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Development of Aluminum Alloy Materials: Current Status, Trend, and Prospects

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Abstract: This study comprehensively analyzes the application status of aluminum alloy materials in fields such as aerospace and transportation and provides an introduction to the industry scale and technical level of aluminum alloy materials in China. Moreover, the main problems of the aluminum alloy industry are systematically summarized in view of the shortcomings of some key aluminum alloy materials in China and the deficiencies in original technologies such as high-performance aluminum alloy development, processing technology, and intelligent control. The market demand for aluminum alloy materials is analyzed based on trends in the development of industries such as the automobile, ship, and aerospace industries. Based on the current status of the aluminum alloy industry in China, the following countermeasures and suggestions are proposed: enhancing the research and development system to improve the development environment, optimizing the production structure to promote production quality and efficiency and coordinate development, strengthening policy support, promoting talent team construction, promoting intelligent manufacturing and the Internet Plus initiative, and strengthening international cooperation, particularly along the Belt and Road. This study is expected to help solve some critical problems of the industry and provide a reference for promoting the advanced and green development of aluminum alloy materials.
Keywords: aluminum alloy materials; automobile industry; ship industry; aerospace domain

1 Introduction

China has a large capacity for the consumption and production of aluminum alloys, which are widely utilized in various industries, including transportation, aeronautics, marine, and aerospace industries. In particular, for some critical lightweight parts in the machines involved in these fields, aluminum alloys are irreplaceable. However, a large proportion of aluminum products in China are medium- and low-grade, and their production involves high energy consumption, low efficiency, high cost, and vicious competition among domestic producers. These situations are difficult to change, and some high-tech products still need to be purchased abroad [1], which impedes the manufacturing process. China has significant advantages in terms of communication and high-speed railways. However, with the continuously evolving international circumstances, a threat of critical materials being cut off is emerging; therefore, self-innovation in this field is extremely urgent. In new industrial situations, developing high-

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tech aluminum materials into eco-friendly products for smart synthesis and manufacturing plays a strategic role in supporting the sustainable and high-quality development of China's critical manufacturing industry. In this study, the development of aluminum alloys worldwide is examined, the market demands of commonly used aluminum alloy systems are analyzed, the current setbacks and future goals in the domestic field are summarized, and the corresponding development strategy is provided to promote the upgrading and progression of related industries.

2 Development and research status of aluminum alloys in China and abroad

2.1 Development and research status of aluminum alloys abroad

In general, industrial countries have a long development and application period for aluminum, well-based research accumulation, well-developed aluminum alloy material systems, and relatively high technical levels. In particular, some industrial superpowers such as the United States and Russia, which have already conducted years of research on aluminum alloys, have broadly applied a large number of alloy materials in the fields of automobiles, planes, vessels, and aerospace and formed a hegemonic pattern to some extent.

In the automobile domain, aluminum alloys play a significant role in reducing car weights. For the 2XXX series aluminum alloy, Rey Luffy of the United States and Sibene of France sequentially developed the 2036–T4 and AU2G–T4 aluminum alloy plates, which were used in car bodies. For the 5XXX series aluminum alloy, ALCOA of the United States developed X5085–O and 5182–O, which were used as car inner panels. For the 6XXX series aluminum alloy, ALCOA developed the 6009 and 6010 aluminum alloys as car bodies. Norsk Hydro A.S. [2] developed the HHS360 alloy with a tensile strength of 360 N/mm^2, an increase of 10.8% compared to 6082, and an elongation rate of 10%. Based on this alloy, the HHS400 alloy was developed, for which the tensile strength reached 400 N/mm^2, yield strength was higher than 370 N/mm^2, and elongation rate was 8%. It was mainly used for automobile production. Constellium [2] developed the HSA6 series of alloys, of which the HSA6–T6 alloy has the lowest yield strength of 370 N/mm^2 and tensile strength of 400 N/mm^2. Compared to a traditional automobile constructed using a full aluminum alloy, the maximum weight is 30% less. Currently, advanced foreign aluminum processing companies are committed to developing low-cost automotive sheets. India's Novelis Aluminum Co., launched the Advanz™ series alloy Ac5754R to further reduce car weight. The company also cooperated with Jaguar Land Rover Automotive Co., Ltd. to develop the AC–170PX aluminum alloy with excellent forming and hemming properties [3] for use in outer automobile panels. Arconic Inc. in the United States has successfully developed a new generation of automotive sheet production equipment and process "Micro-Mill" technology, which has greatly improved the performance of aluminum panels meant for automotive bodies and panels, increasing overall performance by 20% and reducing costs by 30%. Currently, in the field of automobile body panels, the 6082 aluminum alloy is the most widely used, and many companies use extruded profiles of the 6XXX or 7XXX series for front and rear anti-collision beams.

Recently, the application of aluminum alloys in ships has gradually expanded in China, while foreign countries are years ahead in the development of the same. So far, the 5XXX and 6XXX series aluminum alloys have been mainly used for ship hulls and shipbuilding. Deformed aluminum alloys [4] include the 5086 and 5456 alloys from the United States, 5083 alloys from Japan, N8(5083) alloys from the United Kingdom, and AMr6(5A06), AMr61, B48-4(01980), K48-1, and K48-2 alloys from the former Soviet Union. Russia has developed a high-strength Al–Zn–Mg alloy series (such as 01970 and 01975 alloys), which contains scandium (0.1% to 0.3%). The casting aluminum alloys [4] mainly include the former Soviet Union's BAП5, AП4M (ZL111), AП8 (ZL301), AП13, AП25, and AП27 alloys and the 356 (ZL101), SEM328 (ZL106), 514 (ZL302), 515, 518 (YL302), 520 (ZL301), and X250 alloys from the United States. Currently, the use of aluminum alloy materials in the ship industry is primarily based on the 5083 alloy and its improved types that make full use of their comprehensive advantages in corrosion resistance, welding performance, easy formability, and mechanical properties.

In the aerospace industry, modern aluminum materials are developing in the direction of high comprehensive performance, low density, large scale, high uniformity, and the integration of function and structure. Aiming at 2XXX series aluminum alloys, ALCOA and ALCOA France have developed the 2026 and 2027 alloys with high strength and damage tolerance [5]. Compared to the 2024 alloy, its extrusions (thickness 12–82 mm) and plate thickness (thickness 12–55 mm) were increased by 20%–25% and 10%, respectively. In terms of the 7XXX series aluminum alloys [5], ALCOA, ALCOA France, and Aleris have developed high-strength and tough aluminum alloys with low quenching sensitivities of 7085, 7140, and 7081. ALCOA France has developed the 7056–T79/T76 alloy, an ultra-high-strength aluminum alloy that has been used in A380 aircraft wing panels. Russia has developed 1460

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aluminum-lithium (Al–Li) alloys, and the United States has developed Weldlite series alloys and 2097, 2197, and 2195 Al–Li alloys. Kenlian Aluminum in the United States has developed 2050 and 2198 alloys (Al–Cu–Li–Mg–Ag) with low density, high toughness, and high damage tolerance. In 2010, Kenlian Aluminum Corporation registered the Airware trademark for Al–Cu–Li series alloys. Currently, the demand for aluminum alloy materials in the aerospace field is mainly concentrated in high-strength 2XXX and 7XXX series alloys, as well as low-density Al–Li alloys.

2.2 Development and research status of aluminum alloys in China

Since the 13th Five-Year Plan, China's aluminum production capacity and technical level have made great progress [1]. In 2019, aluminum production reached 5.252×10^7 t, ranking first in the world. China has independently developed LC4, LC9, LY12, 2A12, 2A16, 7A04, 7B04, 7A50, 7B50, and other series of aluminum alloys [6,7], and established first-, second-, and third-generation aluminum alloy material processing technology systems. In recent years, the properties of new high-strength and toughness cast aluminum alloys, third-generation Al–Li alloys, and high-performance aluminum alloy profiles developed by China have reached advanced international levels. China has added 29 domestic aluminum alloy brands in the past 10 years in the *Chemical Composition of Wrought Aluminum and Aluminum Alloys* (GB/T 3190-2020). During this time, Beijing University of Technology has mastered the preparation and processing technology of erbium-containing dispersion-strengthened aluminum alloys and developed five alloy grades including the erbium-containing 5E83 aluminum alloy cold-rolled sheet, 5E06 aluminum alloy hot-rolled sheet, and hot-extruded wall panel. These alloys were included in the national standard [8] and have been used in important applications in the fields of national defense and automobiles, and some series have replaced imported products.

Aiming at the extrusion-forming process and equipment for high-performance aluminum alloy profiles, the CRRC Co., Ltd. and universities have developed aluminum alloy refining, purification, and ingot homogenization technologies and developed large-scale extrusion dies and equipment to enable the development of aluminum alloy profiles. The cycle time was shortened by 25%, the cost was reduced by 15%, and the yield rate increased to 62%. Northeastern University and Dalian Jiaotong University developed continuous extrusion short-flow processing technologies for liquid metal, semi-solid metal, and solid metal, respectively, and realized their industrialization, which was achieved in the relevant field in the international lead. Shandong Nanshan Aluminum Co., Ltd. successfully entered Boeing's global supplier list. China Zhongwang Holdings Co., Ltd. has successively acquired controlling rights over Una Aluminum Co., Ltd. of Germany and Silver Yachts Ltd., an all-aluminum superyacht manufacturer based in Australia.

A large number of advanced weapons made of key aluminum alloy materials provided by Chinalco Northeast Light Alloy Co., Ltd., Southwest Aluminum (Group) Co., Ltd., and Northwest Aluminum Co., Ltd. have appeared on the battlefield. In addition, Northeastern University, Shanghai Jiaotong University, China Aluminum Material Application Research Institute Co., Ltd., and Jilin University have reached internationally advanced or leading levels in high-strength and high-conductivity deformable aluminum alloys, aluminum alloys for automobiles, and cast aluminum alloys. Currently, some aluminum alloy materials with intellectual property rights in China have been used in industries such as the automobile, ship, and aerospace industries.

In the automotive field, China's aluminum alloy automotive sheet has begun to take shape; however, mature products are limited to 6016 and 5182 brands, and other brands still do not have a mass supply capacity. In recent years, the Aluminum Corporation of China has achieved certain achievements in the field of lightweight automotive alloys, including 6016, 6014, 5182, and 5754 alloys for automobiles, and realizing small-batch applications in Geely Automobile and Haima Automobile Manufacturing.

In the field of shipbuilding, the commercially available marine aluminum alloy plates/profiles developed by China in recent years are 5083, 6061, and 6082 aluminum alloys. With the implementation of the national deep blue strategy, China has begun to build its own cruise ships, "sea ranch," drilling platforms, power stations, and helicopter platforms. China Merchants Group Co., Ltd.'s first cruise ship, Polar, has been delivered. There are still many gaps in the development of other parts of the hull and aluminum alloy materials that are used in China's ocean and river environments, and multi-field and multi-disciplinary cooperation is still needed.

In the aerospace industry, aluminum processing companies affiliated with Aluminum Corporation of China, Beijing Institute of Aeronautical Materials, GRINM Group Co., Ltd., and Central South University have developed ultra-high-strength aluminum alloys, high-purity and high-damage-tolerant aluminum alloys, Al–Li alloys, rare-earth aluminum alloys, and other aluminum alloys. Based on this, 2124-T351, 2024-T851, and 2024HDT plates, 7050/2124 ultra-wide and ultra-thick plates, 7B50-T7751 thick plates, 7A55-T7751 thick plates, 2A97 Al–Li alloy thin plates and profiles, and 2297 Al–Li alloy thick plates have been developed, enabling the localization of many products. High-strength, high-toughness, and low-quenching sensitivity 7A85 forgings have been developed and applied in batches to fill the domestic gap. The 10-m integral ring developed by Southwest Aluminum (Group) Co., Ltd. continuously broke the world record for the aluminum alloy integral ring.

3 Problems in aluminum alloy field in China

It is worth noting that although China has achieved remarkable development in aluminum alloy materials at the industrial scale and technical level, the construction of China's modern industrial system started with a weak foundation, and it is difficult to catch up with developed countries. A considerable number of key basic materials and core components remain insufficient. China will be a major demand country for key basic materials for a long period of time, and the demand for the quantity and types of such materials will continue to increase. However, high-end materials do not account for a high proportion of the industrial system, which includes few original innovations and insufficient research and development of basic common key technologies and intensive processing technologies. ALCOA has 30 000 patents; in contrast, Chinese companies have few patents. Very few aluminum brands, among hundreds of commonly used brands, have been developed in China. Meanwhile, the consistency, uniformity, and stability of the product quality were not high. The quality stability of pre-stretched thick plates and skin plates for large aircraft and passenger car panels needs to be improved, and some high-end aluminum plates, strips, and foils are still primarily imported. In addition, the extensive development of China's aluminum alloy material industry is a serious problem. Although the scale of the industry is developing rapidly, there has been little research and development. Technological innovations in production, education, and research integration are weak, and universities and enterprises cannot provide the advantages of collaborative innovation. Therefore, it is very important to gradually promote the development of relevant research and industries toward high quality, high innovation, and high efficiency.

In the automotive field, China's automotive aluminum alloy sheets still face three major problems. (1) There is a lack of automotive aluminum alloys with independent intellectual property rights, and high-end automotive aluminum has not been serialized, which makes it difficult to meet the individual needs of automobile companies. (2) There is a lack of research and development platforms for automotive sheet applications. Research needs to be strengthened in advanced forming, connection of dissimilar materials, low-cost and environmentally friendly parts manufacturing, and surface treatment. (3) The application of aluminum alloy profiles in new-energy vehicles needs to be strengthened, and the corresponding technological innovation platforms need to be established to develop related products such as body structures, electric drive systems, battery trays, sub-frames, and surface treatments.

In the ship industry, China's marine aluminum alloys still have two technical bottlenecks. First, there are few types of aluminum alloys developed for marine fields, and the overall performance and quality stability of these alloys are lower than those of the same brand in foreign countries, and the other is the application technology of aluminum alloy materials on ships, which is mainly reflected in the welding technology. There is still a gap between China and foreign countries in friction stir and laser welding, which limits the development of aluminum alloys for ships.

In the aerospace field, there is still a significant gap between China and developed countries in the research and application of aerospace aluminum alloys. The development of new alloys in China is in the imitation stage, and few types of alloys have been developed; there is little research on the basic theory of alloying. There is still a gap between the quality stability and cost of China's aviation material products and imported materials.

4 Market demand and development trend of various aluminum alloy materials

Market demand often determines the types, productivity, and performance characteristics of aluminum alloy products. Because of the wide variety of aluminum alloys, the development process and present situation are different in China and abroad, and some aluminum alloys will be cross-applied in the fields of automobiles, ships, and aerospace; therefore, in this section, aluminum alloy systems are classified and explained.

4.1 2XXX series aluminum alloy

2XXX (A1-Cu-Mg) series aluminum alloys have high tensile strength, toughness, and fatigue strength, good heat resistance, processing, and welding properties, and are widely used in the aerospace, automotive, and weapon industries. The main grades are 2A01, 2A02, 2A06, 2A11, and 2A12. A series of alloys, such as 2024, 2124, 2524,

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and 2324 alloys, have been developed to improve strength, strength and toughness matching, and damage tolerance. China's equipment models are developing toward light weight, long life, high reliability, and low cost, and have high requirements for fracture toughness, crack growth resistance, and corrosion resistance of fuselage skin materials. On the basis of the 2024-T351 aluminum alloy thick plate, foreign countries have developed 2324, 2624, and other high-damage-tolerance aluminum alloys for lower wing surfaces with different strength, toughness, fatigue, and corrosion resistance, and realized installation applications. There is an urgent need to develop a 2XXX series aluminum alloy with a high damage tolerance. In the future, composite microalloying will be an important development direction for Al-Cu-Mg series high-strength aluminum alloys.

4.2 4XXX series aluminum alloy

Currently, automobile pistons in China are mainly fabricated using eutectic and hypoeutectic aluminum silicon (Al–Si) alloys; however, with the continuous tightening of engine performance requirements, meeting the standard is difficult. Hypereutectic Al–Si alloys have a low density, low linear expansion coefficient, high wear resistance, and high volume stability, rendering them more ideal piston materials as opposed to hypoeutectic and eutectic Al–Si alloys. Eutectic Al–Si alloy pistons, such as those composed of the A390 alloy in the United States, AC9A and AC8A (ZL109) alloys in Japan, and A390 alloy in Australia, have been mass-produced abroad and used in trucks and cars. However, there exist few manufacturers of hypereutectic Al–Si alloy pistons in China, and most of them rely on imports. In addition, there exists a large discrepancy between automotive turbocharged aluminum alloy materials produced in China and those in foreign countries. High-performance aluminum alloy materials for turbocharged automotive applications are primarily produced in countries such as Japan. Therefore, it is imperative to develop key automotive aluminum alloy materials for high-performance pistons and turbocharged impellers.

4.3 5XXX series aluminum alloy

Aluminum magnesium (Al–Mg) alloys, especially Al–Mg alloys with a high Mg content, have a high specific strength, good weldability, and corrosion resistance, and will become competitive materials for used in the aerospace and ocean industries, high-speed trains, and other fields. Currently, the use of Al–Mg alloy plates, profiles, and welding wires in aerospace, railway, marine, and other applications is mainly dependent on imports. The high-end welding-wire market is monopolized by the US company ALCOA. ER5183 and ER5356 alloys are mainly imported, and imports from ALCOA account for approximately 70% of all sales, while the Al–Mg alloy used in naval vessels is primarily produced in Russia. Conventional ingots with high Mg contents have coarse dendrites and exhibit severe eutectic phase segregation and poor forming performance. Current processing methods still involve many drawbacks, such as low performance, poor apparent quality, long procedures, unstable quality, and low yield rate. Sub-rapid solidification and formation can inhibit the precipitation of Mg and simultaneously result in control and production of fine equiaxed crystals and nano-precipitated phases, thereby greatly improving the performance and uniformity of the material. Therefore, the development of high-performance technology for sub-rapid solidification, continuous rheological extrusion, and rolling of an Al–Mg alloy is expected to satisfy the demand for high-quality Al–Mg alloys.

4.4 6XXX series aluminum alloy

6XXX series aluminum alloy materials are key in the fields of rail transit, automobiles, and electronics. Since the 1980s, developed countries and regions such as Europe, America, and Japan have developed automotive aluminum alloys and registered trademarks such as 6009, 6016, 6010, 6111, 6022, and 6082, producing a relatively complete car body panel and extrusion, forgings, and other production and application systems. The industrialization of 6XXX series aluminum alloy body panels and forgings in China has just commenced, and there still exists significant scope for improvement. In this regard, 6016-S, 6016-IH, 6016-IBR, 6A16-S, 6A16-IBR, and 6022 automotive aluminum alloy sheets have been proposed by the Ministry of Industry and Information Technology for focused development. The elongation rate of typical 6XXX series aluminum alloy sheets is A50≥25%, r ≥0.60, 60 day parking yield strength $Rp0.2 \leq 140$ N/mm^2, and a baking paint hardening yield strength increase ≥80 N/mm^2. In response to different needs, the advancement of design, preparation, and processing technologies for 6XXX series aluminum alloys has become an inevitable development trend.

4.5 7XXX series aluminum alloy

The 7XXX series aluminum alloy exhibits good stress corrosion resistance, is the highest-strength aluminum alloy series, and is an internationally recognized aviation backbone material. Recently, a 7055 alloy (Al-8Zn-2.05Mg-2.3Cu-0.16Zr) has been developed, with a yield stress of over 620 MPa in the T77511 state, and it is used in Boeing 777 aircraft, reducing the weight thereof by 635 kg. Currently, China's aviation-use 7XXX series aluminum alloy lacks systematic alloy design, preparation, and processing technology, and some products are completely imported. Because large-sized ingots of 7XXX series aluminum alloys have many alloy elements, wide solidification intervals, large casting stress, and undergo easy oxidation/segregation of alloy elements, the metallurgical quality of these ingots is poor, and the room-temperature formability is low. Thus, it is important to develop new 7XXX series aluminum alloys.

4.6 Al–Li alloy

Al–Li alloys, among lightweight aviation materials, have undergone the most rapid development in recent years. They have the characteristics of low density, high elastic modulus, high specific stiffness, and good fatigue performance and corrosion resistance. When used to replace conventional aluminum alloys, Al–Li alloys can reduce the weight by 10%–20% and increase the stiffness by 15%–20%. The ALCOA company of the United States launched the "ALCOA Aviation 20/20 Plan" at the beginning of the 21st century. The goal was to reduce the cost and weight of the aviation aluminum alloy by 20% within 20 years. Constellium has developed 2050 and 2198 Al–Li alloys (Al–Cu–Li–Mg–Ag) with low density, high toughness, and high damage tolerance. There are very few Al–Li alloy grades independently developed in China, and only 1420 alloys have been used. The Al–Li alloy used in the C919 passenger plane was provided by ALCOA. Only limited alloy grades such as 1420, 2195, 2197, and 2A97 can be produced in China, and ingots are only of the size of (310–400) × 1280 × 4000 mm slabs, and round ingots are below ø650 mm in thickness. In high-end aviation applications, slabs (2B16) with a thickness of 60 mm or more and a width of 1500 mm (2B16) and ingots (2B16) with a diameter of 1500 mm or more are not yet undergoing industrial production. Therefore, it is of great significance to realize new Al–Li alloy designs, ultra-large ingot preparations, and deep processing technology.

4.7 Heat-resistant aluminum alloy

Heat-resistant aluminum alloys are highly resistant to oxidation and creep at high temperatures by controlling the Si, Fe, Ni, Ag, rare earth elements, and other elements [9]. They constitute a key basic material in the aerospace, automobile, and rail transit fields. Traditional heat-resistant aluminum alloys include 2519, 2618, 2219, and 2D70. With the rapid development of aerospace and automobile industries, the requirements for heat-resistant aluminum alloys are increasing. The new generation of fighters exhibits a high cruising speed, and the working temperature of the fuselage skin is above 150 °C. The current long-term use temperature of heat-resistant aluminum alloys such as 2618, AK4-1ч, and 2D70 is below 150 ℃. The development of new heat-resistant aluminum alloys is therefore of primary importance.

4.8 Aluminum scandium (Al–Sc) alloy with ultra-low scandium content

Al–Sc alloys have excellent properties such as high strength, good plasticity, and corrosion resistance, and they have become a new generation of lightweight materials for aerospace, ships, etc., after the Al–Li alloy. The tensile strength of the Al–Mg alloy containing trace scandium is 30% higher than that of the 5083 alloy, and the yield strength is more than double. Its weldability is equivalent to that of the conventional 5XXX series alloys. The mechanical properties of the heat-affected zone and welding line are approximately equal to those of the matrix, and the corrosion resistance is equivalent to that of the 5083 alloy. Substituting 5XXX series or 6XXX series alloys with the Al–Sc alloy for aerospace parts manufacturing can yield significant reductions in weight. These alloys are also superior materials for automobiles and rail vehicles. Russia ranks at the forefront globally regarding development of aluminum alloys containing scandium and has developed Al–Mg–Sc, Al–Mg–Li–Sc, Al–Zn–Mg–Sc, Al–Zn–Mg–Cu–Sc, and Al–Cu–Mg–Sc series alloys, with a scandium content of 0.18%–0.5%. To promote the application of Al–Sc alloys in aerospace and automobiles, the Ministry of Industry and Information Technology of China prioritized the development of aluminum alloys containing scandium as a new material. China is rich in scarce resources, and a high-purity scandium oxide extraction production line has been built, laying the foundation for the development of Al–Sc alloys.

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4.9 500 MPa class hot stamping aluminum alloy for automobiles

Hot-stamping high-strength aluminum alloy materials are however still lacking. The combination of new materials and new forming process development is an effective measure to address the challenge of forming high-strength aluminum alloy automotive parts. Focusing on 7XXX series alloys, actively exploring 2XXX alloys, and developing aluminum alloy materials for 500-MPa hot stamping are important prospects for manufacturing complex-shaped automotive parts.

4.10 Aluminum-based composites

Aluminum–steel multi-layer composite panels: The effective connection of aluminum and steel decks has become one of the restrictive factors for the lightweight construction of superstructures on large ships. The aluminum–steel composite transition joint used for welding between aluminum and steel hulls provides a solution to replace the traditional riveting process. Honda has developed steel and aluminum joining technology that will be used in the worldwide mass production of car frames. Currently, the aluminum–steel composite joints used in China are mainly imported, and the price is as high as $4×10^5$ CNY/t. With larger ships in the future, the higher welding temperature, greater load-bearing stress, and stronger bonding interface required for transition joints create an urgency to develop high-performance aluminum–steel joints.

Aluminum alloy composite materials for automobile radiators: Aluminum alloy composite foils, strips, and plates are key materials for the manufacture of brazed heat exchangers such as automobile air conditioners, radiators, and hand dryers. The composite material is fabricated by laminating and rolling two to three types of alloys. The coating layer is mostly a high-silicon alloy or low-potential alloy, such as 4004, 4045, 4047, 4A13, and 7A01 alloys. The core materials are mainly 3003, 3003 + 1.5% Zn, and 3004 alloy.

Aluminum honeycomb panel: It is usually composed of two thin and strong panels and a middle honeycomb core. It has the advantages of light weight, high strength, high rigidity, good stability, heat insulation, and sound insulation, and it has been used in aircraft, trains, and ships. The existing products in the market are generally adhesives, except for imported materials for aviation use, which are welded products. The panels were easily degummed under conditions of high humidity, strong vibration, and high temperature. Lightweight, high-strength, corrosion-resistant, and weldable honeycomb structural panels and core panels are the development trends for honeycomb panels. Some foreign countries developed brazed aluminum honeycomb panels in the early 1990s and developed high-strength, age-strengthened, corrosion-resistant, and weldable honeycomb materials. Honeycomb aluminum production in China has maintained an average growth rate of 22% over the past five years. In 2012, the market capacity of adhesive honeycomb aluminum products in China's construction market alone reached 7.674 billion CNY. It is estimated that by 2035, the demand for high-strength and corrosion-resistant honeycomb composite panels will reach $7×10^7$ m^2, the prospect of which is very broad.

5 Long-term development goals of China's aluminum alloy materials

Combining China's actual situation and the bottleneck encountered in China's aluminum alloy industry, the following mid-term development goals are proposed: By 2030, the quality of high-performance aluminum alloy materials will reach the international advanced level, some of them will reach the international leading level, and the comprehensive mechanical and technological properties of materials will meet the modern manufacturing indicators. To achieve large-scale applications in aerospace vehicles, new energy vehicles, rail transit, vans, and other fields, these goals should be achieved. The localization rate of the fifth-generation aluminum alloy will reach 80% or more, the output and application of light alloys for aerospace will reach $2×10^5$ t/a, and the output of the light alloy for transportation will reach $3×10^5$ t/a.

Long-term development goal: By 2035, the quality of aluminum alloy materials will reach the international leading level, realizing self-sufficiency and output of most aluminum alloy materials, and leading the development of the global aluminum alloy industry. The fifth-generation aluminum alloy will be fully localized, and the sixth-generation aluminum alloy will be successfully developed. The aerospace light alloy output and application will reach $3×10^5$ t/a, and the light alloy for transportation will reach $4×10^6$ t/a.

6 Development countermeasures of aluminum alloy materials in China

With a focus on the above-mentioned problems, development trends, and development goals of aluminum alloy materials and the intention to improve independent innovation capabilities, establishing complementary upstream and downstream advantages in the industry chain and close cooperation mechanisms, shortening the cycle, forming continuous innovation capabilities, and realizing China's strategy from a large to a strong material country, unremitting efforts need to be made in the following aspects.

6.1 Strengthen the construction of the research system and improve the development environment

To achieve these goals, the following efforts are required: focusing on the construction needs of major national projects, strengthening the collaborative innovation of the industry–university–research–application cooperation mechanism, and improving the interest distribution, property rights protection, credit system, security policy, and other topics to solve the current barriers between production, universities, research institutes, and applications to establish a scientific and effective innovation mechanism. Meanwhile, the formulation of a catalog for the development of aluminum alloy materials and investment guidance opinions are required along with the improvement of the industrial chain, innovation chain, and capital chain. The role of the market should be fully considered in resource allocation, scientific guidance, and rational investment, coordinate the country's focused support for key basic material industries, help small- and medium-sized enterprises with high-performance aluminum alloy material to grow healthily, and create an industrial ecological environment with international competitiveness.

6.2 Optimize structure and promote quality, efficiency, and a coordinated development

Promote production capacity replacement and eliminate backward production capacity. Actively expand application areas and application levels, improve the quality stability of high-performance aluminum alloy products, reduce production costs, and enhance industrial support capabilities. Promote the establishment of supply chain collaboration between superior high-end aluminum companies and high-tech equipment manufacturing companies. Through industry–university–research cooperation, optimize the structure variety, promote the integration of products into the global high-end manufacturing supply chain, establish a comprehensive evaluation system, and improve international competitiveness.

6.3 Strengthen related supporting policies

The following should be considered: Strengthening intellectual property protection, increasing fiscal, financial, tax, and other policies to support high-performance aluminum materials, improve risk investment operations, risk aversion, and exit mechanisms, and form a healthy system that encourages the use of domestic high-performance aluminum materials. Increase the policy support for deep-processing aluminum products, implement tax preferential policies for high-tech enterprises, and promote the application and development of aluminum alloys.

6.4 Promote the construction of talent teams

The following should be considered: Implementing a development strategy for innovative talent, strengthening the training of young and middle-aged innovative talents and teams, encouraging enterprises to combine production, study, research, and use; adopt flexible policies such as flexible introductions; establish a national aluminum industry innovation center; cultivate independent innovative talents; and cultivate a number of discipline and professional technological leaders who can effectively improve the activity and promote the talent elements in industrial technological innovation, enhance independent innovation capabilities, and realize the transformation and upgrading of the aluminum industry.

6.5 Promote the integration of smart manufacturing and Internet Plus

Improve the intelligence level of enterprise research and development, production, and service, and establish a digital process system based on big data for process modeling and intelligent control. Pilot demonstration factories improve product performance and quality consistency. Encourage enterprise model innovation, promote the integration of the Internet Plus with the entire process of enterprise production and operation, and promote personalized customization and flexible manufacturing to meet diverse and multi-level needs.

6.6 Strengthen international cooperation, particularly along the Belt and Road

Actively implement the Belt and Road cooperation and enhance the international operational capabilities of the entire industrial chain of equipment, products, technology, standards, and services. In accordance with the *Guiding*

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Opinions of the State Council on Promoting International Cooperation in Production Capacity and Equipment Manufacturing, fully exert the advantages of technology, equipment, and talent, comprehensively consider factors such as resources, energy, politics, law, and markets, and encourage competent enterprises to invest in resource-rich regions. Actively learn the advanced technology and management experiences of foreign companies, continuously optimize products and equipment, and enhance international competitiveness.

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