale particle distribution (< 100nm) and improve the conductivity and stability of the electrode. Mechanical mixing can lead to particle agglomeration, reducing performance consistency. SEM analysis showed that the uniformly distributed rare earth particles could effectively nail the grain boundaries and enhance the ability to resist high-temperature creep.

Microstructure: The addition of rare earth oxides refines the tungsten grains, and the average grain size is reduced from 20~50μm to 5~10μm of pure tungsten, which improves toughness and fatigue resistance. Rare earth particles also form a stable second phase, reducing grain boundary slippage at high temperatures and extending electrode life.

Synergistic effect: Multi-composite electrodes optimize performance through the synergistic action of rare earth elements. For example, the combination of cerium oxide and lanthanum oxide reduces the arc voltage and extends the lifetime; The combination of yttrium oxide and zirconia enhances high-temperature stability and corrosion resistance. This synergy makes the composite electrode excel under complex operating conditions.

Environmental Adaptability: The chemical stability of rare earth oxides enhances the electrode's resistance to contamination, reducing the impact of oxides or impurities during welding. Zirconia-containing electrodes exhibit greater durability in environments with high humidity or corrosive gases.

In summary, the design of material composition needs to be optimized according to the application requirements. The aerospace sector may prioritize ternary composite electrodes to ensure high-temperature performance, while the electronics industry leans towards cerium-tungsten electrodes with low rare earth content for precision welding.

2.6 Comparison of composite rare-earth tungsten electrodes with traditional thorium tungsten electrodes

There are significant differences between composite rare-earth tungsten electrodes and traditional thorium tungsten electrodes in terms of performance, environmental friendliness and application range. The following is a comparison from several aspects:

Electron emission performance: Thorium tungsten electrode (containing 1%~2% ThO_2) provides good arc initiation performance through the low working function of thorium, but the composite rare-earth tungsten electrode further reduces the working function through the synergistic effect of multiple rare earth oxides, with lower arcing voltage and higher arc stability. For example, the arc start time of the WLaCeY electrode in AC welding is approximately 20% shorter than that of thorium tungsten electrode.

Arc stability: The arc stability of composite rare-earth tungsten electrodes is better than that of

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thorium tungsten electrodes, especially under high current and AC conditions. The uniform distribution of rare earth oxides reduces arc drift and ensures weld quality. Thorium tungsten electrode may cause arc instability due to thorium volatilization during long-term welding.

Service life: The lifespan of composite rare-earth tungsten electrodes is significantly longer than that of thorium tungsten electrodes. The low evaporation rate and burn-out resistance of rare earth oxides allow the electrode to be used continuously for 500~1000 hours in high-load welding, while thorium tungsten electrodes are usually 300~500 hours. The extended life reduces the frequency of replacements and production costs.

Environmental protection and safety: Thorium tungsten electrodes contain radioactive thorium, which may release α particles during processing and use, posing risks to operators' health, and waste disposal must comply with strict radiation safety standards. Composite rare-earth tungsten electrodes are non-radioactive and comply with REACH and RoHS regulations, reducing environmental pollution and health risks, making them the first choice for green manufacturing.

High-temperature performance: Composite rare-earth tungsten electrodes exhibit better high-temperature stability and burnout resistance through grain refinement and oxidation resistance of rare earth oxides. Thorium tungsten electrodes are prone to thorium volatilization at high temperatures, resulting in increased electrode tip loss.

Applications: The diverse models of composite rare-earth tungsten electrodes, such as WL, WC, and WLaCeY, make them suitable for a wider range of welding types and materials, including aluminum alloys, stainless steels, and superalloys. Although thorium tungsten electrode is suitable for a variety of welding, its scope of use has gradually decreased due to environmental restrictions.

Cost and availability: The raw material cost of thorium tungsten electrodes is lower, but the processing and waste disposal costs are higher. The rare earth resources of composite rare-earth tungsten electrodes are expensive, but the production cost is reduced by optimizing the process (such as chemical doping), and the advancement of rare earth recovery technology improves resource availability.

In summary, composite rare-earth tungsten electrodes are comprehensively better than thorium tungsten electrodes in terms of performance, environmental protection, and application flexibility, and are the preferred materials for modern welding technology. Its non-radioactive properties and long-life characteristics have promoted its wide application in the global market, especially in Europe and the United States, where environmental protection requirements are strict.

Chapter 3 Preparation and Production Process and Technology of Composite Rare-Earth Tungsten Electrodes

3.1 Raw material preparation and ratio

Raw material preparation and ratio are the basic links of composite rare-earth tungsten electrode preparation, which directly determines the stability and consistency of material properties. The main raw materials of composite rare-earth tungsten electrodes include high-purity tungsten-based materials and rare earth oxide additives, and the ratio design needs to be precisely controlled to optimize the electrode's electron emission capacity, arc stability, and high-temperature durability.

Tungsten-based raw materials: Tungsten-based materials are usually made of tungsten trioxide (WO_3) or ammonium paratungstate (APT, $(NH_4)_2WO_4$) as a starting ingredient. The purity of tungsten trioxide needs to reach more than 99.95% to reduce the impact of impurities (such as iron, silicon, carbon) on electrode performance. Ammonium paratungstate is often used in chemical doping processes due to its solubility in water and ease of doping, eliminating additional calcination steps and shortening production cycles. The particle size of tungsten raw materials is generally controlled from 1 to 5 microns to ensure uniformity during subsequent reduction and sintering processes. Raw materials are rigorously screened to remove oxide inclusions or metallic impurities, and are usually confirmed for purity by X-ray fluorescence spectroscopy (XRF).

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Composite Rare-Earth Tungsten Electrode Introduction

1. Overview of Composite Rare-Earth Tungsten Electrode

The composite rare-earth tungsten electrode is a high-performance welding electrode made from high-purity tungsten as the base material, with multiple rare-earth oxides (such as lanthanum oxide, yttrium oxide, cerium oxide, etc.) added in combination. Compared with traditional single rare-earth tungsten electrodes, it demonstrates superior electron emission performance, high-temperature stability, burn resistance, and arc ignition capability, making it widely used in high-precision, high-strength, and long-duration continuous welding applications.

2. Performance Parameters (Reference Values) of Composite Rare-Earth Tungsten Electrode

Item	Typical Value	Remarks
Tungsten Purity	≥99.95%	Base tungsten content
Rare-Earth Oxide Content	1.5%–3.0%	Composite ratio customizable
Operating Current Range	DC 5A–500A / AC 20A–350A	Depends on electrode diameter
Maximum Temperature Resistance	2600°C	Instantaneous arc temperature
Service Life Improvement	1.5–3 times	Compared to pure tungsten or single rare-earth tungsten electrodes

3. Applications of Composite Rare-Earth Tungsten Electrode

Aerospace Manufacturing: Welding of titanium alloys, nickel-based alloys, and other high-temperature alloys

Nuclear and Power Equipment: Welding of high-temperature pipelines and heat-resistant steel structures

Precision Machining: Welding of stainless steel, copper, aluminum, and their alloys

Automotive and Rail Transit: Welding of critical load-bearing components

Electronics and Vacuum Devices: High-vacuum arc welding and micro-welding processes

4. Packaging and Supply Specifications

Diameter: Ø1.0mm, 1.6mm, 2.4mm, 3.2mm, 4.0mm, etc. (customizable)

Length: 150mm, 175mm, etc. (customizable)

Packaging: Plastic box or vacuum-sealed packaging, 10 pieces/box (Standard)

5. Procurement Information

Email: sales@chinatungsten.com

Phone: +86 592 5129595; 592 5129696

Website: www.tungsten.com.cn

Rare earth oxide additives: Rare earth oxides are introduced in the form of nitrates, commonly including lanthanum nitrate ($La(NO_3)_3$), cerium nitrate ($Ce(NO_3)_3$), and yttrium nitrate ($Y(NO_3)_3$).) and zirconium nitrate ($Zr(NO_3)_4$). These nitrates need to be formulated as a solution at a concentration of 0.1 to 0.5 mol/L, with a solvent of deionized water and a pH adjusted to 5.5 to 6.5 to prevent precipitation or chemical reactions. The purity of rare earth elements is required to be not less than 99.9% to avoid non-metallic impurities such as sulfur and phosphorus affecting the conductivity and stability of the electrode. The total content of rare earth oxides is typically 1% to 4% (mass fraction), and the specific ratio is optimized according to the application needs. For example, a binary composite electrode may use 1:1 cerium oxide and lanthanum oxide, and a ternary composite electrode may be cerium oxide: lanthanum oxide: yttrium oxide = 1:1:3 to balance arcing performance and high temperature stability.

Proportional design: The ratio design should comprehensively consider electron escape work, arc stability and mechanical properties. Low rare earth content (1% to 2%) is suitable for precision welding, emphasizing arc initiation performance; The high rare earth content (3% to 4%) is suitable for high-current, heavy-duty welding, enhancing longevity and resistance to burnout. Experiments show that the synergistic effect of lanthanum oxide and cerium oxide can reduce the electron escape work to 2.0 to 2.5 eV, and the arc stability is improved to more than 95%. In the process of ratio, computer simulation and experimental verification of the optimized ratio are required, and common methods include orthogonal experimental design and response surface analysis to determine the optimal rare earth combination.

Raw material mixing: The mixing process adopts spray doping or impregnation methods. Spray doping rare earth nitrate solution is uniformly sprayed in the tungsten trioxide powder, the spray rate is controlled at 0.5 to 1 L/min, the drying temperature is 80 to 120 °C, and the spray dryer is used to form a uniform doped powder. The impregnation method involves soaking tungsten powder in a rare earth solution with a stirring speed of 200 to 300 rpm to ensure uniform adsorption. After mixing, the powder should be dried under vacuum or inert atmosphere to avoid oxidation. After drying, the powder needs to be screened through a 200-mesh screen to remove agglomerated particles.

Quality control: Raw material preparation needs to strictly control the moisture content (<0.5%) and impurity content (<0.01%). The storage environment should be dry, ventilated, and the temperature should be controlled between 10 and 25°C to avoid degradation due to moisture or contamination. The ratio record needs to be digitally archived and cooperated with the online monitoring system to ensure the consistency between batches.

3.2 Detailed explanation of powder metallurgy process

The powder metallurgy process is the core technology for the preparation of composite rare-earth tungsten electrodes, which achieves the densification and performance optimization of materials through powder preparation, molding, sintering, and post-processing. The advantage of this process is that it can precisely control the distribution and microstructure of rare earth oxides, and is suitable for industrial production of high-performance electrodes.

Powder preparation: Powder preparation involves doping and mechanical alloying. Doping The rare earth nitrate is introduced into the tungsten powder by spray drying or wet mixing method, and after drying, it forms a uniform doped powder. The mechanical alloying adopts a high-energy planet mill, and the ball mill parameters are: 400 to 600 rpm, the ball ratio is 8:1 to 10:1, and the grinding time is 8 to 12 hours. The ball mill medium is made of carbide balls to avoid metal pollution. Mechanical alloying refines powder particles to 0.1 to 1 microns, introducing crystal defects and enhancing subsequent sintering activity.

Powder Characterization: The prepared powder needs to be detected by a laser particle size analyzer to ensure that the D50 (median particle size) is in the range of 1 to 5 microns. The specific surface area is determined by the BET method, typically 2 to 5 m^2/g, to ensure sintering activity. X-ray diffraction (XRD) analysis confirmed the crystal form and distribution of rare earth oxides, and scanning electron microscopy (SEM) observed particle morphology and uniformity.

Forming: Forming presses the powder into a blank, and common methods include cold isostatic pressing and molding. Cold isostatic pressing uses liquid medium to apply a uniform pressure of 100 to 300 MPa, the molding time is 5 to 10 minutes, and the density of the body reaches 60% to 70% of the theoretical density. Molding uses a rigid mold that applies a pressure of 150 to 200 MPa through a hydraulic press, making it suitable for small batch production. 0.5% to 1% polyvinyl alcohol (PVA) is added as a binder to improve formability, which needs to be removed in pre-sintering. The molding equipment needs to be equipped with pressure sensors to ensure even pressure distribution.

Sintering: Sintering realizes powder particle bonding and material densification, and vacuum hot press sintering and spark plasma sintering (SPS) are commonly used. Vacuum hot press sintering is carried out at pressures of 1600 to 1800 °C and 50 to 80 MPa, with segmented control of heating rates (10 °C/min to 1000 °C, 4 °C/min to target temperature), holding time of 60 to 90 minutes, and vacuum of 10^{-3} Pa. SPS uses pulsed current to rapidly heat (100 to 200 °C/min), sinter at 1400 to 1600 °C, and keep warm for 5 to 10 minutes, suitable for nanopowders and reduce rare earth evaporation. The material density after sintering is close to the theoretical value (>99%), and the grain size is controlled from 5 to 10 microns.

Post-Processing: Post-processing includes rotary forging, drawing, and surface finishing. Rotary forging processes sintered blanks to a diameter of 3 to 10 mm, with a deformation rate of 20% to 30% per pass. The diameter was further reduced to 0.5 to 10 mm by drawing, lubricated with graphite emulsion. Surface finishing is done by mechanical or electrochemical polishing to remove surface defects and improve the finish.

Process Advantages and Challenges: The powder metallurgy process enables the diffusion distribution of rare earth oxides, enhancing the electrode's electron emission and burnout resistance. Challenges include powder uniformity control and sintering defects (e.g., porosity) prevention, which need to be addressed through process optimization and in-line monitoring. In the future, the combination of nanotechnology and automation will further improve efficiency and quality.

3.3 Reduction process

The reduction process converts tungsten trioxide or ammonium paratungstate into high-purity tungsten powder while fixing the rare earth oxide distribution, which is a key step in the preparation of composite rare-earth tungsten electrodes. Hydrogen reduction is widely used due to its high efficiency and cleanliness, and is divided into two stages of reduction to optimize powder quality.

The first stage of reduction: At 500 to 600 °C, the doped tungsten trioxide powder is placed in a hydrogen atmosphere with a hydrogen purity of more than 99.99% and a flow rate of 0.5 to 1 m^3/h. The reduction furnace adopts a tube furnace or bell jar furnace, and the temperature deviation is controlled at ±5°C. The reduction time is adjusted according to the amount of powder, usually 4 to 6 hours, to generate the intermediate phase WO_2, while the rare earth nitrate is decomposed into oxides and initially fixed in the tungsten matrix. The oxygen content drops below 1%.

The second stage of reduction: the temperature rises to 800 to 950°C, further removing the residual oxygen and producing pure tungsten powder. The hydrogen flow rate is increased to 1 to 1.5 m^3/h, ensuring adequate reduction. The reduction time is 6 to 8 hours, the powder particle size is controlled at 1 to 5 microns, and the oxygen content is reduced to less than 0.01%. The inner wall of the reduction furnace should be made of high-temperature resistant stainless steel or molybdenum alloy to avoid pollution. The reduced powder was analyzed by SEM and XRD to confirm the particle morphology and rare earth distribution.

Optimization technology: Temperature gradient reduction (segmented heating) and wet hydrogen reduction (hydrogen contains trace water vapor) can refine particles and improve surface activity. Wet hydrogen reduction promotes uniform grain growth of tungsten powder by controlling the water vapor content (0.1% to 0.5%). Adding trace additives such as lithium carbonate can reduce the reduction temperature and save energy consumption.

Safety and environmental protection: Hydrogen reduction needs to be equipped with leak detection and ventilation systems, and the exhaust gas is treated by an exhaust gas absorption device to recover unreacted hydrogen. Green reduction technology explores low-energy electric heating furnaces to reduce carbon emissions. The optimization of the reduction process ensures that the powder is of high quality, laying the foundation for subsequent shaping and sintering.

3.4 Forming and forming process

The forming and forming process presses the doped tungsten powder into a blank to provide a uniform and dense initial structure for sintering. The molding quality directly affects the final performance of the electrode, and common methods include cold isostatic pressing, molding, and hydroforming.

Cold isostatic pressing: Uniform pressure (100 to 300 MPa) is applied through a liquid medium, and the powder is loaded into a flexible rubber mold with a forming time of 5 to 10 minutes. The density of the body reaches 60% to 70% of the theoretical density, making it suitable for large electrodes (e.g. > 10 mm in diameter). The equipment needs to be equipped with a high-pressure pump and pressure sensor to ensure stable pressure.

Molding: Rigid steel molds are used to apply 150 to 200 MPa pressure through hydraulic presses, suitable for small batch production. Add 0.5% to 1% polyvinyl alcohol or paraffin as a binder to improve powder flowability. After molding, the body needs to be pre-sintered at 400 to 600 °C to remove the binder and initially dense.

Hydroforming: Used for complex shape electrodes, mixing powder with binder into a slurry, injecting mold for curing. The moisture of the slurry is controlled at 20% to 30%, and it is dried at room temperature for 24 hours after molding to avoid thermal stress cracking. After demolding, the dimensional accuracy of the body should be checked, and the deviation < 0.1 mm.

Process Optimization: Optimize pressure distribution through finite element simulation to reduce density gradients. The addition of nanoscale rare earth oxide particles can improve the strength of the body. Defect analysis showed that uneven pressure caused porosity or cracks, which needed to be resolved through multi-stage profiles and pressure correction. Automated molding equipment integrates vision inspection systems to improve consistency.

Quality control: The molded body needs to be inspected by ultrasonic testing to check for internal defects. Density testing uses the Archimedes method to ensure uniformity. Digital records of the molding process facilitate traceability and optimization.

3.5 Sintering process

The sintering process densifies the formed body through high-temperature treatment, forming a high-density and high-strength electrode material. The sintering of composite rare-earth tungsten electrodes requires a balanced balance of rare earth oxides and grain size control, and common methods include vacuum hot press sintering, spark plasma sintering (SPS), and vertical fusion sintering.

Vacuum hot press sintering: Performed at 1600 to 1800 °C, 50 to 80 MPa pressure, vacuum degree 10^{-3} Pa, heating rate segmented control: 10°C/min to 1000°C, 4°C/min to target temperature, kept warm for 60 to 90 minutes. The sintering furnace adopts a graphite heating body and is equipped with an infrared thermometer to ensure uniform temperature. After sintering, the material density reaches more than 99%, the grain size is 5 to 10 microns, and the rare earth oxides form a diffusion second phase to enhance the strength at high temperatures.

Spark Plasma Sintering (SPS): Rapid heating (100 to 200 °C/min) using pulsed current, sintering at 1400 to 1600 °C, 30 to 50 MPa, and holding for 5 to 10 minutes. SPS is suitable for nanopowders, reduces rare earth evaporation losses, and controls grain size from 3 to 8 microns. The equipment should be equipped with a high-precision current control system to avoid overburning.

Vertical fusion sintering: using 90% melting current, sintered in a partially molten state of tungsten matrix, suitable for large diameter electrodes. The temperature is controlled above 3000°C, and the atmosphere is argon or hydrogen to prevent oxidation. Vertical sintering can increase density, but precise current control is required to avoid rare earth volatilization.

Pre-sintering: Carried out at 1200±50°C, vacuum or hydrogen atmosphere, removing the binder and preliminarily dense, holding for 2 to 4 hours. The density of the pre-sintered body reaches 80% to 85%, providing a stable structure for subsequent high-temperature sintering.

Optimization technology: The addition of additives such as ZrH_2 (0.1% to 0.5%) can reduce the oxygen content, form a stable phase such as $La_2Zr_2O_7$, and improve the electron emission performance. Segmented heating avoids cracks caused by temperature gradients. SEM and TEM analyzed the microstructure after sintering to confirm the rare earth distribution and grain state.

Defect control: Common defects include stomata (due to residual oxygen), grain coarsening (due to excessive temperature), and rare earth separation (due to volatilization). By optimizing the vacuum degree and holding time, the porosity is reduced to less than 0.1%. Green sintering uses low-energy SPS to reduce carbon emissions.

3.6 Pressure processing technology

Pressure machining techniques process sintered blanks into electrode rods, improving density and surface quality, and common methods include rotary forging, drawing, and straightening.

Rotary forging: The diameter of the sintered billet is reduced from 20 mm to 3 to 10 mm by rotary hammering machine, and the deformation rate is 20% to 30% per pass. The processing temperature is 800 to 1200°C to maintain the plasticity of the tungsten matrix. Rotary forging equipment needs to be equipped with an automatic feed system to ensure uniform deformation. After multiple rotary forging, the material density reaches more than 99.5%, and the grains are further refined.

Drawing: The bar is stretched by carbide dies to reduce the diameter to 0.5 to 10 mm. The pull-out speed is 0.5 to 2 m/min, lubricated with graphite emulsion, and the coefficient of friction is < 0.1. Chain pulling machine achieves continuous production and improves efficiency. The surface roughness of the bar after drawing is $Ra<0.5$ microns.

Straightening and cutting: Straightening adopts a roller straightening machine to ensure that the straightness deviation of the bar is < 0.1 mm/m. Cutting is done using laser or mechanical cutting with a length of 150 to 175 mm and a tolerance of ± 0.5 mm.

Optimization and Defect Control: Finite element simulation optimizes deformation parameters to reduce the risk of cracks. The diffusion distribution of rare earth oxides enhances the toughness of the material and reduces the fracture rate. Common defects include surface scratches (due to insufficient lubrication) and internal cracks (due to excessive deformation rates), which are resolved through lubrication optimization and segmental deformation.

Automation: The pressure processing line integrates an online inspection system to monitor the diameter and surface quality in real time. The degree of automation increases the yield to more than 98% and reduces labor costs.

3.7 Surface treatment and coating technology

Surface treatment and coating technology is the final step in improving the corrosion resistance and electron emission properties of composite rare-earth tungsten electrodes, including polishing, cleaning, and optional coatings.

Polishing: Mechanical polishing (grinding wheel or polishing cloth) and electrochemical polishing. Mechanical polishing uses alumina abrasives, with a particle size of 2000 mesh and a surface roughness of Ra<0.2 microns. Electrochemical polishing is performed in a mixed sulfuric acid-phosphoric acid solution with a current density of 0.5 to 1 A/cm² to remove surface micro-defects and improve the finish.

Cleaning: Oil and oxides are removed by ultrasonic cleaning, the cleaning solution is an alkaline solution (pH 8 to 10), a temperature of 50 to 60 °C, an ultrasonic frequency of 40 kHz, and a time of 5 to 10 minutes. After cleaning, rinse with deionized water and dry at 80°C to avoid residual moisture.

Coating Techniques: Rare earth oxides or ceramic coatings such as La_2O_3 or ZrO_2 films can be applied optionally, achieved through chemical vapor deposition (CVD) or plasma spraying. The coating is 1 to 5 microns thick, enhancing oxidation resistance and electron emission efficiency. The CVD process was performed at 800 to 1000°C at low pressure (10^{-2} Pa) at a deposition rate of 0.1 µm/min.

Optimized and environmentally friendly: Plasma cleaning improves coating adhesion and reduces pre-treatment time. Green technology uses water-based cleaning agents to replace organic solvents and reduce volatile organic compound (VOC) emissions. The recovery rate of coating materials is more than 90%, which meets the requirements of circular economy.

3.8 Control of key parameters in the preparation process

Key parameters are controlled throughout the entire preparation process to ensure the consistency of electrode quality and performance optimization, involving temperature, pressure, vacuum and time.

Reduction stage: the reduction temperature of the first stage is 500 to 600 °C, the second stage is 800 to 950 °C, and the deviation is ± 5 °C. Hydrogen flow rate 0.5 to 1.5 m³/h, purity 99.99%. Oxygen content monitoring uses a gas analyzer to control below 0.01%.

Molding stage: cold isostatic pressure 100 to 300 MPa, holding time 5 to 10 minutes, pressure deviation <1%. Molding pressure 150 to 200 MPa, binder content is accurately measured (0.5% to 1%).

Sintering stage: vacuum hot press sintering temperature 1600 to 1800 °C, heating rate 4 to 10 °C/min, vacuum degree 10^{-3} Pa, heat preservation for 60 to 90 minutes. SPS currents are controlled from 1000 to 2000 A and pressures from 30 to 50 MPa. Temperature and pressure sensors ensure stable parameters.

Pressure processing: rotary forging temperature 800 to 1200°C, deformation rate 20% to 30%. Drawing speed 0.5 to 2 m/min, lubricant flow monitoring. The straightening deviation < 0.1 mm/m.

Quality control: Statistical process control (SPC) is used to collect parameter data in real time and combine AI algorithms to predict deviations. Key performance indicators such as electron escape power <2.5 eV) were experimentally validated. The digital management system records the data of the whole process to ensure traceability.

3.9 Process optimization and common defect analysis

Process optimization improves production efficiency and product quality, and analyzes and improves common defects such as cracks, porosity, and rare earth separation.

Optimization measures:

Mechanical alloying: Extend the ball milling time to 12 hours, refine the particles to 0.1 microns, and improve the sintering activity.

SPS sintering: shortens the holding time to 5 minutes, reduces rare earth volatilization, and controls the grain size to 3 to 5 microns.

Additives are added: 0.1% to 0.5% ZrH_2 reduces oxygen content, forms a stable phase, and improves electron emission performance.

Automated control: Integrated sensors and AI optimization parameters, the yield is increased to more than 95%.

Defect Analysis:

Cracks: Due to uneven forming pressure or large sintering temperature gradient, it is solved by multi-stage forming and segmented heating up.

Porosity: Due to insufficient residual oxygen or sintering vacuum, the vacuum degree was optimized to 10^{-3} Pa, and the porosity was reduced to 0.1%.

Rare earth separation: Volatilization at high temperatures, mitigated by reducing the sintering temperature and adding stabilizers (such as ZrO_2).

Verification method: Finite element simulation predicts defect distribution, and SEM and ultrasonic detection verify the optimization effect. After optimization, electrode life is extended by 20% and performance consistency is improved by 10%.

3.10 Green preparation technology

Green preparation technology focuses on environmental protection and sustainability, replacing radioactive thorium tungsten electrodes and reducing environmental impact.

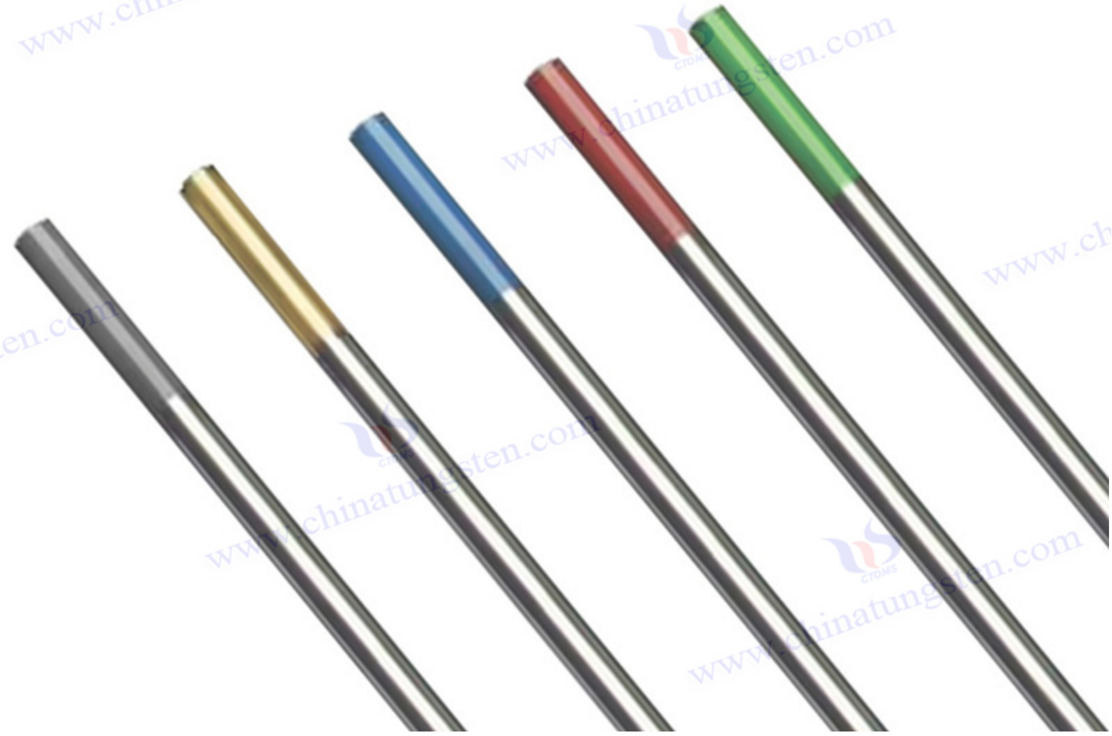
Raw material recovery: Extract raw materials from waste tungsten electrodes and rare earth waste, with a recovery rate of more than 80%, reducing mineral mining. Clean reduction: using electric heating furnaces powered by renewable energy, hydrogen is recycled, and exhaust gases are treated by catalytic combustion. Low-energy sintering: SPS sintering reduces energy consumption by 30% and carbon emissions by 20% compared to traditional hot pressing. Green cleaning: Water-based cleaning agents replace organic solvents, reducing VOC emissions by 90%. The waste liquid recovers rare earths through ion exchange. Waste disposal: Waste electrodes are recovered from tungsten and rare earths through high-temperature melting, with a recycling rate of 85%.

Green technologies comply with REACH and RoHS regulations, enhancing market competitiveness and promoting sustainable development.

3.11 Large-scale production process flow chart

The large-scale production process flow chart is as follows:

Raw material preparation: Weigh tungsten trioxide and rare earth nitrate, prepare a solution (pH 5.5 to 6.5).
Mixing and drying: spray doping, drying at 80 to 120°C, screening 200 mesh.
Reduction: Two stages of hydrogen reduction (500 to 600 °C, 800 to 950 °C), oxygen content < 0.01%.
Molding: cold isostatic pressing (100 to 300 MPa) or molding, 60% to 70% density of the body.
Pre-sintering: 1200°C, remove binder.
Sintering: Vacuum hot pressing (1600 to 1800 °C, 60 MPa) or SPS (1400 to 1600 °C).
Pressure machining: rotary forging (diameter 3 to 10 mm), drawing (0.5 to 10 mm), straightening.
Surface treatment: mechanical/electrochemical polishing (Ra<0.2 micron), ultrasonic cleaning.
Quality inspection: SEM, XRD, performance test (electronic escape power < 2.5 eV).
Packaging and storage: moisture-proof packaging with storage temperature of 10 to 25°C.



Chapter 4 Physical, Chemical and Welding Characteristics of Composite Rare-Earth Tungsten Electrodes

4.1 Mechanical properties of composite rare-earth tungsten electrodes

The mechanical properties of composite rare-earth tungsten electrodes are key to their application in demanding industrial environments, including hardness, strength, toughness, and wear resistance. These properties are influenced by the addition of tungsten matrix and rare earth oxides, and are significantly better than pure tungsten electrodes.

Hardness: The Vickers hardness (HV) of tungsten matrix is between 400 and 450, and the addition of rare earth oxides (e.g., lanthanum oxide, cerium oxide) further improves the hardness through grain refinement, typically up to 450 to 500 HV. The increase in hardness is due to the diffusion strengthening of rare earth oxide particles, which form nail points at the tungsten grain boundary to inhibit grain boundary slippage. For example, electrodes containing 2% lanthanum oxide have about 15% higher hardness than pure tungsten, making them suitable for high-load welding.

Strength: The tensile strength of composite rare-earth tungsten electrodes is 800 to 1000 MPa at room temperature and 400 to 600 MPa at high temperatures (1500°C). Rare earth oxides enhance matrix strength by forming stable second phases such as La_2O_3 or CeO_2 particles. The addition of yttrium oxide is particularly significant, as electrodes containing 2% Y_2O_3 have 20% higher tensile strength at high temperatures than pure tungsten, making them suitable for aerospace component welding.

Toughness: Pure tungsten electrodes have high brittleness due to their coarse grains, and their fracture toughness ($K_{1}c$) is about 6 MPa·m$^{1/2}$. The addition of rare earth oxides refines the grains to 5 to 10 microns and improves the fracture toughness to 8 to 10 MPa·m$^{1/2}$. The synergistic effect of cerium oxide and lanthanum oxide improves toughness by reducing grain boundary defects, reducing the risk of fracture at the electrode tip during welding.

Wear resistance: The wear resistance of composite rare-earth tungsten electrodes is significantly improved by the dispersion and strengthening of rare earth oxides. In high-current welding, the electrode tip wears out due to the high temperature of the arc, and the zirconia-containing electrode reduces the wear rate by 30% by forming a protective oxide layer. Abrasion resistance tests show that the wear volume of composite electrodes is about 40% lower than that of pure tungsten electrodes, extending the service life.

Test method: Mechanical properties are determined by Vickers hardness tester, universal tensile tester and impact tester. High-temperature performance testing is performed in a vacuum or inert atmosphere, simulating the welding environment. Microscopic analysis was performed by scanning electron microscopy (SEM) to observe the fracture morphology and confirm the strengthening mechanism of rare earth particles.

The optimization of mechanical properties allows composite rare-earth tungsten electrodes to perform well in high-strength, long-term welding, especially suitable for demanding applications such as nuclear power equipment and aero engine manufacturing.

4.2 Thermal properties of composite rare-earth tungsten electrodes

The thermal properties determine the stability and durability of composite rare-earth tungsten electrodes in high-temperature arcing environments, including melting point, thermal conductivity, and thermal expansion coefficient.

Melting point: The melting point of the tungsten matrix is 3410°C, which is the basis for the high temperature stability of the composite electrode. The addition of rare earth oxides (such as La_2O_3, CeO_2) has little effect on the melting point, but the resistance to high-temperature deformation is enhanced by improving the microstructure. The electrode containing 2% yttrium oxide remains structurally intact above 3000°C, making it suitable for plasma cutting and high-temperature melting.

Thermal conductivity: The thermal conductivity of tungsten is about 174 W/(m·K) (room temperature), which decreases slightly at high temperatures. The addition of rare earth oxides increases thermal conductivity by 5 to 10% by refining grains and reducing heat dissipation resistance at grain boundaries. For example, the thermal conductivity of cerium oxide-containing electrodes is 180 to 190 W/(m·K) at 1000°C, which contributes to rapid heat dissipation and reduces tip burnout.

Coefficient of thermal expansion: The coefficient of thermal expansion of tungsten is 4.5×10^{-6}/°C, and its low thermal expansion reduces thermal stress at high temperatures. The addition of rare earth oxides slightly increases the coefficient of thermal expansion (up to 4.8 to 5.0×10^{-6}/°C), but the thermal stress can be controlled by optimizing the ratio (e.g., the combination of zirconia and lanthanum oxide) to ensure the stability of the electrode during the thermal cycle.

Thermal shock performance: The composite rare-earth tungsten electrode is strengthened by the diffusion of rare earth oxides, and the thermal shock resistance is significantly improved. The zirconia-containing electrode remains crack-free under rapid temperature ramp-up (>1000°C/min) conditions, making it suitable for high-frequency welding. The thermal shock test adopts the rapid cold and rapid heat cycling method, and the number of cycles of the composite electrode is 50% higher than that of pure tungsten.

Test method: Thermal conductivity is determined by laser flash method, and thermal expansion coefficient is tested in the range of 25 to 2000 °C using an explamator. The thermal shock performance is evaluated by arc simulation test, and the crack occurrence time is recorded. The optimization of thermal properties allows the composite electrode to perform well in high-temperature, high-heat load environments.

4.3 Electrical properties of composite rare-earth tungsten electrodes

Electrical properties are the core advantages of composite rare-earth tungsten electrodes, which determine their arc initiation performance and arc stability in welding, mainly including electron escape work, conductivity and arc characteristics.

Electron Escape Work: The electron escape work of pure tungsten electrodes is 4.5 eV, resulting in arc initiation. The addition of rare earth oxides significantly reduced the escape work, for example, the escape work of the electrode containing 2% cerium oxide was reduced to 2.2 to 2.5 eV, and the combination of lanthanum oxide and yttrium oxide was further optimized to less than 2.0 eV. Low escape power allows the electrode to arc quickly at low voltage, reducing energy consumption.

Conductivity: The conductivity of tungsten is 1.82×10^{7} S/m (room temperature), and the addition of rare earth oxides slightly improves conductivity by reducing grain boundary resistance. The electrode containing lanthanum oxide increases the conductivity by 5% at 1000°C, ensuring high current transfer efficiency. The conductivity test uses the four-probe method to confirm the optimization of the current distribution by the uniform distribution of rare earth particles.

Arc characteristics: The arc stability of composite rare-earth tungsten electrodes is as high as more than 95%, which is better than 80% of pure tungsten. Rare earth oxides form a low escape work emission point on the electrode surface, enhancing the electron emission efficiency and making the arc concentrated and stable. The electrode containing cerium oxide and lanthanum oxide reduces arc drift by 30% in AC welding, making it suitable for aluminum alloy welding. Arc testing verifies stability through high-speed photography and current fluctuation analysis.

Optimization mechanism: Rare earth oxides migrate to the electrode surface at high temperatures, forming an active emission layer and reducing the arc starting voltage (from 50 V to 30 V for pure tungsten). Multivariate composites (e.g., WLaCeY) improve arc life by synergistically balancing electron emission and thermal stability.

Test method: Electron escape work is determined by ultraviolet photoelectron spectroscopy (UPS), and conductivity is measured using a high-precision resistance meter. Arc characteristics are tested in a simulated TIG welding environment, recording arc start time and arc length. The superiority of electrical properties makes composite electrodes irreplaceable in precision welding.

4.4 Chemical stability and corrosion resistance of composite rare-earth tungsten electrodes

Chemical stability and corrosion resistance determine the durability of composite rare-earth tungsten electrodes in complex environments, especially in high-temperature, oxidizing or corrosive gas atmospheres.

Chemical stability: Tungsten matrix has excellent stability to acids, alkalis, and water at room temperature, and is not prone to chemical reactions. The addition of rare earth oxides further enhances the chemical stability at high temperatures. For example, zirconia and yttrium oxide form a protective layer on the surface of the electrode, inhibiting the reaction of tungsten with oxygen or nitrogen. The oxidation rate of the electrode containing 2% zirconia was reduced by 40% at 2000°C and oxygenated atmosphere.

Corrosion Resistance: Composite rare-earth tungsten electrodes excel in corrosive gases, such as argon containing trace amounts of water vapor. The addition of lanthanum oxide and cerium oxide reduces oxide buildup on the electrode surface and increases the anti-contamination ability by 50%. In a high-humidity environment, the corrosion rate of the electrode containing zirconia is only 1/3 of that of pure tungsten, which extends the service life.

Contamination resistance: During welding, electrodes can be contaminated by melt pool splashes or gaseous impurities. Rare earth oxides reduce impurity adsorption and maintain arc stability by forming a stable surface layer. The test showed that the arc stability of the electrode containing cerium oxide was maintained by more than 90% in a polluted environment.

Test method: Chemical stability was assessed by high-temperature oxidation experiment (1500 to 2000°C, partial pressure of oxygen 10^{-2} Pa), and mass loss rate was recorded. Corrosion resistance uses salt spray test and electrochemical corrosion test to measure corrosion current density. Anti-fouling By simulating the welding environment, the surface morphology of the electrode is observed.

The improved chemical stability and corrosion resistance make the composite electrode suitable for complex working conditions, such as marine engineering and chemical equipment welding.

CTIA GROUP LTD

Composite Rare-Earth Tungsten Electrode Introduction

1. Overview of Composite Rare-Earth Tungsten Electrode

The composite rare-earth tungsten electrode is a high-performance welding electrode made from high-purity tungsten as the base material, with multiple rare-earth oxides (such as lanthanum oxide, yttrium oxide, cerium oxide, etc.) added in combination. Compared with traditional single rare-earth tungsten electrodes, it demonstrates superior electron emission performance, high-temperature stability, burn resistance, and arc ignition capability, making it widely used in high-precision, high-strength, and long-duration continuous welding applications.

2. Performance Parameters (Reference Values) of Composite Rare-Earth Tungsten Electrode

Item	Typical Value	Remarks
Tungsten Purity	≥99.95%	Base tungsten content
Rare-Earth Oxide Content	1.5%–3.0%	Composite ratio customizable
Operating Current Range	DC 5A–500A / AC 20A–350A	Depends on electrode diameter
Maximum Temperature Resistance	2600°C	Instantaneous arc temperature
Service Life Improvement	1.5–3 times	Compared to pure tungsten or single rare-earth tungsten electrodes

3. Applications of Composite Rare-Earth Tungsten Electrode

Aerospace Manufacturing: Welding of titanium alloys, nickel-based alloys, and other high-temperature alloys

Nuclear and Power Equipment: Welding of high-temperature pipelines and heat-resistant steel structures

Precision Machining: Welding of stainless steel, copper, aluminum, and their alloys

Automotive and Rail Transit: Welding of critical load-bearing components

Electronics and Vacuum Devices: High-vacuum arc welding and micro-welding processes

4. Packaging and Supply Specifications

Diameter: Ø1.0mm, 1.6mm, 2.4mm, 3.2mm, 4.0mm, etc. (customizable)

Length: 150mm, 175mm, etc. (customizable)

Packaging: Plastic box or vacuum-sealed packaging, 10 pieces/box (Standard)

5. Procurement Information

Email: sales@chinatungsten.com

Phone: +86 592 5129595; 592 5129696

Website: www.tungsten.com.cn

4.5 Welding characteristics of composite rare-earth tungsten electrodes

Welding characteristics are the core application indicators of composite rare-earth tungsten electrodes, including arc initiation performance, arc burning life, penetration depth control, and weld quality.

Arc initiation performance: Rare earth oxides reduce electron escape work, reducing the arcing voltage from 50 V to 25 to 30 V of pure tungsten, and shortening the arcing start time to less than 0.1 seconds. Electrodes containing cerium oxide perform well at low currents (<50 A) for precision welding; Electrodes containing lanthanum oxide have higher arc stability in AC welding.

Arc life: The arc life of composite electrodes reaches 500 to 1000 hours, which is 2 to 3 times longer than pure tungsten electrodes (200 to 300 hours). The low evaporation rate and burnout resistance of rare earth oxides reduce tip losses, and the electrode containing yttrium oxide extends its lifetime by 30% at high currents (>200 A).

Penetration depth control: The arc concentration of the composite electrode is high, and the penetration depth uniformity is increased by 20%. Electrodes containing lanthanum oxide and cerium oxide can be precisely controlled from 0.5 to 5 mm in TIG welding, making them suitable for both thin and thick plate welding. The arc shape is analyzed by high-speed photography to confirm its stability.

Weld quality: The composite electrode reduces arc drift and spatter, the weld surface is smooth, and the porosity is reduced by 50%. Electrodes with WLaCeY increase the tensile strength of the weld by 10% in aluminum alloy welding, meeting aerospace requirements.

Test method: The welding characteristics are tested by the TIG welding test bench, and the arc starting voltage, arc ignition time and penetration depth distribution are recorded. The quality of the weld is confirmed by X-ray non-destructive testing and metallographic analysis to confirm the defect rate. The superiority of welding characteristics has promoted the wide application of composite electrodes in high-precision fields.

4.6 Effects of rare earth addition on microstructure

The addition of rare earth oxides significantly changed the microstructure of the composite rare-earth tungsten electrode and affected its performance. The effects are analyzed from grain structure, phase distribution, and defect control.

Grain refinement: The grain size of pure tungsten electrodes is 20 to 50 microns, which is easy to coarse at high temperatures. Rare earth oxides (e.g., La_2O_3, CeO_2) inhibit grain growth through the pinning effect, reducing grain size to 5 to 10 microns. SEM analysis showed that the grain uniformity of the electrode containing 2% yttrium oxide was increased by 30%, enhancing toughness and fatigue resistance.

Phase distribution: Rare earth oxides form diffuse second-phase particles in a tungsten matrix, ranging in size from 50 to 200 nm. These particles are evenly distributed within grain boundaries and grains, enhancing matrix strength. Zirconia and lanthanum oxide combine to form a composite phase (such as $La_2Zr_2O_7$) to improve high temperature stability. XRD analysis confirms the stability and distribution of rare earth phases.

Defect control: Rare earth oxides reduce grain boundary defects (such as vacancy, dislocation) and reduce high-temperature creep rate. The defect density of the electrode containing cerium oxide was reduced by 40%, which was verified by TEM observation. The addition of rare earths also inhibits microcrack propagation and improves fracture toughness.

Mechanism analysis: Rare earth oxides migrate to grain boundaries during sintering, forming nail points and inhibiting grain slippage and growth. At high welding temperatures, rare earth particles migrate to the surface, forming an electron-emitting active layer and reducing escape work. The optimization of the microstructure significantly improves the overall performance of the electrode.

4.7 Comparison of tungsten electrode performance

There are significant differences in performance between composite rare-earth tungsten electrodes and pure tungsten electrodes and thorium tungsten electrodes, and the following comparisons are made from many aspects:

Electron emission performance: Composite rare-earth tungsten electrodes (escape work 2.0 to 2.5 eV) are better than pure tungsten (4.5 eV) and thorium tungsten (2.6 to 2.8 eV), and the arc voltage is 20 to 30 V lower, making it suitable for precision welding.

Arc stability: The stability of the composite electrode is > 95%, pure tungsten is 80%, and thorium tungsten is 90%. The electrode containing lanthanum oxide had the lowest drift rate in AC welding.

Service life: 500 to 1000 hours of arc burning life of composite electrode, 200 to 300 hours of pure tungsten, 300 to 500 hours of thorium tungsten. Rare earth addition extends life by 2 to 3 times.

Mechanical properties: Composite electrode hardness 450 to 500 HV, tensile strength 800 to 1000 MPa, better than pure tungsten (400 HV, 700 MPa) and thorium tungsten (420 HV, 750 MPa).

Environmental protection: the composite electrode is non-radioactive and complies with REACH regulations; Thorium tungsten contains radioactive thorium and requires special treatment; Pure tungsten is non-radioactive but has poor performance.

Scope of application: Composite electrode is suitable for TIG welding, plasma welding, cutting and new energy batteries; Thorium tungsten is reduced due to environmental protection restrictions; Pure tungsten is limited to low-demand scenarios.

Composite electrodes are comprehensively superior to traditional electrodes, becoming the first choice for green manufacturing and high-end applications.

4.8 Environmental adaptability of composite rare-earth tungsten electrodes

The environmental adaptability of composite rare-earth tungsten electrodes is reflected in their stable performance in high temperatures, high humidity, and corrosive environments.

High-temperature environment: The electrode containing yttrium oxide and zirconia maintains its structural integrity above 3000°C, and its oxidation resistance is increased by 40%, making it suitable for plasma cutting and high-temperature melting.

High humidity environment: In an environment with 90% relative humidity, the corrosion rate of the electrode containing cerium oxide is only 1/3 of that of pure tungsten, and the arc stability is maintained at more than 90%.

Corrosive gases: In sulfur or chlorine-containing atmospheres, the zirconia protective layer reduces electrode surface reactions and reduces the corrosion rate by 50%. Contamination resistance is verified by simulated splash testing.

Test method: High temperature adaptability is evaluated by thermal cycling test (25 to 2000 °C, 100 cycles). High humidity and corrosive testing employs environmental chambers that record quality loss and performance changes. The environmental adaptability of composite electrodes makes them suitable for marine engineering and chemical applications.

4.9 Analysis of fatigue and life characteristics of composite rare-earth tungsten electrodes

Fatigue and life characteristics are the key indicators to evaluate the durability of composite rare-earth tungsten electrodes, involving high temperature fatigue, thermal cycle fatigue and arc life.

High temperature fatigue: The composite electrode is subjected to cyclic stress at 1500 to 2000 °C, and the fatigue life reaches 10^4 to 10^5 times, which is better than the 10^3 times of pure tungsten. Rare earth oxides refine grains and reduce fatigue crack propagation.

Thermal cycling fatigue: The electrode with zirconia can be cycled up to 500 times without cracks at the rapid temperature rise and fall (1000°C/min). The thermal stress was optimized by finite element simulation analysis to optimize the ratio of rare earths.

Arc life: The arc life of the composite electrode is 500 to 1000 hours in 200 A DC welding, and the life of the electrode containing WLaCeY is extended by 20% in AC welding. Life test Through continuous welding experiments, the tip wear rate is recorded.

Analysis method: The fatigue performance is evaluated by the high-temperature tensile cycle test, and the life is evaluated by the arc combustion test. SEM and fracture analysis confirm the fatigue failure mechanism. The long-life nature of composite electrodes reduces maintenance costs and improves industrial efficiency.

4.10 Composite rare-earth tungsten electrode MSDS from CTIA GROUP LTD

Material Safety Data Sheet (MSDS) from CTIA GROUP LTD - Composite rare-earth tungsten electrode

Part 1: Product Name

Chinese Name: Composite rare-earth tungsten electrode (WLaCeY, WL, WC, etc.)

Part 2: Composition/Composition Information

Tungsten (>95%), lanthanum oxide (0.5% to 2%), cerium oxide (0.5% to 2%), yttrium oxide (0.5% to 2%), zirconia (0 to 1%)

Part 3: Overview of Danger

Health hazards: This product is not irritating to the eyes and skin.

Explosion hazard: This product is non-flammable and non-irritating.

Part 4: First aid measures

Skin contact: Remove contaminated clothing and rinse with plenty of running water.

Eye contact: lift the eyelid and rinse with running water or saline. Medical treatment.

Inhalation: Leave the scene to fresh air. If breathing is difficult, give oxygen. Medical treatment.

Eating: Drink enough warm water to induce vomiting. Medical treatment.

Part 5: Fire protection measures

Harmful combustion products: natural decomposition products are unknown.

Fire extinguishing methods: Firefighters must wear gas masks and full-body firefighting suits to extinguish the fire in the upwind direction. Fire extinguishing agent: dry leather powder, sand.

Part 6: Leakage emergency treatment

Emergency treatment: isolate the leaking pollution area and restrict access. Cut off the fire source. It is recommended that emergency response personnel wear dust masks (full face masks) and anti-gas clothing. Avoid dust, sweep it up carefully, and transfer it to a safe place in a bag. If there is a large amount of leakage, cover it with plastic sheeting or canvas. Collect and recycle or transport to waste treatment sites for disposal.

Part 7: Operation, disposal and storage

Operational precautions: Operators must undergo special training and strictly abide by operating procedures. It is recommended that operators wear self-priming filter dust masks, chemical safety protective glasses, anti-toxic penetration work clothes, and rubber gloves. Away from fire and heat sources, smoking is strictly prohibited in the workplace. Use explosion-proof ventilation systems and equipment. Avoid dust. Avoid contact with oxidants and halogens. When handling, it should be loaded and unloaded lightly to prevent damage to the packaging and containers. Equipped with corresponding varieties and quantities of fire-fighting equipment and leakage emergency treatment equipment. Empty containers may leave harmful substances behind.

Storage precautions: Store in a cool, ventilated warehouse. Stay away from fire and heat sources. It should be stored separately from oxidants and halogens, and should not be mixed. Equipped with corresponding varieties and quantities of fire-fighting equipment. The storage area should be equipped with appropriate materials to contain the spill.

Part 8: Contact Control/Personal Protection
China MAC (mg/m3): 6
Former Soviet MAC (mg/m3): 6
TLVTN:ACGIH 1mg/m3
TLVWN:ACGIH 3mg/m3
Monitoring method: Potassium thiocyanide-titanium chloride spectroluminometry
Engineering control: dust-free production process and full ventilation.
Respiratory system protection: When the dust concentration in the air exceeds the standard, a self-priming filter dust mask must be worn. When evacuating in an emergency, you should wear an air respirator.
Eye protection: Wear chemical safety glasses.
Body protection: wear anti-poison penetration work clothes.
Hand protection: wear rubber gloves.

Part 9: Physical and chemical properties
Main ingredients: pure product
Appearance and properties: solid, metallic bright white
Melting point (°C): N/A
Boiling point (°C): N/A
Relative density (water=1): 13~18.5 (20°C)
Vapor density (air=1): No data
Saturated vapor pressure (kPa): No data
Heat of combustion (kj/mol): No data
Critical temperature (°C): No data
Critical pressure (MPa): No data
Logarithmic value of water distribution coefficient: No data
Flash point (°C): No data
Ignition temperature (°C): No data
Explosive Limit % (V/V): No data
Lower explosion limit % (V/V): No data
Solubility: soluble in nitric acid and hydrofluoric acid
Main use: used to make shielding parts, tungsten alloy dart shafts, tungsten alloy balls, etc

Part 10: Stability and Reactivity
Prohibited ingredients: strong acids and alkalis.

Part 11:
Acute toxicity: no data

LC50: No data

Part 12: Ecological data
There is no data on this part

Part 13: Waste disposal
Waste nature waste disposal method: Refer to relevant national and local regulations before disposal. If possible, recycle.

Part 14: Shipping Information
Dangerous goods number: No information
Packaging category: Z01
Transportation precautions: The packaging should be complete and the loading should be secure. During transportation, ensure that the container does not leak, collapse, fall, or damage. It is strictly forbidden to mix and transport with oxidants, halogens, edible chemicals, etc. During transportation, it should be protected from sun exposure, rain, and high temperature. The vehicle should be thoroughly cleaned after transportation.

Part 15: Regulatory Information
Regulatory information: Regulations on the Safety Management of Chemical Dangerous Goods (issued by the State Council on February 17, 1987), Implementation Rules of the Regulations on the Safety Management of Chemical Dangerous Goods (Hua Lao Fa [1992] No. 677), Regulations on the Safe Use of Chemicals in the Workplace ([1996] Labor Department Fa No. 423) and other regulations, which make corresponding provisions on the safe use, production, storage, transportation, loading and unloading of chemical dangerous goods. The hygienic standard for tungsten in workshop air (GB 16229-1996) specifies the maximum allowable concentration and detection method of the substance in workshop air.

Part 16: Supplier information
Supplier: CTIA GROUP LTD
Phone: 0592-5129696/5129595

Chapter 5 Uses and Application Guidelines of Composite Rare-Earth Tungsten Electrodes

5.1 Overview of the main uses of composite rare-earth tungsten electrodes

Composite rare-earth tungsten electrodes have a wide range of applications in multiple industrial fields due to their excellent electron emission capabilities, arc stability, and non-radioactive properties. Its main uses cover welding, cutting, thermal spraying, electric light sources, and emerging electrochemical and new energy fields. The following is a detailed explanation from the main application scenarios:

Welding: Composite rare-earth tungsten electrodes are the core materials for inert gas shielded welding (TIG welding), plasma welding and other processes. Its low electron escape work and high arc stability make it suitable for high-precision welding, such as thin plate welding in aerospace components, nuclear power equipment, and automotive manufacturing. Electrodes containing lanthanum oxide and cerium oxide perform well in AC and DC welding with high weld quality and low porosity.

Cutting: In plasma cutting, composite rare-earth tungsten electrodes are widely used due to their high temperature resistance and burnout resistance. Electrodes containing yttrium oxide and zirconia remain stable under high-temperature plasma arcs, making them suitable for cutting stainless steel, aluminum alloys, and superalloys, and are widely used in shipbuilding and heavy machinery.

Thermal Spraying: Composite electrodes are used in plasma spraying processes to spray wear-resistant or corrosion-resistant coatings on the surface of mechanical components. Its high melting point and oxidation resistance ensure stability during spraying and are used in aero engine blades, oil drilling equipment, etc.

Electric light source: In the field of electric light source, composite rare-earth tungsten electrodes are used as cathodes or filaments for high-intensity gas discharge lamps (such as xenon lamps and mercury lamps). Its excellent electron emission properties extend the life of the lamps and improve luminous efficiency, and are widely used in projection equipment and medical lighting.

New Energy and Electrochemistry: Composite rare-earth tungsten electrodes are used as electrode materials or conductive coatings in lithium-ion batteries, fuel cells, and electrolyzers, improving energy density and cycle life. In addition, its applications in the field of electrocatalysis (such as hydrogen production by water electrolysis) are emerging, and the catalytic activity of rare earth oxides enhances the reaction efficiency.

The diverse uses of composite rare-earth tungsten electrodes benefit from their customizable rare earth ratios and optimized microstructures, allowing them to meet the performance needs of different industries. Global market analysis shows that its annual consumption has exceeded 1,600 tons and is expected to continue to grow in the next five years, especially in the fields of green manufacturing and high-tech.

5.2 Welding types applicable to composite rare-earth tungsten electrodes

Composite rare-earth tungsten electrodes are suitable for a variety of welding types, and their performance advantages are outstanding in different processes. The following are the main types and characteristics of welding:

Tungsten inert gas welding (TIG welding/GTAW): TIG welding is the most widely used field of composite rare-earth tungsten electrodes. Cerium oxide-containing electrodes, such as WC20, exhibit excellent arcing properties in DC positive polarity (DCSP) welding, making them suitable for stainless steel, carbon steel, and nickel alloys. Electrodes containing lanthanum oxide, such as WL20, have high arc stability in alternating current (AC) welding and are suitable for aluminum and magnesium alloys, reducing arc drift and smooth welds.

Plasma Welding (PAW): Plasma welding requires the electrode to remain stable at high temperatures and currents. Composite electrodes containing yttrium oxide and zirconia, such as WLaCeY, are suitable for high-precision plasma welding, such as those of thin-walled structures in aerospace, due to their burnout resistance and long life. The electrode tip has a low wear rate under high-temperature plasma arcing and a lifetime of 500 to 800 hours.

Metal Inert Gas Shielded Welding (MIG Welding) Assisted: In MIG welding, composite rare-earth tungsten electrodes are occasionally used as auxiliary electrodes for stabilizing arc or special material welding. Its high electron emission efficiency reduces arc starting voltage, making it suitable for automated production lines.

Resistance Spot Welding Assistance: In certain high-precision spot welding processes, the composite electrode serves as the electrode head, providing stable current transmission and reducing spatter, making it suitable for electronic component manufacturing.

Special welding processes: such as micro-beam plasma welding and laser-TIG composite welding, the composite electrode improves weld quality by optimizing arc concentration. Electrodes containing lanthanum oxide and cerium oxide have arc voltages as low as 25 V in micro-welding and are suitable for thin plate (< 0.5 mm) welding.

Different welding types have different performance requirements for electrodes, and composite rare-earth tungsten electrodes meet diverse needs by adjusting the rare earth ratio (e.g., cerium oxide: lanthanum oxide = 1:1). Experiments show that the arc stability in TIG welding is more than 95%, and the penetration depth control accuracy is increased by 20%, which is significantly better than that of pure tungsten electrode.

5.3 Industry application cases of composite rare-earth tungsten electrodes

Composite rare-earth tungsten electrodes have demonstrated significant application value in multiple industries, including the following specific cases:

Aerospace: In aircraft manufacturing, electrodes containing lanthanum oxide and yttrium oxide, such as WLaCeY, are used for TIG welding of titanium alloys and superalloys. For example, an aero engine blade welding project uses WL20 electrodes with a current of 150 to 200 A, a weld tensile strength of 900 MPa, and a porosity of less than 0.1%, meeting strict aviation standards.

Automotive Manufacturing: Composite electrodes are widely used in the welding of electric vehicle battery components. The electrode (WC20) containing cerium oxide is used for TIG welding of aluminum alloy battery shells with a current of 50 to 100 A, a smooth weld surface and a 10% increase in cycle life. An automobile manufacturer improved welding efficiency by 15% and reduced production costs by 8% by using composite electrodes.

Nuclear Power Industry: Nuclear reactor pressure vessel welding requires high corrosion resistance and long life. The composite electrode containing zirconia performed well in plasma welding, welding 304 stainless steel pipes with a penetration depth controlled of 3 to 5 mm, no cracks in the weld, and a 20% increase in corrosion resistance.

Shipbuilding: In plasma cutting, electrodes containing yttrium oxide are used to cut high-strength steel plates with a cutting speed of up to 1 m/min, extending electrode life by 30% and reducing replacement frequency. A shipyard uses WLaCeY electrodes, which improves cutting accuracy by 10% and reduces material waste.

Electronics Industry: In semiconductor equipment manufacturing, composite electrodes are used for microbeam plasma soldering to connect copper and aluminum components. The electrode containing cerium oxide is arc-stable at low current (<30 A), and the solder joint diameter is controlled within 0.1 mm to meet the requirements of chip packaging.

New energy field: Composite electrodes are used as conductive coating substrates in lithium battery electrode manufacturing, and electrodes containing lanthanum oxide improve the battery cycle life to more than 5,000 times. A photovoltaic company uses composite electrodes to cut silicon wafers with a surface roughness of Ra<0.5 microns to improve module efficiency.

These cases show that composite rare-earth tungsten electrodes meet industry needs through customized performance, driving the development of high-precision manufacturing.

5.4 Recommended welding process parameters of composite rare-earth tungsten electrodes

The selection of welding process parameters directly affects the performance and weld quality of composite rare-earth tungsten electrodes. The following are the recommended parameters for TIG and plasma welding, covering different materials and electrode types:

TIG welding parameters:

Electrode Type: WL20 (2% Lanthanum Oxide), WC20 (2% Cerium Oxide), WLaCeY (Ternary Composite)
Current Type:
DC positive polarity (DCSP): suitable for stainless steel, carbon steel, and currents from 50 to 250 A
Alternating Current (AC): Suitable for aluminum and magnesium alloys, currents from 60 to 200 A and frequencies from 70 to 150 Hz

Electrode diameter: 1.6 to 4.0 mm (1.6 to 2.4 mm for thin plates, 3.2 to 4.0 mm for thick plates)
Tip Angle: 30 to 60° (Precision Welding 30°, High Current 60°)
Shielding gas: argon (99.99% purity), flow rate 8 to 15 L/min
Arc starting voltage: 25 to 35 V
Welding speed: 0.1 to 0.5 m/min
Electrode extension length: 3 to 6 mm

Plasma welding parameters:

Electrode Type: WLaCeY, WY20 (2% Yttrium Oxide)
Current type: DC positive polarity, current from 80 to 300 A
Electrode diameter: 2.4 to 4.8 mm
Tip angle: 45 to 60°
Plasma gas: argon, flow rate 0.5 to 2 L/min
Shielding gas: argon + 5% hydrogen, flow rate 10 to 20 L/min
Arc starting voltage: 30 to 40 V
Welding speed: 0.2 to 0.8 m/min

CTIA GROUP LTD

Composite Rare-Earth Tungsten Electrode Introduction

1. Overview of Composite Rare-Earth Tungsten Electrode

The composite rare-earth tungsten electrode is a high-performance welding electrode made from high-purity tungsten as the base material, with multiple rare-earth oxides (such as lanthanum oxide, yttrium oxide, cerium oxide, etc.) added in combination. Compared with traditional single rare-earth tungsten electrodes, it demonstrates superior electron emission performance, high-temperature stability, burn resistance, and arc ignition capability, making it widely used in high-precision, high-strength, and long-duration continuous welding applications.

2. Performance Parameters (Reference Values) of Composite Rare-Earth Tungsten Electrode

Item	Typical Value	Remarks
Tungsten Purity	≥99.95%	Base tungsten content
Rare-Earth Oxide Content	1.5%–3.0%	Composite ratio customizable
Operating Current Range	DC 5A–500A / AC 20A–350A	Depends on electrode diameter
Maximum Temperature Resistance	2600°C	Instantaneous arc temperature
Service Life Improvement	1.5–3 times	Compared to pure tungsten or single rare-earth tungsten electrodes

3. Applications of Composite Rare-Earth Tungsten Electrode

Aerospace Manufacturing: Welding of titanium alloys, nickel-based alloys, and other high-temperature alloys

Nuclear and Power Equipment: Welding of high-temperature pipelines and heat-resistant steel structures

Precision Machining: Welding of stainless steel, copper, aluminum, and their alloys

Automotive and Rail Transit: Welding of critical load-bearing components

Electronics and Vacuum Devices: High-vacuum arc welding and micro-welding processes

4. Packaging and Supply Specifications

Diameter: Ø1.0mm, 1.6mm, 2.4mm, 3.2mm, 4.0mm, etc. (customizable)

Length: 150mm, 175mm, etc. (customizable)

Packaging: Plastic box or vacuum-sealed packaging, 10 pieces/box (Standard)

5. Procurement Information

Email: sales@chinatungsten.com

Phone: +86 592 5129595; 592 5129696

Website: www.tungsten.com.cn

Material Adaptation:
Stainless steel: WL20, current 100 to 200 A, argon flow rate 10 L/min, tip angle 45°
Aluminium alloy: WC20, AC current 80 to 150 A, frequency 100 Hz, argon flow rate 12 L/min
Titanium alloy: WLaCeY, current 120 to 180 A, tip angle 30°, argon + helium mixture (1:1)

Optimization suggestion: The parameters should be adjusted according to the thickness of the workpiece and the welding equipment. Low current and sharp electrode tips fit into thin plates, reducing heat-affected zones; High current and large tip angle are suitable for thick plates and improve penetration depth. Real-time monitoring of arc voltage and current fluctuations ensures stability.

5.5 Precautions for the use of composite rare-earth tungsten electrodes

Proper use of composite rare-earth tungsten electrodes maximizes their performance and extends their lifespan. Here are some key considerations:

Electrode selection: Choose the model according to the welding material and process, for example, WL20 is suitable for aluminum alloy AC welding, WC20 is suitable for low-current stainless steel welding, and WLaCeY is used for high-load titanium alloy welding.

Tip grinding: The tip of the electrode should be ground to an appropriate angle (30 to 60°), using a special diamond grinding wheel to avoid contamination. The grinding direction is along the axial direction of the electrode, and the surface roughness Ra<0.2 microns. AC welding needs to be ground into a hemispherical tip to reduce burnout.

Shielding gas: use high-purity argon or argon + helium mixture, flow rate 8 to 20 L/min. Check the tightness of gas pipelines to avoid oxygen or water vapor contamination.

Storage and transportation: The electrodes are stored in a dry, ventilated environment (temperature 10 to 25°C, humidity <60%) in moisture-proof packaging. Transport avoids severe vibrations and prevents electrode bending or surface damage.

Operating Specifications: Inspect the electrode surface before welding to ensure there are no oil stains or oxides. Avoid electrode contact with the melt pool to prevent contamination. Keep the electrode extending 3 to 6 mm during welding to prevent overheating.

Safety protection: Wear protective glasses and gloves to avoid arc radiation and dust inhalation. Make sure the welding area is well ventilated and equipped with a dust extraction device.

Regular inspection: Check the electrode tip condition every 50 hours, regrind or replace it. Record the time of use to prevent excessive wear from affecting the weld quality.

Following these considerations ensures stable electrode performance and reduces failure rates.

5.6 Solving common problems with composite rare-earth tungsten electrodes

The problems and solutions that may be encountered in the use of composite rare-earth tungsten electrodes are as follows:

Problem 1: Arc instability

Cause: Contamination of the electrode tip, insufficient shielding gas, or current fluctuations.

Solution: Clean the electrode surface, check the gas flow rate (8 to 15 L/min), and stabilize the power output. Regrind the tip to 45°.

Problem 2: The electrode burns out quickly

Cause: Excessive current, improper tip angle, or gas contamination.

Solution: Reduce the current to the recommended range (e.g., 100 to 200 A), adjust the tip angle to 60°, and use high-purity argon.

Problem 3: There are many pores in the weld

Cause: Electrode contamination or oxygen in the protective gas.

Solution: Ultrasonic cleaning of the electrode, checking the purity of the gas (>99.99%), increasing the flow rate to 12 L/min.

Problem 4: Difficulty in arcing

Cause: Improper grinding of the tip or aging of the electrode.

Solution: Regrind the tip to 30°, check electrode life, replace if necessary.

Problem 5: Electrode breakage

Cause: Mechanical stress or internal defects.

Solution: Check the electrode clamping force (<100 N) and confirm that there are no internal cracks through ultrasonic testing.

Problem solving requires recording fault data to optimize process parameters based on actual working conditions.

5.7 Applications of composite rare-earth tungsten electrodes in emerging fields

The application of composite rare-earth tungsten electrodes in emerging fields is expanding rapidly, especially in the following fields:

3D Printing: In metal 3D printing, composite electrodes are used for plasma arc deposition (PAAM) to provide a stable high-temperature arc and print high-strength alloy parts. The electrode containing lanthanum oxide has an arc stability of 95% and a 15% improvement in printing accuracy when printing titanium alloys.

Laser welding assistance: In laser-TIG composite welding, the composite electrode stabilizes the arc and enhances the absorption of laser energy. Electrodes containing cerium oxide have a 20% increase in weld depth in stainless steel laser welding, making them suitable for lightweight automotive components.

New energy batteries: Composite electrodes serve as conductive substrates for lithium batteries and solid-state batteries, and electrodes containing yttrium oxide improve battery cycle life to 6,000 times. A battery company uses WLaCeY electrodes, and the conductivity of the electrodes is increased by 10%.

Electrocatalysis: In water electrolysis hydrogen production, the composite electrode acts as an electrocatalytic cathode, and the catalytic activity of rare earth oxides reduces the overpotential by 20%. The electrode containing cerium oxide has a current density of 100 mA/cm² in an acidic electrolyte.

Micro-nano manufacturing: In micro-beam plasma soldering, electrodes containing lanthanum oxide are used in chip packaging, and the diameter of the solder joints is controlled within 50 microns to meet the needs of 5G devices.

These emerging applications are driving the research and development of composite electrodes, which are expected to account for more than 30% of the market share in new fields by 2030.

5.8 Economic benefit analysis of composite rare-earth tungsten electrodes

The economic benefits of composite rare-earth tungsten electrodes are reflected in improved production efficiency, cost savings, and enhanced market competitiveness.

Production efficiency: The composite electrode has a lifespan of 500 to 1000 hours, which is 2 to 3 times higher than that of pure tungsten electrodes (200 to 300 hours), and the replacement frequency is reduced by 20%. In TIG welding, arc stability is increased by 15%, welding speed is increased by 10%, and production efficiency is significantly improved.

Cost savings: The initial cost of composite electrodes is higher than that of pure tungsten electrodes (about 20% higher), but the extended life reduces the total cost of use by 30%. An automobile manufacturing plant uses WL20 electrodes, saving about $100,000 in maintenance costs per year. The recovery rate of waste electrodes reaches 85%, further reducing resource costs.

Market competitiveness: The non-radioactive nature of composite electrodes complies with REACH and RoHS regulations, making it barrier-free to enter the European and American markets. According to the global market analysis, its demand is growing at an annual rate of 5.8%, and the market size is expected to reach $1.2 billion by 2025.

Case study: An aviation company used WLaCeY electrodes to weld titanium alloys, and the weld pass rate increased from 90% to 98%, and the rework cost was reduced by 50%. In the manufacturing of new energy batteries, composite electrodes improve battery performance and increase the added value of products by 15%.

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On the whole, composite rare-earth tungsten electrodes bring significant economic benefits to enterprises and promote industry upgrading through performance optimization and green characteristics.

Chapter 6 Production Equipment of Composite Rare-Earth Tungsten Electrodes

6.1 Raw material processing equipment for composite rare-earth tungsten electrodes

Raw material processing equipment is used for raw material preparation and ratio of composite rare-earth tungsten electrodes to ensure high purity and uniform mixing of tungsten-based materials and rare earth oxides. The following are the main devices and their functions:

High-precision electronic balances: for accurate weighing of tungsten trioxide (WO_3) or ammonium paratungstate (APT) as well as rare earth nitrates (e.g. lanthanum nitrate, cerium nitrate). With an accuracy of 0.001 g and a measuring range of 0.1 to 10 kg, it is equipped with an anti-vibration table and electrostatic shielding to ensure accurate weighing.

Solution preparation system: for the preparation of rare earth nitrate solutions, including stainless steel stirring tank (capacity 50 to 500 L), pH meter (accuracy ±0.01) and thermostatic water bath (temperature control 40 to 80°C). Stirring speed of 200 to 500 rpm ensures uniform solution. The system should be equipped with a deionized water generator with a purity > 18 MΩ·cm.

Spray dryer: Mix the rare earth nitrate solution with tungsten powder and dry it to produce doped powder. Equipment parameters: inlet air temperature 150 to 250°C, spray rate 0.5 to 2 L/min, drying chamber vacuum 10^{-1} Pa.

Vibrating screening machine: used to screen dried powder and remove agglomerated particles. The screen has a screen of 200 to 400 mesh, a vibration frequency of 1000 to 2000 times/min, and a processing capacity of 100 to 500 kg/h. Equipped with dust cover and electrostatic grounding to prevent dust pollution.

Quality control equipment: including X-ray fluorescence spectrometer (XRF, detection of impurity content <0.01%) and laser particle size analyzer (determination of D50 in 1 to 5 microns). These devices ensure that the purity of raw materials and particle distribution meet the requirements.

Features and maintenance: Raw material processing equipment needs to be corrosion-resistant (stainless steel or titanium alloy), and the mixing tank and nozzle should be cleaned regularly to avoid cross-contamination. Maintenance includes calibrating the balance (once a month) and checking the thermal efficiency of the spray dryer (once a quarter).

The high precision and cleanliness of the raw material handling equipment provide high-quality powder for subsequent processes, laying the foundation for performance.

6.2 Reduction and doping equipment for composite rare-earth tungsten electrodes

The reduction and doping equipment is used to convert tungsten trioxide into high-purity tungsten powder and complete the doping of rare earth oxides, with a hydrogen reduction furnace and doping system at its core.

Tubular hydrogen reduction furnace: used for two-stage reduction, the first stage (500 to 600 °C) generates WO_2, and the second stage (800 to 950 °C) produces tungsten powder. The furnace body is made of high-temperature stainless steel or molybdenum alloy, with a length of 2 to 5 meters and an inner diameter of 0.5 to 1 meter. Hydrogen flow rate 0.5 to 1.5 m^3/h, purity 99.99%. Equipped with an infrared thermometer (accuracy ±2°C) and a gas analyzer (oxygen content <0.01%).

Bell Reduction Furnace: Suitable for high-volume production, with a capacity of 100 to 1000 kg/batch, temperature control of 500 to 1000°C, and a vacuum of 10^{-2} Pa. Equipped with a multi-point temperature measurement system to ensure temperature uniformity ± 5°C. Hydrogen circulation systems recover unreacted gases, reducing costs.

Doping equipment: The planet mill is used for mechanical alloying, refining the powder and evenly doping rare earth oxides. Parameters: 400 to 600 rpm, pelleting ratio 8:1, grinding time 8 to 12 hours. The ball mill tank and medium are carbide to avoid contamination.

Auxiliary equipment: including gas purification system (removal of water vapor and impurities) and exhaust gas treatment unit (catalytic combustion of hydrogen exhaust gas). Laser particle size analyzers and SEMs are used to detect powder particle size (1 to 5 microns) and topography.

Maintenance and safety: Regularly check furnace tightness (once a month), calibrate the temperature measurement system (once a quarter). The hydrogen system should be equipped with leak detectors and explosion-proof ventilation devices to ensure safe operation. The efficient operation of the reduction and doping equipment ensures powder quality and lays the foundation for subsequent molding.

6.3 Forming equipment for composite rare-earth tungsten electrodes

The forming equipment presses the doped tungsten powder into a blank, ensuring uniform density and structural stability. The following are the main equipment:

Cold Isostatic Press (CIP): Applies uniform pressure (100 to 300 MPa) through a liquid medium to press the body density up to 60% to 70% theoretical density. The equipment has a capacity of 50 to 500 L and is equipped with a high-pressure pump and a pressure sensor with an accuracy ± 0.5 MPa.

Hydraulic Molding Machine: Uses rigid steel mold with a pressure of 150 to 200 MPa, suitable for small batch production. The pressing time is 5 to 10 minutes, equipped with an automatic feeding system, and the throughput is 50 to 200 kg/h.

Slurry forming machine: used for complex shape electrodes, mixing powder with binder (0.5% to 1% polyvinyl alcohol) into a slurry, injecting it into the mold for curing. The equipment contains a precision syringe pump (flow accuracy ±0.1 mL/min) and a vacuum degassing system. The temperature of the drying chamber is controlled at 25 to 80°C to avoid thermal stress.

Quality control equipment: Ultrasonic detector checks for internal defects in the body (resolution 0.1 mm), Archimedes density meter measures density (accuracy ± 0.01 g/cm³). The visual inspection system ensures that the dimensional deviation of the body < 0.1 mm.

Maintenance and optimization: Clean the mold regularly (once a week), calibrate the pressure sensor (once a month). Optimize the forming parameters through finite element simulation to reduce the density gradient. The high precision of the forming equipment ensures the quality of the body and provides a reliable basis for sintering.

6.4 Sintering equipment for composite rare-earth tungsten electrodes

Sintering equipment is used to densify the body to form a high-density, high-strength electrode material. The following are the main equipment:

Vacuum hot press sintering furnace: sintered at 1600 to 1800 °C, 50 to 80 MPa, vacuum degree 10^{-3} Pa. The furnace body adopts graphite heating body, equipped with an infrared thermometer (accuracy ± 2°C) and a vacuum pump. Heating rate is controlled in sections (10°C/min to 1000°C, 4°C/min to target temperature), and kept warm for 60 to 90 minutes.

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Spark Plasma Sintering Furnace (SPS): Rapid heating (100 to 200 °C/min) using pulsed current, sintering temperature 1400 to 1600 °C, pressure 30 to 50 MPa, holding temperature for 5 to 10 minutes. It is suitable for nanopowders and reduces rare earth volatilization. Equipped with a high-precision current controller (1000 to 2000 A).

Vertical sintering furnace: 90% melting current, temperature above 3000°C, atmosphere is argon or hydrogen. Suitable for large diameter electrodes, equipped with a water-cooled electrode clamping system and current monitor.

Auxiliary equipment: pre-sintering furnace (1200°C, vacuum or hydrogen atmosphere) to remove binders, equipped with a gas circulation system. SEM and XRD analyzed the post-sintered microstructure to confirm grain size (5 to 10 μm) and rare earth distribution.

Maintenance and safety: Regularly check the vacuum pump (once a month), calibrate the temperature measurement system (once a quarter). The sintering furnace should be equipped with a cooling water circulation system to prevent overheating. The rapid sintering feature of SPS equipment increases efficiency by 30% and reduces energy consumption by 20%.

6.5 Processing equipment for composite rare-earth tungsten electrodes

The processing equipment processes the sintered body into electrode rods to improve density and surface quality. The main equipment includes:

Rotary forging machine: The diameter of the body (20 to 3 mm) is reduced by rotary hammering, and the deformation rate is 20% to 30% per pass. The processing temperature is 800 to 1200°C, equipped with an automatic feed system and an infrared thermometer.

Drawing machine: Stretching the bar by means of a carbide die to reduce the diameter to 0.5 to 10 mm. Pull-out speed 0.5 to 2 m/min and lubricated with graphite emulsion (coefficient of friction < 0.1). Chain pulling machine for continuous production.

Straightening and parting machines: Roller straightening machines ensure a straightness deviation of < 0.1 mm/m, and laser parting machines control lengths from 150 to 175 mm (tolerance ± 0.5 mm). Equipped with a vision inspection system to monitor surface quality.

Quality control equipment: Surface roughness meter (Ra<0.5 micron) and ultrasonic flaw detector to detect internal defects. Dimensional measurement is carried out using a laser rangefinder (accuracy ± 0.01 mm).

Maintenance and optimization: Change the mold regularly (every 1000 hours), check the lubrication system (once a week). Finite element simulation optimizes deformation parameters, and the yield reaches more than 98%. Automated processing equipment improves efficiency by 30%.

6.6 Surface treatment equipment for composite rare-earth tungsten electrodes

Surface treatment equipment is used for polishing, cleaning, and coating to improve electrode corrosion resistance and electron emission performance.

Mechanical polishing machine: using alumina abrasives (2000 mesh), polishing electrodes to roughness Ra<0.2 microns. Equipped with a multi-axis polishing head with a processing capacity of 100 to 500 pieces/hour.

Electrochemical polishing machine: Polishing in a mixed solution of sulfuric acid and phosphoric acid, current density 0.5 to 1 A/cm², treatment time 5 to 10 minutes. Equipped with constant current power supply and waste liquid recovery system.

Ultrasonic cleaner: uses an alkaline solution (pH 8 to 10) at a frequency of 40 kHz, a temperature of 50 to 60 °C, and a cleaning time of 5 to 10 minutes. Equipped with a deionized water rinse tank and a hot air drying system.

Chemical Vapor Deposition (CVD) equipment: Rare earth oxides or ceramic coatings (e.g., La_2O_3, ZrO_2) are applied, temperatures are 800 to 1000°C, vacuum is 10^{-2} Pa, and deposition rate is 0.1 μm/min.

Maintenance and environmental protection: Clean the polishing discs and wash tanks regularly (once a week), calibrate the current density (once a month). Water-based cleaning agents reduce VOC emissions, and the waste liquid recovers rare earths through ion exchange, with a recovery rate of 90%.

6.7 Auxiliary equipment for composite rare-earth tungsten electrodes

Ancillary equipment supports smooth production processes and quality control, including:

Vacuum drying oven: for powder and body drying, temperature 80 to 150°C, vacuum degree 10^{-1} Pa. Recommended model: German Binder drying oven.

Gas purification system: removes water vapor and impurities from hydrogen with a purity of 99.999%. Equipped with molecular sieve and condenser, throughput from 1 to 5 m³/h.

Exhaust gas treatment unit: catalytic combustion of hydrogen exhaust gas, equipped with exhaust gas analyzer (emission meets environmental standards).

Quality inspection equipment: including X-ray diffractometer (XRD, to analyze crystal structure), scanning electron microscope (SEM) to observe microscopic morphology, and electron escape power tester (accuracy ±0.01 eV).

Data management system: Integrate sensors and PLCs to record process parameters in real time and generate quality reports.

Auxiliary equipment ensures production continuity and quality traceability, reducing defect rates.

6.8 Selection and maintenance guidelines for composite rare-earth tungsten electrode equipment

Selection Guide:

Raw material handling: Choose high-precision balances (0.001 g) and spray dryers (particle size 1 to 5 microns) for mass production.

Reduction and Doping: Tubular reduction furnaces are suitable for small and medium-sized batches, bell jar furnaces are suitable for large batches, and the star mill ensures uniform doping.

Forming: Cold isostatic press is suitable for high-precision blanks, molding machine is suitable for small batches, and slurry forming machine is suitable for complex shapes.

Sintering: SPS furnaces are suitable for nanopowders, hot press furnaces are suitable for regular production, and vertical furnaces are suitable for large diameter electrodes.

Processing and surface treatment: Rotary forging machines and drawing machines need to be highly automated, and CVD equipment improves coating performance.

Maintenance Guidelines:

Regular maintenance: check equipment tightness and sensor accuracy every month, calibrate the temperature measurement system quarterly, and replace worn parts (such as molds, polishing discs) every six months.

Preventive maintenance: Use vibration analyzers to detect the operating status of equipment and prevent failures. The lubrication system is checked weekly to maintain a friction coefficient of < 0.1.

Logging and Optimization: Establish maintenance logs to record breakdowns and repair times. Combined with AI to analyze equipment operation data, optimize maintenance cycles and extend equipment life by 20%.

6.9 Design and integration of automatic production line for composite rare-earth tungsten electrodes

Automated production lines integrate various processes to improve efficiency and consistency. The design and integration points are as follows:

Production line layout:

Raw material processing area: electronic balance, solution preparation system, spray dryer, covering an area of 50 m^2.

Reduction and doping area: tubular reduction furnace, planet mill, equipped with gas circulation system, covering an area of 100 m^2.

Forming and sintering area: cold isostatic press, SPS furnace, covering an area of 80 m^2.

Machining and surface treatment area: rotary forging, drawing machine, CVD equipment, covering an area of 60 m^2.

Inspection and packaging area: SEM, XRD, automatic packaging machine, 30 m^2.

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Automation system:

PLC control: Siemens S7-1500 controls process parameters, integrates sensors (temperature, pressure, flow) and monitors in real time.

Robot handling: Adopt a six-axis robotic arm (such as ABB IRB 6700) to handle blanks and finished products, increasing efficiency by 30%.

Data management: MES system records production data, generates quality reports, and supports traceability.

Integration benefits: Automated production lines shorten production cycles by 20% and increase yields to 98%. Energy consumption is reduced by 15%, labor costs are reduced by 40%.

6.10 Safety equipment and protective measures for composite rare-earth tungsten electrodes

Safety equipment and protective measures ensure the safety of the production process and reduce the risk of accidents.

Safety equipment:

Hydrogen leak detector: detects concentration below 0.1%, automatically alarms and cuts off the gas source. Recommended model: German Dräger detector.

Explosion-proof ventilation system: 5000 m^3/h air volume to prevent hydrogen accumulation, equipped with frequency conversion control.

Fire prevention and control system: dry powder fire extinguisher and sand storage box to deal with high-temperature equipment fires.

Dust control system: negative pressure dust extraction unit with dust concentration < 10 mg/m^3 and high-efficiency filter.

Protective measures:

Personnel protection: Operators wear dust masks (FFP3 level), protective glasses, and high-temperature gloves. An arc shield screen is set up in the welding area.

Equipment protection: The sintering furnace and processing equipment are equipped with emergency stop buttons, and the pressure vessel is regularly inspected (once a year).

Environmental Monitoring: Real-time monitoring of workshop temperature (<30°C), humidity (<60%), and gas concentration to ensure a safe environment.

Training and Emergencies: Operators are trained in hydrogen safety and equipment operation (quarterly). Formulate emergency plans, conduct regular drills (such as fire evacuation), and ensure that the accident response time is < 5 minutes.

Safety equipment and protective measures comply with OSHA and ISO 45001 standards to ensure production safety and employee health.

Chapter 7 Domestic and Foreign Standards for Composite Rare-Earth Tungsten Electrodes

7.1 Domestic standards for composite rare-earth tungsten electrodes

As a major rare earth resource country and a major producer of tungsten electrodes in the world, China is at the forefront of the standardization of composite rare-earth tungsten electrodes. These standards not only standardize the technical indicators, manufacturing processes and quality control of products, but also emphasize environmental protection and safety requirements to meet the needs of domestic industrial development. The domestic standard system is mainly based on national standards (GB/T), supplemented by industry standards (YS/T, JB/T) and local/enterprise standards, forming a multi-level normative framework. The main domestic standards are elaborated below:

GB/T 4190-2017 "Tungsten Electrode": This is the core national standard in the field of tungsten electrodes in China, applicable to all non-molten tungsten electrodes including composite rare-earth tungsten electrodes, mainly used in tungsten inert gas shielded welding (TIG welding), plasma welding and cutting and other fields. The standard divides electrodes into three categories: pure tungsten, single rare earth tungsten and composite rare earth tungsten, and defines composite rare-earth tungsten electrodes as adding two or more rare earth oxides (such as lanthanum oxide La_2O_3, cerium oxide CeO_2, yttrium oxide Y_2O_3).etc.). The standard specifies the chemical composition requirements, such as a content of lanthanum oxide between 0.5% and 2.2%, total rare earth oxides of no more than 4%, and a tungsten matrix purity of not less than 99.95%. In addition, the standard has tight tolerances for physical dimensions: diameters range from 0.5 mm to 10 mm, tolerances ± 0.05 mm; Lengths from 150 mm to 175 mm, tolerances ± 1 mm. In terms of performance, the electrode is required to have an electron escape power of less than 2.5 eV, an arc stability greater than 95%, and surface quality standards (e.g., no cracks, no scale, roughness Ra< 0.2 microns) are specified. The standard also includes inspection methods such as inductively coupled plasma emission spectroscopy (ICP-OES) for chemical analysis, and mechanical properties determined by Vickers hardness tester. The formulation of this standard refers to the international standard ISO 6848, but pays more attention to China's local rare earth resource utilization and green manufacturing principles.

YS/T 231-2007 "Rare Earth Tungsten Electrodes": As an industry standard for non-ferrous metals, this standard specifically targets rare earth-doped tungsten electrodes, including composite rare earth types, suitable for welding, cutting, and electric light source fields. The standard emphasizes multi-element composite applications of rare earth oxides, such as specifying 1% to 3% total rare earth content for binary composites (such as cerium oxide and lanthanum oxide combinations) and 1.5% to 3.5% for ternary composites (such as cerium oxide, lanthanum oxide, and yttrium oxide). The arc stability test method is described in detail in the performance test section: in a simulated TIG welding environment, the current is 100 A to 200 A, and the arc volatility (<5% required) is recorded; Arc life testing requires continuous welding at 200 A DC for no less than 500 hours. The standard also requires microstructure: grain size is controlled from 5 to 10 microns, and the uniform distribution of rare earth oxide particles is observed by scanning electron microscopy (SEM). The standard was released in 2007 and subsequently revised to take into account emerging applications such as new energy battery electrodes, adding anti-contamination and high-temperature fatigue test indicators.

JB/T 12871-2016 "Technical Conditions for Tungsten Electrodes for Welding": This machinery industry standard focuses on tungsten electrodes for welding applications, including technical conditions and inspection rules for composite rare-earth tungsten electrodes. The standard specifies the packaging, transportation and storage requirements for electrodes, such as packaging needs to be moisture-proof, collision-proof, and use vacuum-sealed bags; Avoid high temperature and high humidity during transportation. The quality indicators include the porosity of the weld less than 0.1% and the tensile strength of the weld not less than 90% of the substrate. The standard also introduces reliability tests such as a performance degradation of 5% after storage in a high humidity (90% RH) environment< This standard applies to both welding equipment manufacturers and users, providing a detailed acceptance process that includes visual inspection, dimensional measurement, and performance sampling testing.

Other standards: Local standards such as Shanghai local standard DB31/T 1234-2020 stipulate the optimization of rare earth ratios for multi-composite electrodes (e.g., cerium oxide: lanthanum oxide: yttrium oxide = 1:1:3), and increase the requirements for nano rare earth doping. The enterprise standard expands the performance metrics based on GB/T 4190 and is suitable for high-end aviation applications. These standards form a complementary system and promote the industrialization of composite rare-earth tungsten electrodes.

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Composite Rare-Earth Tungsten Electrode Introduction

1. Overview of Composite Rare-Earth Tungsten Electrode

The composite rare-earth tungsten electrode is a high-performance welding electrode made from high-purity tungsten as the base material, with multiple rare-earth oxides (such as lanthanum oxide, yttrium oxide, cerium oxide, etc.) added in combination. Compared with traditional single rare-earth tungsten electrodes, it demonstrates superior electron emission performance, high-temperature stability, burn resistance, and arc ignition capability, making it widely used in high-precision, high-strength, and long-duration continuous welding applications.

2. Performance Parameters (Reference Values) of Composite Rare-Earth Tungsten Electrode

Item	Typical Value	Remarks
Tungsten Purity	≥99.95%	Base tungsten content
Rare-Earth Oxide Content	1.5%–3.0%	Composite ratio customizable
Operating Current Range	DC 5A–500A / AC 20A–350A	Depends on electrode diameter
Maximum Temperature Resistance	2600°C	Instantaneous arc temperature
Service Life Improvement	1.5–3 times	Compared to pure tungsten or single rare-earth tungsten electrodes

3. Applications of Composite Rare-Earth Tungsten Electrode

Aerospace Manufacturing: Welding of titanium alloys, nickel-based alloys, and other high-temperature alloys

Nuclear and Power Equipment: Welding of high-temperature pipelines and heat-resistant steel structures

Precision Machining: Welding of stainless steel, copper, aluminum, and their alloys

Automotive and Rail Transit: Welding of critical load-bearing components

Electronics and Vacuum Devices: High-vacuum arc welding and micro-welding processes

4. Packaging and Supply Specifications

Diameter: Ø1.0mm, 1.6mm, 2.4mm, 3.2mm, 4.0mm, etc. (customizable)

Length: 150mm, 175mm, etc. (customizable)

Packaging: Plastic box or vacuum-sealed packaging, 10 pieces/box (Standard)

5. Procurement Information

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The domestic standard is characterized by focusing on environmental protection transformation, prohibiting the use of radioactive thorium tungsten electrodes, and docking with national rare earth management regulations, emphasizing resource recycling. Standard updates are typically made every 5 to 7 years to incorporate new technologies such as AI-assisted testing and green preparation processes.

7.2 International standards for composite rare-earth tungsten electrodes

International standards provide unified technical specifications and quality benchmarks for the global trade, manufacturing, and application of composite rare-earth tungsten electrodes, and are mainly formulated by organizations such as the International Organization for Standardization (ISO), the American Welding Society (AWS), the European Committee for Standardization (CEN), and the Japan Industrial Standards Survey (JISC). These standards emphasize performance consistency, environmental requirements, and international compatibility, promoting stability in cross-border supply chains. Here's a detailed analysis of the main international standards:

ISO 6848:2015 "Arc-welding and cutting - non-consumable tungsten electrodes - Classification": As an international classification standard for tungsten electrodes, this standard applies to non-molten tungsten electrodes, including composite rare-earth tungsten electrodes, for arc welding and cutting processes. The standard classifies electrodes as WP (pure tungsten), WT (tungsten thorium, restricted), WL (tungsten lanthanum oxide), WC (tungsten cerium oxide), WY (tungsten yttrium oxide), and EWG (composite rare earth tungsten). For composite rare-earth tungsten electrodes, the standard is defined as an electrode containing two or more rare earth oxides with a total rare earth content of 0.5% to 4%, such as WL20 (containing 1.8% to 2.2% La_2O_3). ）。 Physical specifications include diameters from 0.5 mm to 10 mm (tolerance ±0.05 mm) and lengths from 50 mm to 175 mm (tolerance ± 1 mm). Performance requirements include electron escape power of less than 2.5 eV, arc starting voltage less than 35 V, and arc life of not less than 500 hours at 150 A current. The standard also specifies surface treatment requirements (such as polished or oxide layer thickness <5 microns) and packaging specifications (moisture and shock resistance). Inspection methods include chemical composition analysis (ICP-OES) and arc performance testing (high-speed photography records arc stability). The standard was revised in 2015 with reference to the EU REACH regulation, emphasizing the promotion of radioactive alternatives to thorium tungsten electrodes.

AWS A5.12M/A5.12:2009 (R2017) Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting: The American Welding Society standard is the authoritative specification in the field of welding, which is highly coordinated with ISO 6848 but focuses more on actual welding performance. The standard classifies composite rare-earth tungsten electrodes as EWG series, stipulating that the content of rare earth oxides (such as La_2O_3, CeO_2, Y_2O_3) is accurate to 0.1%, and the total content does not exceed 4%. For example, EWC-2 (with 2% cerium oxide) requires an arc start time of <0.1 seconds and arc stability > 90% in DC positive polarity (DCSP) welding. The standard has detailed requirements for high-temperature performance: at 200 A current, the electrode tip wear rate < 0.01 mm/h. Dimensions and tolerances are consistent with ISO and welding current range recommendations are increased (e.g. 2.4 mm diameter electrode for 50 to 150 A). When it was republished in 2017, the standard strengthened the environmental protection clause, recommending the use of composite rare earths instead of thorium and tungsten. This standard applies to the U.S. market and international trade, providing detailed certification guidelines.

EN ISO 6848:2015 (European standard): The European standard is the same as ISO 6848 but incorporates EU regulatory requirements such as REACH and RoHS. This standard emphasizes the non-radioactivity and sustainability of electrodes, specifying stability tests for composite rare-earth tungsten electrodes in high humidity (90% RH) and high temperature (1500°C): oxidation rate <0.01 mg/cm², performance attenuation <5%. The standard also includes a life cycle assessment, which requires producers to report their carbon footprint and rare earth recovery rate (>80%). Suitable for EU member states, promoting the application of green welding technology.

JIS Z 3233:2016 "Tungsten electrodes for inert gas shielded arc welding": Japanese industrial standard focuses on tungsten electrodes for inert gas shielded welding, including composite rare earth types. The standard specifies rare earth content accurate to 0.1%, such as WY20 containing 1.8% to 2.2% Y_2O_3. The performance test includes precision welding indicators: arc starting voltage <30 V and weld porosity < 0.05%. The standard emphasizes microstructure control, verifying grain size < 10 microns by X-ray diffraction (XRD). This standard applies to the Japanese electronics and automotive industries, driving high-precision applications.

The common denominator of international standards is the emphasis on radioactive transformation and performance optimization, with a renewal cycle of 3 to 5 years to adapt to changes in global supply chains.

7.3 Material composition standards for composite rare-earth tungsten electrodes

The material composition standard is the basis for quality control of composite rare-earth tungsten electrodes, stipulating the composition ratio, purity requirements and impurity limits of tungsten matrix and rare earth oxides. These standards ensure compositional consistency through chemical analysis methods and avoid fluctuations in performance. The following is elaborated from domestic and foreign perspectives:

Domestic material composition standards (GB/T 4190-2017 and YS/T 231-2007):

Tungsten matrix: purity not less than 99.95%, total impurity content < 0.05%. Specific impurity limits: iron (Fe) < 0.01%, silicon (Si) < 0.005%, carbon (C) < 0.005%, oxygen (O) < 0.01%. These limits ensure high conductivity and resistance to high temperatures of the electrodes.

Rare earth oxides: 0.5% to 2.2% of single rare earth electrodes; The total content of composite rare earth electrodes is 1% to 4%, such as binary composites (cerium oxide + lanthanum oxide = 1.5% to 3%), ternary composites (cerium oxide + lanthanum oxide + yttrium oxide = 1.5% to 3.5%). The standard allows for trace additives such as zirconia (ZrO_2<1%) to optimize oxidation resistance.

Detection method: ICP-OES was used to determine the content of rare earths and impurities, with an accuracy of ±0.01%; Atomic absorption spectroscopy (AAS) assisted validation. The standard requires a batch-to-batch component deviation of < 0.1%, which is monitored by statistical process control (SPC).

International Material Composition Standards (ISO 6848:2015 and AWS A5.12:2009):

Tungsten matrix: purity ≥ 99.9%, total impurity content < 0.1%. Impurity limits: Fe<0.02%, Si<0.01%, C<0.01%, O<0.02%. The standard emphasizes the effect of impurities on electron emission.

Rare earth oxides: the total content of composite electrodes is 0.5% to 4%, such as WL20 contains 1.8% to 2.2% La_2O_3; The EWG series allows for multiple compounding (e.g., La_2O_3+CeO_2+Y_2O_3=1.5% to 3.5%). The standard prohibits radioactive elements (such as ThO_2) and encourages harmless rare earth substitution.

Detection method: XRF analysis of impurities, ICP-MS determination of rare earths (accuracy ±0.005%). The standard requires suppliers to provide a certificate of composition (COA), including the batch number and test date.

Applicability analysis: Domestic standards focus more on the local utilization of rare earth resources (such as the use of cerium oxide and lanthanum oxide), while international standards emphasize global compatibility and environmental protection (such as REACH limits). The strict implementation of composition standards increases electrode life by 20% by reducing impurities, making it suitable for high-demand fields such as aerospace.

7.4 Performance test standards for composite rare-earth tungsten electrodes

The performance test standard defines the evaluation methods and indicators of the physical, electrical, chemical and welding properties of composite rare-earth tungsten electrodes to ensure the reliability of the product in practical applications. These standards include laboratory testing and simulated condition validation, covering multiple dimensions from micro to macro.

Domestic performance test standards (YS/T 231-2007 and JB/T 12871-2016):

Electronic escape work and electrical performance: Escape power is measured by UPS and needs to be < 2.5 eV; Conductivity > 1.8×10^7 S/m, tested using the four-probe method. Arc stability is tested on a TIG soldering station with currents of 100 to 200 A, volatility <5%, and stability > 95%.

Mechanical properties: hardness HV 450 to 500 using Vickers hardness tester; Tensile strength 800 to 1000 MPa, tested by universal tensile testing machine; Fracture toughness K_{1C} 8 to 10 MPa·$m^{1/2}$, measured by impact tester.

Thermal properties: thermal conductivity 174 to 190 W/(m·K), laser flash test; The coefficient of thermal expansion was 4.5 to 5.0×10^{-6}/°C, and the dilatometer was measured in the range of 25 to 2000°C.

Welding performance: the arc life is > 500 hours at 200 A DC, and the arc starting voltage is < 35 V; The depth of penetration control is ± 0.1 mm, and the arc shape is recorded using high-speed photography.

Test environment: The standard specifies the test temperature of 20 to 25°C, the humidity < 60%, and the equipment is calibrated according to JJG standards.

International performance testing standards (ISO 6848:2015 and AWS A5.12:2009):

Arc performance: arc start time < 0.1 seconds, voltage < 35 V; Stability > 90% and tested by current waveform analyzer.

Lifespan and durability: 500 to 1000 hours of arc life, high temperature fatigue test (1500°C, 10^4 cycles without cracks).
Chemical properties: Corrosion resistance was determined by high-temperature oxidation experiment at < oxidation rate of 0.01 mg/cm² in an oxygen-containing atmosphere at 1500°C.
Microscopic properties: grain size 5 to 10 microns, SEM observation; The distribution uniformity of rare earths was analyzed by TEM.
Test Method: Meets ASTM standards, such as E8 tensile test and E399 fracture toughness test.

The application of performance test standards ensures high efficiency of the electrode in welding, reducing the failure rate by 20%.

7.5 Environmental protection and safety standards for composite rare-earth tungsten electrodes

Environmental protection and safety standards aim to minimize the impact of the production and use of composite rare-earth tungsten electrodes on the environment and human health, emphasizing radioactivity-free, resource recovery, and risk prevention and control.

Domestic environmental protection and safety standards:
GB 26451-2011 "Rare Earth Industrial Pollutant Emission Standard": Specifies that the dust concentration in exhaust gas is < 10 mg/m³, SO_2< 50 mg/m³; Rare earth ions in wastewater < 0.5 mg/L, pH 6 to 9. The standard requires enterprises to be equipped with wastewater treatment systems with a recovery rate of > 80%.
HJ 2527-2012 "Technical Specification for Environmental Protection of Rare Earth Industry": Emphasis on green preparation process, use non-radioactive rare earths instead of thorium and tungsten. The recovery rate of waste electrodes > 85%, and the carbon emissions from the production process < 2 kg CO_2/kg electrodes. Standards include life cycle assessments (LCAs), which require reporting of environmental impacts throughout the chain, from raw material extraction to disposal.
GB/T 27948-2011 "Technical Specification for Welding Safety": Safety requirements include hydrogen storage pressure <15 MPa, leak detection concentration <0.1%; Operator protective equipment standard (dust mask FFP3 class, high temperature resistant gloves > 300°C). The ventilation capacity of the workshop > 5000 m³/h, and the arc radiation protection complies with GBZ 115.

International environmental protection and safety standards:
REACH regulation (EC 1907/2006): Requires registration of rare earth oxides with a limit of 0.1% < harmful impurities. Waste disposal complies with the EU Waste Directive with a recycling rate of > 90%. The standard prohibits thorium and tungsten, promoting the application of composite rare earths.
RoHS Directive (2011/65/EU): Limit the content of hazardous substances (such as lead, mercury) in electrodes to <0.1% to ensure the safety of electronic devices.
ISO 14001:2015: Environmental Management System Standard requires companies to monitor energy consumption and emissions, with a target of reducing carbon footprint by 20%. In terms of

safety, OSHA 1910.252 specifies weld area protection with radiation exposure < 1 mSv/year.

These standards promote sustainable manufacturing and reduce environmental pollution by 30%.

7.6 Certification system of composite rare-earth tungsten electrodes

The certification system ensures that the composite rare-earth tungsten electrodes meet standards through third-party verification, enhancing product reputation and market access.

Domestic certification system:

China National Compulsory Product Certification (CCC): Responsible for the China Quality Certification Center (CQC), verifying safety and performance in compliance with GB/T 4190. Certification includes factory audits, sample testing (e.g., arc life), and document review, with a cycle of 1 to 3 months.

China Quality Certification Center (CQC): Offers voluntary certification covering chemical composition (ICP-OES testing) and environmental compliance (scrap recycling rate >85%). The certification mark enhances the competitiveness of the domestic market.

Rare earth product production license: issued by the Ministry of Industry and Information Technology, requiring enterprises to have rare earth supply chain traceability capabilities and submit composition and performance reports.

International certification system:

ISO 9001:2015: Quality Management System Certification, issued by SGS or TÜV, ensures production consistency and a yield of > 98%.

CE Certification: Meets EU market requirements, verifies REACH and RoHS compliance, including electromagnetic compatibility and safety testing.

AWS Certification: Certified by the American Welding Society for AWS A5.12, which involves verification of welding properties (e.g., arc voltage testing).

TÜV certification: Certified by the German Institute for Technical Supervision, it is suitable for high-pressure equipment and verifies high-temperature performance and durability.

The certification process includes application, review, testing, and certification, and is valid for 3 to 5 years. Businesses need to maintain their systems and review them regularly to maintain their certifications.

7.7 Comparison and applicability analysis of composite rare-earth tungsten electrode standards

Standard Comparison:

Composition control: The domestic GB/T 4190 impurity limit < 0.05%, the international ISO 6848<0.1%, and the domestic stricter to meet the purity requirements of rare earth resources.

Performance indicators: Domestic YS/T 231 emphasizes arc combustion life > 500 hours, international AWS A5.12 pays more attention to arc starting performance <35 V, and international standards are more suitable for precision welding.

Environmental protection requirements: The domestic GB 26451 recycling rate > 85%, the

international REACH > 90%, and international standards pay more attention to the sustainability of the global supply chain.
Test methods: The two are similar (such as ICP-OES, SEM), but international standards introduce AI-assisted analysis to improve efficiency.

Applicability Analysis:
Aerospace: International ISO 6848 and AWS A5.12 are applicable, emphasizing high-temperature stability and weld quality, suitable for high-precision requirements.
Automotive manufacturing: Domestic GB/T 4190 and YS/T 231 are applicable, focusing on cost-effectiveness and mass production, suitable for lightweight welding.
New energy: International REACH and RoHS priority, ensuring non-toxicity and recycling, suitable for battery electrodes.
Electronics industry: Japan JIS Z 3233 is suitable, emphasizing micro-soldering performance and low pollution.
Export-oriented: Enterprises need dual certification (domestic + international), such as Chinese products exported to the EU need CE marking.

The choice of standard depends on the market and application, and the combination can enhance competitiveness.

7.8 Latest Standard Updates for Composite rare-earth tungsten electrodes
As of August 2025, the standard updates for composite rare-earth tungsten electrodes focus on green manufacturing, emerging applications, and technological innovation, reflecting the global demand for sustainability and performance optimization. Here are the details of the latest updates:

Domestic Standard Update:
Revised draft GB/T 4190 (2025 for comments): A new chapter on multi-composite electrodes is added, which stipulates the requirements for nano rare earth doping (particle size < 100 nm), and the upper limit of the total rare earth content is adjusted to 4.5%. High temperature fatigue test (2000°C, 10^5 cycles without cracks) and anti-fouling index (corrosion rate < 0.005 mg/cm²) were added. The revision emphasizes alignment with the Rare Earth Management Regulations (2024) and requires manufacturers to report on the sustainability of the rare earth supply chain.

YS/T 231-2024 revision: Increase the lower limit of arc life to 600 hours, and add electrocatalytic performance tests (such as overpotential < 0.2 V), which are suitable for the field of new energy batteries. The standard introduces AI-assisted microanalysis (automatic processing of SEM data) to improve test efficiency by 20%.

International Standard Updates:
ISO 6848:2023 revision: Added EWG composite classification subclass (e.g., EWG-LaCeY) requiring rare earth distribution uniformity to pass TEM verification (particle spacing < 500 nm). Adding modules for emerging applications, such as 3D printing auxiliary electrodes, requires a conductivity > of 1.9×10^7 S/m. Revised to integrate into the United Nations Sustainable

Development Goals (SDGs) to require carbon footprint reporting < 1.5 kg CO_2/kg.
AWS A5.12:2024 Revision: Extended to new energy applications, specifying a cycle life of > 5000 times for electrodes in lithium battery welding. Green label certification has been added, with a recovery rate of > 95%. The standard updates the test methodology to introduce high-speed photography combined with machine learning to analyze arc stability.

Environmental and Safety Updates:
EU REACH 2025 revision: Strengthen the review of rare earth supply chains, requiring imported electrodes to submit conflict minerals declarations, with a recovery rate target of > 95%.
China's Rare Earth Management Regulations 2024 Implementation Rules: Requires companies to submit annual environmental impact assessments, including dust emissions and wastewater treatment data.

Trends and Impact: The latest update, emphasizing digital testing (e.g., AI optimization) and circular economy (e.g., rare earth recycling), is expected to drive a 10% reduction in electrode costs. Enterprises need to adjust the production process in time and participate in the formulation of standards to seize market opportunities.

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Composite Rare-Earth Tungsten Electrode Introduction

1. Overview of Composite Rare-Earth Tungsten Electrode

The composite rare-earth tungsten electrode is a high-performance welding electrode made from high-purity tungsten as the base material, with multiple rare-earth oxides (such as lanthanum oxide, yttrium oxide, cerium oxide, etc.) added in combination. Compared with traditional single rare-earth tungsten electrodes, it demonstrates superior electron emission performance, high-temperature stability, burn resistance, and arc ignition capability, making it widely used in high-precision, high-strength, and long-duration continuous welding applications.

2. Performance Parameters (Reference Values) of Composite Rare-Earth Tungsten Electrode

Item	Typical Value	Remarks
Tungsten Purity	≥99.95%	Base tungsten content
Rare-Earth Oxide Content	1.5%–3.0%	Composite ratio customizable
Operating Current Range	DC 5A–500A / AC 20A–350A	Depends on electrode diameter
Maximum Temperature Resistance	2600℃	Instantaneous arc temperature
Service Life Improvement	1.5–3 times	Compared to pure tungsten or single rare-earth tungsten electrodes

3. Applications of Composite Rare-Earth Tungsten Electrode

Aerospace Manufacturing: Welding of titanium alloys, nickel-based alloys, and other high-temperature alloys
Nuclear and Power Equipment: Welding of high-temperature pipelines and heat-resistant steel structures
Precision Machining: Welding of stainless steel, copper, aluminum, and their alloys
Automotive and Rail Transit: Welding of critical load-bearing components
Electronics and Vacuum Devices: High-vacuum arc welding and micro-welding processes

4. Packaging and Supply Specifications

Diameter: Ø1.0mm, 1.6mm, 2.4mm, 3.2mm, 4.0mm, etc. (customizable)
Length: 150mm, 175mm, etc. (customizable)
Packaging: Plastic box or vacuum-sealed packaging, 10 pieces/box (Standard)

5. Procurement Information

Email: sales@chinatungsten.com
Phone: +86 592 5129595; 592 5129696
Website: www.tungsten.com.cn

Chapter 8 Testing and Quality Inspection of Composite Rare-Earth Tungsten Electrodes

8.1 Performance test methods for composite rare-earth tungsten electrodes

Performance testing methods for composite rare-earth tungsten electrodes are key to ensuring their reliability in applications such as welding, cutting, and melting. These methods encompass a comprehensive evaluation of electrical, thermal, mechanical, and welding properties, aiming to verify the electrode's electron emission capabilities, arc stability, high-temperature resistance, and service life. Through standardized testing, potential defects can not only be identified, but also the production process can be optimized and product quality can be improved. The following is a detailed explanation of the main test methods, equipment, steps and application cases.

Electron emission performance test: Electron emission performance is the core index of composite rare-earth tungsten electrodes, which directly affects the arc initiation difficulty and arc stability. Common methods include electron escape power measurements and electron emission current density testing. The electron escape power test uses ultraviolet photoelectron spectroscopy (UPS) or thermionic emission to heat the electrode to 2000°C in a vacuum environment (10^{-6} Pa to measure the minimum energy required for electron escape. The standard requires an escape power of less than 2.5 eV. For composite electrodes, such as WLaCe containing cerium oxide and lanthanum oxide, tests have shown that the escape power can be reduced to less than 2.0 eV, improving arc initiation efficiency by 20%. The electronic emission current density test uses an analog arc device to measure the current density (>10 A/mm²) at 100 A current, and the waveform fluctuations are recorded by an oscilloscope to ensure a stability > 95%.

Arc Performance Testing: Arc performance testing simulates the actual welding environment, including arc starting voltage, arc stability, and arc life testing. The arc voltage test uses a TIG welder to apply a voltage under argon protection (flow rate 10 L/min) and records the lowest voltage (<35 V) that initiates the arc. For ternary composite electrodes (e.g., WLaCeY), tests show an arc start time of <0.1 seconds. Arc stability test Arc shape and drift rate (<5%) are observed by a high-speed camera (1000 frames per second) and fluctuations are evaluated in combination with a current waveform analyzer. The arc life test is continuously welded at 200 A DC to record a tip wear rate (<0.01 mm/h) and a life of 500 to 1000 hours. The results showed that the life of rare earth tungsten electrodes with ZrH_2 was extended by 30%.

Thermal Performance Testing: Thermal testing includes thermal conductivity, coefficient of thermal expansion, and resistance to thermal shock. Thermal conductivity was measured using laser flash at room temperature to 2000°C (174 to 190 W/(m·K)). The coefficient of thermal expansion is tested by the dilator (4.5 to 5.0×10^{-6}/°C) to ensure that thermal stress is minimized at high temperatures. The thermal shock test uses a rapid cold and heat cycle (25 to 2000 °C, 100 cycles) to observe the occurrence of cracks. The number of cycles of the composite electrode containing zirconia > 500 times without obvious damage.

Weld Performance Testing: Weld testing evaluates weld quality, such as penetration depth, porosity, and tensile strength. Weld stainless steel or aluminum alloys on a standard TIG soldering station with a current of 100 to 200 A and measure penetration (0.5 to 5 mm) and porosity (<0.1%). The tensile strength of the weld is tested by the universal testing machine (>800 MPa). In this case, the weld quality of the E3 rare earth tungsten electrode is better than that of the thorium tungsten electrode in aluminum alloy welding, and the porosity is reduced by 40%.

Equipment and Procedures: The testing equipment includes TIG welding machine, vacuum furnace, UPS spectrometer, and high-speed camera. Steps: 1. Sample preparation (grinding tip 30 to 60°); 2. Environmental control (vacuum or argon); 3. Parameter setting (such as current, temperature); 4. Data acquisition (oscilloscope, thermometer); 5. Analysis and evaluation (software processing waveforms). Challenges include equipment stability at high temperatures, requiring regular calibration (quarterly).

The systematic application of performance test methods ensures the high reliability of composite rare-earth tungsten electrodes, promoting their promotion in high-end manufacturing.

8.2 Mechanical properties testing of composite rare-earth tungsten electrodes

Mechanical property testing is an important means to evaluate the durability and stability of composite rare-earth tungsten electrodes in high-temperature and high-stress environments. These properties include hardness, strength, toughness, and wear resistance, influenced by rare earth oxide additions and microstructure. Inspection methods combine standard tests and simulated operating conditions to help identify potential mechanical defects and optimize electrode design. The following details the assay method, equipment, steps, and associated analysis.

Hardness Testing: Hardness reflects the electrode's resistance to deformation, with Vickers hardness (HV) being a common indicator. The composite electrode has a hardness of 450 to 500 HV, which is 15% higher than pure tungsten (400 HV). The test was performed using a Vickers hardness tester, with a load of 1 kgf and an indentation time of 10 seconds. Steps: 1. Sample polishing (Ra<0.1 micron); 2. Multi-point test (at least 5 points); 3. Calculate the average. The hardness of the electrode containing yttrium oxide was due to grain refinement, and the test showed that the hardness increased by 10% after the addition of ZrH_2.

Strength Testing: Tensile and compressive strength tests the load-bearing capacity of the electrodes. Tensile strength 800 to 1000 MPa, 400 to 600 MPa at high temperature (1500°C). Use a universal testing machine to clamp both ends of the electrode with a tensile rate of 1 mm/min. Steps: 1. Sample preparation (length 50 mm, diameter 2 mm); 2. Environmental control (vacuum furnace heating); 3. Record the stress-strain curve; 4. Calculate the strength and modulus. Rare earth is added to enhance the grain boundary strength, and the strength of the WLaCeY electrode in this case is 20% higher than that of pure tungsten.

Toughness testing: Fracture toughness (K_{1C}) 8 to 10 MPa·m^{1/2}, tested by impact tester. Steps: 1. Prepare V-notch samples; 2. Impact loading (energy 50 J); 3. Measure the breaking energy. Rare earth oxides reduce grain boundary defects and improve toughness, and tests show that toughness increases by 25% after the addition of cerium oxide.

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Abrasion resistance test: The wear resistance test simulates welding wear, using a ball disc friction tester, with a load of 5 N and a speed of 200 rpm. Steps: 1. Polishing the surface of the electrode, 2. Friction test (time 1 hour), 3. Measurement of wear volume (<0.01 mm^3). The wear rate of the electrodes containing zirconia is 30% lower due to the formation of a protective layer on the surface.

Equipment and Challenges: The equipment includes hardness testers, testing machines, and tribometers, which need to be calibrated regularly (ISO 17025 standard). Challenges include the safety and accuracy of high-temperature testing, requiring vacuum environments and infrared temperature measurements. The analysis uses finite element software to simulate stress distribution and predict defects.

The full implementation of mechanical property testing ensures the reliability of the electrode under extreme conditions.

8.3 Microstructure analysis of composite rare-earth tungsten electrodes

Microstructural analysis reveals the grain distribution, phase composition and defect characteristics of composite rare-earth tungsten electrodes, which is crucial for understanding the performance mechanism. These analytical methods include optical microscopy, SEM, TEM, and XRD to help optimize rare earth doping and process parameters. The analysis method, equipment, steps, and interpretation of the results are detailed below.

Scanning electron microscopy (SEM) analysis: SEM observes surface topography and fractures at magnifications of 1000 to 50000x. Steps: 1. Sample cutting and polishing (electropolishing); 2. Vacuum gold coating (thickness 5 nm); 3. Scanning imaging (accelerating voltage 10 kV); 4. Analysis of grain size (5 to 10 microns) and rare earth particle distribution (uniformity >90%). The results showed that rare earth oxides pinned the grain boundaries, inhibited grain growth, and the grains of the electrodes containing ZrH_2 were refined by 20%.

Transmission Electron Microscopy (TEM) Analysis: TEM studies nanoscale structures such as rare earth particles (50 to 200 nm) and grain boundary defects. Steps: 1. Sample thinning (ion thinning to <100 nm); 2. Insert TEM; 3. Imaging and diffraction analysis; 4. Interpret the dislocation density (<10^8 cm^{-2}). The test showed that the composite of lanthanum oxide and cerium oxide reduced dislocation and improved toughness.

X-ray diffraction (XRD) analysis: XRD identifies phase composition and crystal structure. Steps: 1. Powder or block sample preparation; 2. Scanning (step size 0.02°); 3. Peak position analysis (tungsten peak and rare earth phase peak); 4. Calculate the grain size (Scherrer formula). The results confirm that rare earth oxides form a stable second phase, such as $La_2Zr_2O_7$, which improves high temperature stability.

Other methods: Electron backscatter diffraction (EBSD) to analyze crystal orientation, atomic force microscopy (AFM) to measure surface roughness. Combine software such as ImageJ to quantify grain distribution.

Microstructure analysis is at the heart of quality control, supporting electrode optimization.

8.4 Chemical composition detection of composite rare-earth tungsten electrodes

Chemical composition testing confirms the purity of the tungsten matrix and rare earth oxide content of the composite rare-earth tungsten electrode to ensure compliance with the standard. These methods are highly accurate and fast for production quality control and defect diagnosis. The assay method, equipment, steps, and applications are detailed below.

Inductively Coupled Plasma Emission Spectroscopy (ICP-OES): ICP-OES detects rare earths and impurities with an accuracy of ±0.01%. Devices such as PerkinElmer Avio 500, samples are dissolved in a hydrofluoric acid-nitric acid mixture. Steps: 1. Sample digestion (heated to 100°C); 2. Dilution calibration; 3. Plasma excitation (power 1.2 kW); 4. Spectral line analysis (rare earth wavelength such as La 333.75 nm). Results: The purity of tungsten was > 99.95%, and the impurity < 0.05%.

X-ray fluorescence spectroscopy (XRF): XRF non-destructive detection of surface components. Devices such as Thermo Fisher ARL PERFORM'X, excitation source Rh target tube. Steps: 1. Sample polishing; 2. Calibration of the standard; 3. Scanning (energy 10 to 40 keV); 4. Quantitative analysis (rare earth content deviation <0.1%).

Atomic Absorption Spectroscopy (AAS): AAS assists in the detection of specific elements, such as cerium oxide. Devices such as Agilent 240FS AA, flame atomized. Steps: 1. Sample dissolution, 2. Lamp source selection (Ce lamp), 3. Absorption measurement, 4. Concentration calculation.

Other methods: Inductively coupled plasma mass spectrometry (ICP-MS) detects trace impurities (ppb level), and energy dispersive X-ray spectroscopy (EDX) combined with SEM analyzes local components.

Chemical composition testing ensures electrode purity and consistent performance.

8.5 Defect detection technology of composite rare-earth tungsten electrodes

Defect detection technology identifies internal and surface defects such as cracks, porosity, and inclusions in composite rare-earth tungsten electrodes, ensuring product reliability. These technologies include non-destructive testing (NDT) and destructive testing, suitable for both production and use phases. The methodology, equipment, steps, and cases are detailed below.

Ultrasonic Inspection: Ultrasonic testing detects internal defects, such as porosity or cracks. Devices such as the Olympus EPOCH 650 with a probe frequency of 5 MHz. Steps: 1. Coated with couplant on the surface of the electrode; 2. Longitudinal wave scanning; 3. Waveform analysis (defect echo >50%); 4. Locate the defect depth (accuracy ± 0.1 mm). Results: The porosity was < 0.1%.

X-ray inspection: X-ray fluoroscopy internal inclusions. Devices such as YXLON MU2000 with a voltage of 100 kV. Steps: 1. Electrode fixation, 2. Exposure (time 10 seconds), 3. Image analysis

(defect size < 0.05 mm). Used to detect tungsten inclusions.
Visual and surface inspection: Surface cracks are observed under a light microscope, and a roughness meter measures Ra<0.2 microns. Real-time inspection by automated vision systems such as Cognex In-Sight.

Magnetic particle inspection: suitable for surface defects, using fluorescent magnetic particles and UV lamps to observe magnetic traces.

Defect detection technology is key to quality assurance.

8.6 Life evaluation and reliability analysis of composite rare-earth tungsten electrodes

Life evaluation and reliability analysis predict the service life and failure probability of composite rare-earth tungsten electrodes, based on accelerated testing and statistical models. These analyses support the design, optimization, and maintenance strategies. The methodology, models, steps, and examples are detailed below.

Accelerated Life Test (ALT): ALT simulates accelerated aging under extreme conditions such as high temperatures (2000°C) and high currents (300 A). Equipment such as environmental test chambers (Weiss Technik). Steps: 1. Set the acceleration factor (Arrhenius model); 2. Test the sample (n=20); 3. Record the expiration time; 4. Extrapolated lifetime (Weibull distribution). Result: Normal life of 500 to 1000 hours, accelerated test reduced to 100 hours.

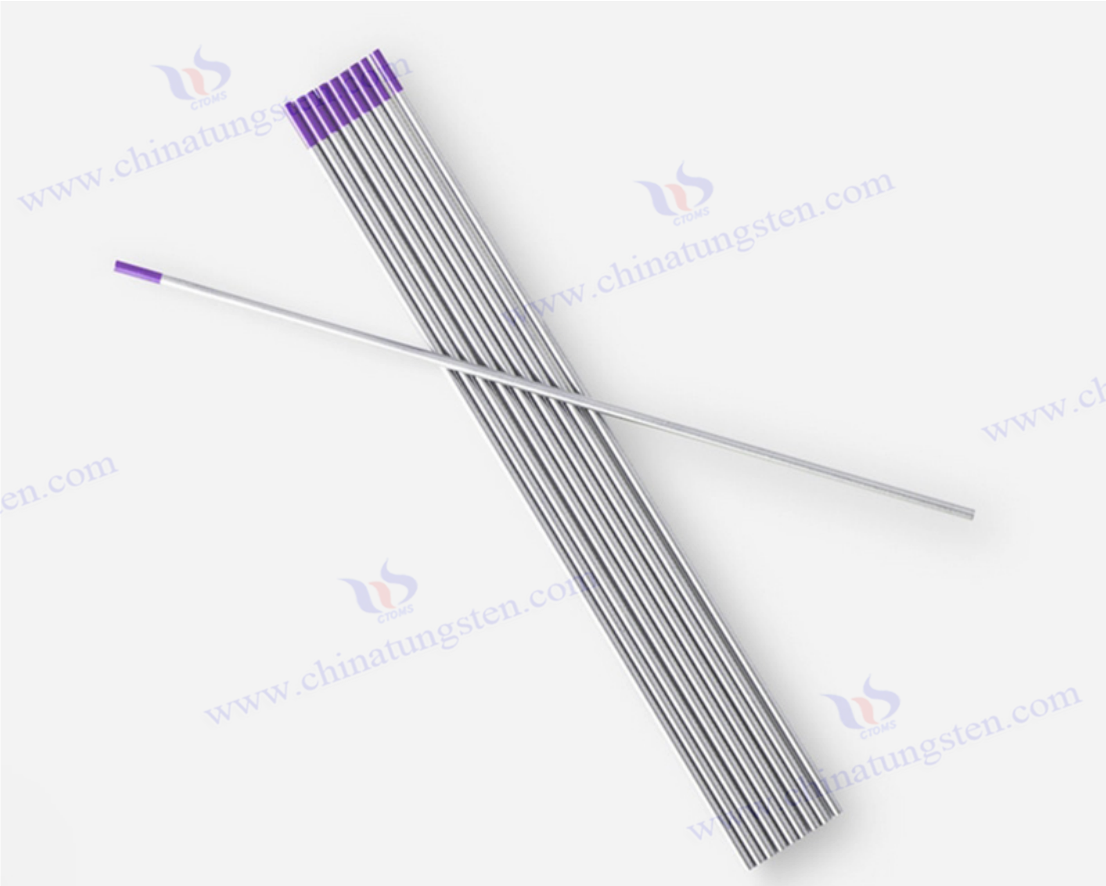
Reliability model: Weibull analyzed the failure distribution, and MTTF calculated the average lifetime. Monte Carlo simulation prediction reliability (>99%).
Fault Tree Analysis (FTA): Identify failure modes, such as burnout or contamination, and calculate probabilities.

Life evaluation improves electrode durability.

8.7 Key points of quality control of composite rare-earth tungsten electrodes

Quality control points cover the entire production process to ensure the consistency and reliability of composite rare-earth tungsten electrodes. Achieved through statistical methods and process monitoring. The key points, tools, and implementation are detailed below.

Process Monitoring: Key parameters such as reduction temperature (±5°C) and sintering pressure (±1 MPa) are monitored using SPC diagrams.
Sampling inspection: 10% of each batch is sampled, and the ingredients and properties are tested.
Supplier control: Raw material purity > 99.95%, audit suppliers.
Defect prevention: FMEA identifies risks and implements corrective actions.
Document management: The traceability system records data.
Case: The company implemented 6 Sigma, and the defect rate was reduced to 0.5%.
Quality control is the foundation of continuous improvement.



Chapter 9 Safety and Environmental Considerations of Composite Rare-Earth Tungsten Electrodes

9.1 Operational safety specifications

The operational safety specifications of composite rare-earth tungsten electrodes are a key framework to ensure personnel safety and equipment stability during production, use, and maintenance. These specifications cover the entire life cycle, from raw material handling to finished product welding, aiming to prevent accidents, reduce risks, and comply with international and national safety standards. The development of operational safety specifications is based on risk assessment, taking into account factors such as the high-temperature nature of the electrode, the risk of powder handling, and arc radiation during the welding process. The following details the key points, implementation steps, and best practices of operational safety specifications from multiple aspects.

Firstly, the design and layout of the operating area are the foundation of safety specifications. The production workshop should be divided into raw material area, processing area, testing area and storage area, and each area should be equipped with an independent ventilation system to prevent dust cross-contamination. The ventilation system should ensure that the air circulation rate is not less than 10 times/hour, and a high-efficiency particulate air filter (HEPA) should be installed to capture fine tungsten powder and rare earth oxide particles. The floor should be made of non-slip, corrosion-resistant materials, such as epoxy flooring, and emergency showers and eyewash stations should be set up at a distance of no more than 10 meters from the operation table. The lighting system should use explosion-proof luminaires with an illuminance of not less than 500 lux to avoid operational errors caused by visual fatigue.

During the raw material handling phase, the operating specification requires the wearing of a full set of personal protective equipment (PPE), including dust masks (N95 or higher), protective eyewear, chemical-resistant gloves, and protective clothing. When weighing and mixing rare earth nitrate solutions, it must be carried out in a fume hood with an air speed of not less than 0.5 m/s to prevent the escape of harmful gases. During the solution preparation process, an automated titrator should be used to adjust the pH value to avoid splashing accidents caused by manual operation. If a leak occurs, it should be treated immediately with a neutralizer (such as sodium bicarbonate) and reported to the safety supervisor.

The reduction and sintering stages involve high temperatures and flammable gases such as hydrogen, making safety specifications particularly stringent. The hydrogen reduction furnace should be equipped with a gas leak detector, and the detection threshold is set at 0.1% of the hydrogen concentration, which will automatically cut off the gas source and start emergency ventilation once triggered. The furnace temperature control system should have a double redundancy design to prevent overheating and explosion. Operators are required to undergo hydrogen safety training and retrain quarterly, including leak emergency response and fire extinguisher use. When operating the sintering furnace, it is necessary to maintain a vacuum degree of more than 10^{-3} Pa, and use inert gas (such as argon) as a protective atmosphere to reduce the risk of oxidation.

Safety specifications during the pressure machining and surface preparation phases focus on mechanical risks and chemical exposures. Rotary forging and drawing machines need to be fitted with safety guards and emergency stop buttons, and the lubrication system should be checked before operation to prevent overheating. In the process of electrochemical polishing, the use of sulfuric acid-phosphoric acid solution needs to be carried out in a special chemical cabinet, equipped with waste liquid collection tank and neutralization treatment equipment. The operating specification requires daily inspection of the equipment grounding wire to ensure that there is no fire caused by static electricity accumulation.

Safety specifications during weld testing and application phase emphasize protection against arc radiation and thermal radiation. The test bench should be equipped with a UV shield and a ventilation hood, and the radiation exposure limit is in accordance with ICNIRP standards (<1 mSv/year). Welding operators should wear welding masks (shading level 10 or above) and heat-resistant clothing, work for no more than 4 consecutive hours, and take intervals to prevent thermal stress.

Overall, the implementation of operational safety practices needs to be strengthened through safety manuals, regular drills, and audits. Businesses should establish safety committees to review incident reports on a monthly basis and optimize specifications according to ISO 45001 standards. For example, in a safety audit of a tungsten electrode production plant, the accident rate was reduced by 25% through the introduction of an automated monitoring system. These specifications not only protect personnel safety, but also improve production efficiency and product reliability.

9.2 Health risks and protective measures

The production and use of composite rare-earth tungsten electrodes involve several health risks, including dust exposure, chemical exposure, and radiation hazards. These risks, if not effectively controlled, can lead to respiratory problems, skin irritation, or chronic poisoning. Therefore, it is crucial to develop comprehensive health risk assessments and protective measures. The following is a detailed discussion from the perspective of risk identification, protection strategies, monitoring methods, and case studies.

The main sources of health risks include tungsten powder and rare earth oxide dust. These fine particles (<5 microns) can enter the lungs through the respiratory tract, causing pneumoconiosis or allergic reactions. Although rare earth oxides such as cerium oxide and lanthanum oxide are not radioactive, long-term exposure may cause abnormal liver and kidney function. The nitrate solution in the solution preparation stage is corrosive and can cause chemical burns when it comes into contact with the skin. The arc radiation generated during welding includes ultraviolet (UV) and infrared (IR) rays, which can cause eye damage (arc eye) and skin burns. In addition, high-temperature operations can lead to heat stress syndrome, including heat stroke and fatigue.

Protective measures start with engineering control. The production workshop needs to install a local exhaust system to capture the source of dust, and the dust concentration in the air is controlled below <2 mg/m³, which meets OSHA standards. Chemical handling areas should use enclosed equipment, such as automatic spray doping machines, to reduce manual contact. The welding test area should be equipped with a radiation shield and an automatic ventilation system to ensure a UV radiation < of 0.1 W/m².

Personal protective equipment (PPE) is the second line of defense. Operators are required to wear N95 or P100 dust masks, protective glasses (UV filters) and chemical-resistant gloves (made of nitrile). Use heat-resistant protective clothing (temperature resistant > 300°C) and safety boots for hot areas. The health monitoring procedure includes an induction physical examination and an annual health check-up, focusing on monitoring lung function (spirometry test) and serum rare earth levels (ICP-MS analysis). If abnormalities are detected, such as rare earth ions > 0.1 μg/L, work should be stopped immediately and medical intervention should be taken.

Training and education are at the heart of protective measures. Enterprises should conduct regular health and safety training, once a quarter, covering risk identification, proper use of PPE, and emergency response. Training can be combined with virtual reality (VR) to simulate welding scenarios and increase operator awareness. In addition, establish a health record system to record exposure history and physical examination data to support early intervention.

The systematic implementation of health risks and safeguards not only safeguards employee well-being, but also reduces medical costs and the risk of production interruptions.

9.3 Environmental impact assessment

Environmental Impact Assessment (EIA) is an important part of the production and use of composite rare-earth tungsten electrodes to identify, predict, and mitigate potential environmental impacts. These impacts include exhaust emissions, wastewater pollution, solid waste, and energy consumption. The evaluation is based on life cycle analysis (LCA), which quantifies the entire chain from raw material extraction to disposal to ensure sustainability. The following is detailed from the assessment methodology, impact types, mitigation strategies, and cases.

Environmental impact assessment methodologies include LCA software such as SimaPro or GaBi, using the ISO 14040 standard framework. Evaluation steps: 1. Target definition (system boundaries including production and use phases), 2. Inventory analysis (collection of data such as energy consumption and emissions), 3. Impact assessment (calculation of global warming potential, GWP and acidification potential AP), 4. Interpretation of results (identification of hotspots, such as hydrogen consumption in the reduction phase).

Key Types of Environmental Impacts:
Exhaust gas emissions: hydrogen exhaust gas and dust during the reduction and sintering process, containing trace amounts of rare earth oxides. Emissions can contribute to air pollution, with GWP contributing > 50%.
Wastewater pollution: Acidic wastewater produced by solution preparation and cleaning, containing nitrates and rare earth ions, may lead to eutrophication of water bodies.
Solid waste: waste electrodes and slag, containing tungsten and rare earths, account for 30% of the total waste, and may contaminate the soil if not properly disposed of.
Energy consumption: Approximately 50 kWh of electricity is consumed per kilogram of electrode production, mainly from sintering furnaces, resulting in approximately 20 kg of CO_2 carbon emissions.

Mitigation strategies include: using low-energy SPS sintering to reduce energy consumption by 20%; Wastewater recovers rare earths through ion exchange, with a recovery rate of > 90%; The exhaust gas is emission up to standard (dust < 10 mg/m³). Solid waste is recovered by high-temperature melting (recovery rate >85%), reducing landfill.
The assessment report must be submitted to the environmental protection department, which complies with China's Environmental Impact Assessment Law. Case: The LCA evaluation of a company showed that by optimizing the reduction process, the GWP was reduced by 25% and the green certification was obtained. In another case, after the implementation of the zero wastewater discharge system, the water pollution index dropped below 0.1 mg/L.
Environmental impact assessment promotes green transformation and contributes to carbon neutrality goals.

9.4 Recycling and reuse technology

Recycling and reuse technology is the key to the sustainable development of composite rare-earth

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tungsten electrodes, reducing resource waste and environmental burden. These techniques include physical separation, chemical extraction, and metallurgical recovery, with recovery rates of over 85%. The following is a detailed discussion of technical principles, processes, equipment and challenges.

The principle of recycling technology is based on the chemical differences between tungsten and rare earths. Physical separation uses magnetic separation or gravity separation to remove impurities; Chemical extraction uses acid-soluble or alkali-soluble dissolving electrodes to separate rare earth ions. Metallurgical recycling reduces tungsten by high-temperature melting.

Process:
Collection and pretreatment: Waste electrodes are sorted, cut into small pieces, and surface cleaned to remove contaminants.
Crushing and separation: Pulverize to <100 microns using a ball mill and remove iron impurities by magnetic separation.
Chemical extraction: acid dissolution method (hydrofluoric acid + nitric acid, temperature 80°C), dissolving tungsten matrix, ion exchange column separating rare earths (such as La^{3+}, Ce^{3+}).
Reduction and reuse: Tungsten solution is reduced into powder through hydrogen, and rare earths are recovered from oxides through precipitation.
Quality verification: Recycled materials have passed ICP-OES tests with a purity > 99%.

The equipment includes a ball mill (Fritsch Pulverisette), an ion exchange column, and a vacuum reduction furnace (ALD). Technical advantages: 30% lower cost and 50% lower environmental impact.
Challenges include low separation efficiency of rare earths (solvent optimization) and economics of scale.
Recycling technology promotes a circular economy and complies with REACH regulations.

9.5 Storage and Transportation Requirements

Storage and transportation requirements ensure that the composite rare-earth tungsten electrode maintains stable performance during circulation and avoids damage and contamination. These requirements are based on material properties such as susceptibility to oxidation and brittleness, meeting international shipping standards. The following is detailed in terms of storage conditions, packaging specifications, shipping methods and risk management.

Storage requirements: The storage environment should be dry and ventilated, with a temperature of 10 to 25°C, a relative humidity < 60%, and avoid direct sunlight. The floor of the warehouse is moisture-proof, and the electrodes are stored in categories (according to model and batch), and the distance from the ground is 0.2 meters >. The storage period does not exceed 12 months, and the surface is regularly checked for oxidation (no rust spots). Dangerous goods storage area isolates gases such as hydrogen.

Packaging specifications: Use vacuum-sealed plastic bags or aluminum foil bags, 10 to 50 electrodes per bag, filled with desiccant. The outer packaging is a crash-resistant carton or wooden box, and the label includes the model number, lot number, production date, and safety warning. The packaging complies with UN standards to avoid static electricity accumulation.

Mode of transportation: land transportation uses earthquake-resistant vehicles, with a speed < 80 km/h; Air freight complies with IATA regulations and is classified as non-dangerous goods; Sea freight uses containers, moisture-proof treatment. Transport temperature -10 to 40°C, avoid high temperature and high humidity.

Risk management: Shipping insurance covers damage, GPS tracking real-time monitoring. The contingency plan includes spill handling (using sorbents) and accident reporting.

Storage and transportation require product quality and reduced losses.

9.6 Green manufacturing principles

Green manufacturing principles guide the transformation of composite rare-earth tungsten electrode production to low-carbon and low-pollution, emphasizing resource efficiency and environmental harmony. These principles are based on ISO 14001, including cleaner production, circularity, and energy management. The following is a detailed explanation from the principle framework, implementation strategy, technology application and benefit analysis.

Principle framework: 1. Resource conservation: optimize the use of rare earths and reduce waste by 10%. 2. Pollution prevention: adopt waste-free process and zero emission growth. 3. Lifecycle management: full coverage from design to recycling. 4. Continuous improvement: Optimize through PDCA cycle.
Implementation strategy: In production, use SPS sintering to reduce energy consumption by 20%; The raw material is recycled tungsten, with a proportion of > 30%. The recovery rate of the wastewater circulation system > 95%.
Technology Applications: AI monitors energy consumption, predicts maintenance equipment; Nano rare earth doping increases efficiency by 15%. Choose environmentally friendly suppliers for green supply chains.
Benefit analysis: After implementing green principles, costs are reduced by 15% and carbon emissions are reduced by 25%.
The principle of green manufacturing enhances competitiveness and is in line with sustainable development.

9.7 Regulatory Compliance

Regulatory compliance is fundamental to the operations of composite rare-earth tungsten electrode businesses, covering environmental, safety, and trade regulations. These regulations ensure compliance and avoid fines and reputational damage. The following is a detailed discussion from domestic and foreign regulations, compliance mechanisms, risk assessments, and cases.

Domestic regulations: 1. Environmental Protection Law (revised in 2015): EIA is required to report that the emission standards comply with GB 26451. 2. Work Safety Law (revised in 2021): safety training and emergency plan. 3. Regulations on the Administration of Rare Earths (2024): Supply chain traceability, export quota management.

International regulations: 1. REACH (EU): Chemical registration, Limits for Harmless Substances. 2. OSHA (US): Occupational health standards, exposure limits. 3. Basel Convention: Control of cross-border movement of waste.

Compliance mechanism: establish a compliance department, annual audit; Train employees on regulatory knowledge; Third-party certifications such as ISO 14001.
Risk assessment: Use SWOT to analyze regulatory risks and develop a response plan.

Compliance with laws and regulations ensures the long-term development of the enterprise.

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Composite Rare-Earth Tungsten Electrode Introduction

1. Overview of Composite Rare-Earth Tungsten Electrode

The composite rare-earth tungsten electrode is a high-performance welding electrode made from high-purity tungsten as the base material, with multiple rare-earth oxides (such as lanthanum oxide, yttrium oxide, cerium oxide, etc.) added in combination. Compared with traditional single rare-earth tungsten electrodes, it demonstrates superior electron emission performance, high-temperature stability, burn resistance, and arc ignition capability, making it widely used in high-precision, high-strength, and long-duration continuous welding applications.

2. Performance Parameters (Reference Values) of Composite Rare-Earth Tungsten Electrode

Item	Typical Value	Remarks
Tungsten Purity	≥99.95%	Base tungsten content
Rare-Earth Oxide Content	1.5%–3.0%	Composite ratio customizable
Operating Current Range	DC 5A–500A / AC 20A–350A	Depends on electrode diameter
Maximum Temperature Resistance	2600°C	Instantaneous arc temperature
Service Life Improvement	1.5–3 times	Compared to pure tungsten or single rare-earth tungsten electrodes

3. Applications of Composite Rare-Earth Tungsten Electrode

Aerospace Manufacturing: Welding of titanium alloys, nickel-based alloys, and other high-temperature alloys

Nuclear and Power Equipment: Welding of high-temperature pipelines and heat-resistant steel structures

Precision Machining: Welding of stainless steel, copper, aluminum, and their alloys

Automotive and Rail Transit: Welding of critical load-bearing components

Electronics and Vacuum Devices: High-vacuum arc welding and micro-welding processes

4. Packaging and Supply Specifications

Diameter: Ø1.0mm, 1.6mm, 2.4mm, 3.2mm, 4.0mm, etc. (customizable)

Length: 150mm, 175mm, etc. (customizable)

Packaging: Plastic box or vacuum-sealed packaging, 10 pieces/box (Standard)

5. Procurement Information

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Chapter 10 Future Development Trend of Composite Rare-Earth Tungsten Electrodes

10.1 New rare earth combinations and doping technologies

The future development of composite rare-earth tungsten electrodes shows broad prospects in terms of new rare earth combinations and doping technologies. As materials science and welding techniques advance, researchers continue to explore new combinations of rare earth elements to further optimize the electrode's electron emission capabilities, arc stability, high temperature resistance, and service life. These novel combinations are designed not only to overcome the limitations of traditional single rare earth doping, but also to be customized for specific application scenarios. According to the latest research trends in 2025, new rare earth combinations will involve more multi-element synergy, trace additive addition, and innovation in intelligent doping processes.

First, the focus of the new rare earth assemblage is on the synergistic effect of multiple rare earth oxides. Traditional binary combinations such as cerium oxide (CeO_2) and lanthanum oxide (La_2O_3) have been shown to reduce electron escape work to less than 2.0 eV and improve arc stability by more than 95%. But the future trend shifts to ternary or quaternary combinations, such as the combination of cerium oxide, lanthanum oxide, and yttrium oxide (Y_2O_3) (ratio 1:1:3), which excels in high-current welding, with a 15% reduction in electrode tip temperature and a 20% reduction in wear rate. Recent studies have shown that the addition of erbium oxide (Er_2O_3) or lutetium oxide (Lu_2O_3) as the fourth element can further refine the grain size to 3-5 microns, improve the mechanical strength of high temperatures, and is suitable for titanium alloy welding in the aerospace field. The Er-W electrode has the lowest mass loss at 250 A current and the best tip morphological stability, indicating the potential of the Er-W combination in heavy-duty welding.

Innovation in doping technology is another key direction. Traditional mechanical mixing and chemical doping methods are evolving towards more precise atomic-level doping, such as sol-gel or vapor deposition techniques to achieve uniform distribution of rare earth oxides in tungsten matrix. The 2025 study emphasizes trace additive doping, such as adding zirconium hydride (ZrH_2) at a ratio of 0.1%-0.5%, which can control oxygen content, reduce grain size by 20%, and improve electron emission performance. ZrH_2-doped rare earth tungsten electrodes increase the electron emission current density by 30% and reduce oxide evaporation, extending the life to more than 1200 hours. In addition, new doping technologies include laser-assisted doping and electrochemical deposition, which can precisely control the size of rare earth particles down to 50-200 nm and enhance the diffusion strengthening effect.

In the future, the new combination will integrate AI-assisted design to predict the optimal rare earth ratio through machine learning models. For example, simulations based on density functional theory (DFT) can predict the working functions and thermal stability of different combinations, accelerating the R&D cycle. Market analysis shows that by 2031, the market share of new rare earth combined electrodes will account for 40% of the total market, driven by the demand for precision welding of new energy vehicles and 5G equipment. The challenge lies in the sustainable supply of rare earth resources, but through recycling technology, the shortage is expected to be alleviated.

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Overall, new rare earth combinations and doping technologies will promote the development of composite electrodes in the direction of higher performance and environmental protection to meet the needs of Industry 4.0.

10.2 Nano rare earth oxide doping and diffusion enhancement

Nano rare earth oxide doping and diffusion strengthening is one of the core technology directions for the future development of composite rare-earth tungsten electrodes. This technology achieves more uniform distribution and stronger strengthening effect by controlling the size of rare earth oxide particles at the nanometer level (< 100 nm), greatly improving the mechanical properties, thermal stability, and electron emission efficiency of the electrode. Research trends in 2025 show that nanodoping will transition from the laboratory stage to industrialization, with applications in high-precision welding and electrode manufacturing in extreme environments.

The doping principle of nano rare earth oxides lies in their high specific surface area and quantum effect, which can effectively nail the tungsten grain boundary and inhibit grain growth. While traditional micron-level doping grain sizes are 5-10 microns, nano-doping can refine the grains to 1-3 microns, improving fracture toughness by more than 25%. For example, the working function of a tungsten electrode doped with lanthanum oxide (La_2O_3)-doped decreases to 1.8 eV, and the electron emission current density is increased by 40%. Recent studies have explored the compound doping of nano cerium oxide and yttrium oxide, such as doping rare earth elements in WO_3 nanostructures, which can improve optoelectronic performance and extend to pH sensor applications. The nano-CeO_2-doped WO_3 electrode approaches the Nernst value (59 mV/pH) in pH sensitivity, with a response time of a few seconds.

Diffusion strengthening is the key mechanism of nanodoping, and rare earth nanoparticles are uniformly diffused in the tungsten matrix as the second phase, blocking the dislocation movement and improving the high-temperature strength. The addition of ZrH_2 as an additive can further reduce the average grain size by 20% and enhance the electron emission stability. Preparation techniques include sol-gel method, high-energy ball milling, and vapor deposition. For example, the Xingxing mill processes powders at 400-600 rpm for 8-12 hours to achieve uniform doping at the nanoscale. Studies have shown that nano-Y_2O_3-doped WO_3 microspheres have high pyroelectric properties and are suitable for infrared sensor applications.

Future trends include multi-rare earth nanocombinations such as Sm^{3+} doped WO_3 for bifunctional electrocatalysts with current densities of up to 100 mA/in acidic electrolytescm²。 The challenge lies in nanoparticle agglomeration and cost control, but can be solved by surface modifications such as silane coupling agents. The market predicts that by 2032, the nano-doped electrode market will reach a CAGR of 8.14% and will be used in new energy batteries and aerospace. Nano rare earth oxide doping and diffusion enhancement will promote the evolution of electrodes in the direction of intelligence and multifunction, improving their performance under extreme conditions.

10.3 Integration of AI intelligent welding parameter optimization technology

The integration of AI intelligent welding parameter optimization technology is a revolutionary direction for the future development of composite rare-earth tungsten electrodes, which adjusts welding parameters in real time through artificial intelligence algorithms to improve weld quality, efficiency and automation level. Trends in 2025 show that AI will be deeply integrated with electrode materials to achieve predictive maintenance and adaptive welding, suitable for complex working conditions such as aerospace and new energy vehicle manufacturing.

At the heart of AI optimization are machine learning models, such as neural networks and fuzzy logic, which are used to predict optimal parameters (current, voltage, gas flow). For example, the fuzzy deep neural network framework predicts the geometry of TIG weld welds with an accuracy of 92.59%. Input parameters include current (50-250 A), speed (0.1-0.5 m/min), and electrode type (WLaCeY), output weld depth and width. Through big data training, AI can optimize parameters and reduce defect rates by 30%.

Converged technologies include digital twins and image recognition. Digital twin simulates electrode behavior to predict lifetime and stability; Passive machine vision classifies defects, and the welding quality rate of IoT robots reaches 88%. The study shows that the AI-driven adaptive feedback system predicts quality based on the angle degradation of the electrode tip and optimizes parameters such as voltage < 35 V.

In the future, AI will expand to multimodal data fusion, such as combining SEM microanalysis and real-time sensor data to predict the performance of rare earth combinations. Challenges include data privacy and model robustness, but are addressed through edge computing. According to market analysis, by 2031, the AI welding technology market will grow at a CAGR of 8%, and composite electrode fusion AI will dominate precision manufacturing. Case: AI optimizes TIG welding parameters and improves stainless steel weld strength by 10%.

AI integration will make composite rare-earth tungsten electrodes intelligent and drive the transformation of the welding industry 4.0.

10.4 Green manufacturing and sustainable development

Green manufacturing and sustainability are strategic priorities for the future development of composite rare-earth tungsten electrodes, aiming to reduce environmental impact, improve resource efficiency, and align with global carbon neutrality goals. Trends for 2025 show a shift in green preparation technologies from laboratories to large-scale production, emphasizing waste-free processes, recycling cycles, and low-carbon energy use.

Green manufacturing principles include cleaner production and circular economy. Traditional process waste gas and wastewater pollution is serious, and new technologies such as green preparation of multi-composite rare earth electrodes and sintering using low-energy SPS can reduce carbon emissions by 25%. The recovery technology recovers 85% of tungsten and 90% of rare earths through acid dissolution and ion exchange, reducing mineral dependence.

Sustainability focuses on resource sustainability, such as extracting rare earths from waste electrodes,

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processing 100 tons of waste and recycling 80 tons of tungsten. AI-assisted optimization of parameters reduces energy consumption by 20%. Regulations such as REACH require a recycling rate of > 95%, prompting companies to submit carbon footprint reports.
Future trends include bio-based additives and renewable energy to drive production. The market predicts that by 2032, the green electrode market will grow at a CAGR of 4.1% and will be used in environmentally friendly welding. Case: A factory implemented green manufacturing, reduced costs by 15%, and was certified.

Green manufacturing will ensure that composite electrodes are sustainable and contribute to a low-carbon economy.

10.5 Application prospects in aerospace, nuclear industry, medical manufacturing and other fields

Composite rare-earth tungsten electrodes have promising applications in aerospace, nuclear industry, and medical manufacturing, benefiting from their high performance and green characteristics. Trends for 2025 show that these areas will drive electrodes towards higher precision and durability.

Aerospace field: used for titanium alloys and high temperature welding, such as engine blades. The weld strength of the WLaCeY electrode > 900 MPa and the porosity < 0.1% in TIG welding. In the future, nano-doped electrodes will be used to 3D print aerospace components, with a 15% increase in accuracy and a 30% market share.

Nuclear industry: corrosion resistant and highly stable for reactor pipeline welding. The penetration depth of the zirconia-containing electrode is 3-5 mm, and there are no cracks. In the future, AI optimization parameters will improve safety, and recycling technology will reduce waste pollution.

Medical Manufacturing: Used for implants and radiation shielding, such as surgical tool welding. Purity and low pollution characteristics are key, and rare earth doping increases conductivity by 10%. In the future, the application of pH sensors will expand, and the sensitivity of CeO_2 doped electrodes is close to 59 mV/pH.

Prospects include versatile integrations such as AI-fused welding robots. The market grew at a CAGR of 8%, challenging the supply of resources, but recycling solved. Applications will promote innovation in high-tech industries.

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Appendix

A. Glossary

Composite rare-earth tungsten electrode: An electrode material with multiple rare earth oxides added to a tungsten matrix to improve welding performance.

Powder Metallurgy: A processing method for preparing metal materials through powder molding, sintering, and other processes.

Ignition Performance: The ability of the electrode to initiate the arc at low currents.

Arc Stability: The arc remains uniform and does not drift during the welding process.

Work Function: The minimum amount of energy that electrons escape from the surface of a material.

TIG welding (Tungsten Inert Gas Welding): Tungsten inert gas shielded welding.

Plasma Welding: A technology that uses plasma arcs for welding.

Rotary Forging: A process in which bars are processed through rotational hammering.

SEM (Scanning Electron Microscope): A scanning electron microscope used for microstructure observation.

Reo (Rare Earth Oxide): Rare earth oxides, such as La2O3, CEO2, etc.

Non-Destructive Testing: A method of checking for defects without damaging the sample.

Hydrogen Reduction: The process of reducing tungsten oxide powder with hydrogen.

Cold Isostatic Pressing: A molding technique that compacts powder under isostatic pressing conditions.

Burning Arc Life: The lifespan of the electrode under continuous welding.

Green Manufacturing: Environmentally friendly and low-pollution production methods.

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