Mg-Al-R, also known as the AE series magnesium alloy, is mainly used in environments such as aerospace, automobiles, and high-speed trains, where high-temperature service is required or high-strength performance is needed [20]. The addition of rare earth elements gives this series of magnesium alloys good creep resistance, followed by superior deformation processing performance and good mechanical properties at room temperature. It has the potential to be developed into a new type of wrought magnesium alloy.

1.3.2 Smelting and Casting of Magnesium Alloys

Pure magnesium has poor mechanical properties and cannot be directly used as a structural material. The mechanical properties of magnesium alloys can be significantly improved by alloying, deformation hardening, grain refinement, heat treatment, or a combination of these methods. Among them, alloying is the most fundamental, effective, and commonly used method, and other methods for strengthening magnesium alloys are often based on alloying.

1.3.2.1 Smelting Process of Magnesium Alloys

The casting methods of magnesium alloys can be classified into four types: casting, semisolid forming, powder metallurgy, and jet deposition. In traditional casting processes, the most commonly used casting method is die casting, which can directly produce magnesium and magnesium alloy parts. Die castings account for about 90% of magnesium alloy parts. With the rapid development of the world's industry, the demand for high-performance magnesium alloys has been increasing, and new magnesium alloy preparation techniques have been developed, such as semisolid molding, rapid solidification, and jet deposition.

During the smelting process of magnesium alloys, magnesium is prone to oxidation or combustion. Smelting processes can be classified into flux-protected smelting processes and flux-free smelting processes based on preventing oxidation or combustion of magnesium. Flux protection refers to covering the surface of a metal melt with a flux that removes impurities from magnesium and forms a protective film on the surface of the melt to isolate it from air, thereby preventing the oxidation and combustion of magnesium. But the air-isolating effect of the flux film is not ideal, and the oxidation loss of magnesium is still significant. In addition, the process is prone to flux inclusion, which reduces the mechanical properties and corrosion resistance of the castings. Moreover, the corrosive fumes produced during the smelting process make the working environment extremely harsh. Each magnesium alloy has its own specific flux, and the use of the flux must strictly follow the merchant's instructions. During the smelting process, local overheating of the charge must be prevented. Before pouring, the slag should be carefully removed, especially chlorides that affect corrosion resistance. After pouring, sulfur powder should be sprinkled on the surface of the melt to alleviate oxidation during the solidification process of the magnesium alloy. The commonly used fluxes are basically mixed salts of metal chlorides and fluorides.

In the 1970s, a flux-free protected smelting process was developed, in which a mixed protective gas was introduced into the smelting furnace to isolate the melt from contact with air. The common shielding gases are SF_6, N_2, and SO_2: SO_2 reacts with the chemical products of magnesium to form a dense composite film that effectively inhibits magnesium oxidation and was the most commonly used protective flux for magnesium alloys before SF_6 was used as a shielding gas. The mixed gas will react with the magnesium chemical products to form MgF_2, which can protect the melt well, but it must be noted that when the mixed protective gas contains SF_6, it must be kept dry, as the presence of moisture will accelerate the oxidation of magnesium and generate harmful gases. The most commonly used gas is SF_6. Since the greenhouse effect of this gas is more than 20,000 times that of CO_2, to reduce the content of this gas, dry gas or air is usually mixed in, and the mixed gas can provide better protection. The selection of SF_6 content should be made carefully. Too much will reduce the service life of the crucible, and too little will not provide protection. The concentration of SF_6 in the mixed protective gas is generally no more than 2%, and the concentration of this gas is related to the casting process and the airtightness of the casting equipment. Usually, the concentration is 1% for sand casting, higher for gravity casting, and no more than 0.25% for pressure casting. Since SF_6 generates a large amount of toxic gas during the smelting process and the greenhouse effect is significant, there is an urgent need to reduce the use of SF_6 or find alternative shielding gases. At present, methods such as improving the airtightness of crucible LIDS, optimizing the SF_6 content of mixed gases, modifying gas supply systems, enhancing the airtightness of smelting equipment, and increasing the recovery of SF_6 are all effective ways to reduce the use of SF or lower its environmental hazards. In addition, a company in the United States has achieved a 98% recovery rate of SF_6 through polymer films; among the many alternatives to SF_6, NovecTM612 is superior in performance. It is a fluoroketone that not only provides protection but also does not emit harmful gases. Its greenhouse effect is only 1% of SF_6, and it is easier to form a protective film, thus reducing the use of this gas relatively.

The flux-protected magnesium alloy smelting and casting process is roughly as follows: primary magnesium, pretreated alloying elements, and flux are successively added to the smelting furnace for smelting; an impurity remover is added to obtain the refined alloy melt; then poured into the mold; sulfur powder is sprinkled on the surface to prevent oxidation; then cooled and solidified to obtain the alloy ingot; and the remaining slag in the crucible is collected for recovery. The magnesium alloy undergoes surface treatment and hot air drying to obtain the commercial magnesium alloy.

The basic process of melting and casting of magnesium alloys without flux protection is as follows: first, the quality of the magnesium ingot is strictly controlled. The preheated magnesium ingot is placed in a melting furnace with protective gas for melting, refining, primary analysis in front of the furnace, alloying, stirring, modification treatment, refining, crystallization, secondary analysis in front of the furnace, and pouring to obtain the alloy ingot. After surface treatment, the commercial magnesium alloy is obtained. The entire smelting process is protected by a protective gas, and the residual coating on the surface of the ingot mold is cleaned before casting, and a new coating is reapplied regularly.

1.3.2.2 Magnesium Alloy Melt Purification and Grain Refinement

Magnesium alloys are susceptible to the influence of the surrounding environmental medium during the smelting process, which, in turn, affects the quality of the alloy melt, resulting in defects such as porosity, slag inclusion, and shrinkage cavities in the castings. As a result, magnesium alloy melts need to be purified.

The quality of the melt is usually improved in three aspects: the proper use of the flux, the enhanced protection of the melt surface, and the thorough purification of the melt. The main ways to treat the melt are the following:

Degassing The main gas in magnesium alloys is hydrogen, which comes from damp fluxes, furnace charges, and water vapor brought in by the corrosion of metal furnace charges, so degassing is necessary. The common degassing methods in industry include: introducing inert gases (such as Ar and Ne) at 750–760 °C and introducing 0.5% of Ar by mass into the melt, which can reduce the hydrogen content by nearly half. Attention should be paid to controlling the speed and time of aeration to avoid melt splashing and coarse grains. At 740–760 °C, an active gas (Cl_2) is introduced. If the temperature is too high, inclusions will form; if it is too low, magnesium combustion cannot be prevented. The amount of chlorine introduced should be such that the chlorine content in the melt is less than 3% (by volume fraction), and the speed should be 2.5 to 3 L/min. At around 750 °C, the C_2Cl_2 method is introduced with an amount not exceeding 0.1% of the melt mass, which can achieve both degassing and grain refinement. The 670 °C combined degassing method, which involves introducing CO_2 into the melt first and then blowing $TiCl_4$ with He, can effectively reduce the gas content in the melt.

Deslagging Inclusions in the magnesium alloy melt have a certain density difference from the melt, and the appropriate process can make the inclusions settle to the bottom part. Refining is an effective process for removing nonmetallic inclusions such as oxide scale from magnesium alloy melts. The refining process requires the selection of an appropriate refining temperature (generally between 730 and 750 °C) and the stirring of the melt. An appropriate amount of flux is added during the refining process to completely remove inclusions. The refining process of the Mg-Zn-Zr series and Mg-R-Zr series alloys is different. After the melting furnace is preheated, the flux is added first, then the remelted and fresh materials are added in batches, then heated to a specific temperature, the flux is added for antioxidation and slag removal, and the conditions of the melt surface are not damaged for thorough stirring. Finally, after the fracture sample is qualified, the flux is added for refining, and the pouring temperature is adjusted. When smelting Mg-Al alloys, the amount of flux is equal to the mass of the melt, and the melt is stirred. When melting zirconium-containing magnesium alloys, the flux is 6–8% of the melt mass, or even up to 10%, of which 1.5–2% is used for refining.

Grain refinement is an important way to improve the performance of magnesium alloy castings. The finer the grains of magnesium alloys, the better their mechanical properties and plastic deformability. Proper grain refinement during the magnesium alloy smelting process can reduce the tendency of hot cracking during the solidification of the casting. In addition, after grain refinement of magnesium alloys, the intermetallic compound phases in the castings are finer and more evenly distributed, thereby shortening the homogenization process time or improving the homogenization process efficiency. There are two types of grain refinement methods in magnesium alloy smelting, namely modification and strong external field action. The mechanism of the former is to add high-melting-point substances to the alloy liquid to form a large number of nucleating particles to promote nucleation crystallization of the melt and obtain a fine-grained structure. The basic principle of the latter is to apply an external field (such as an electric field, magnetic field, ultrasonic, mechanical vibration, and stirring) to the alloy melt to promote nucleation and break the formed dendrites into free crystals, increase the number of nuclei, and also strengthen the conduction process in the melt to eliminate composition segregation. In addition, rapid solidification techniques can also increase the nucleation rate of magnesium alloys, inhibit the growth of nuclei, and significantly refine the grain structure.

Modification is widely used in the actual production of magnesium alloy casting. Early superheated modification, which could significantly refine the $Mg_{17}Al_{12}$ phase through rapid cooling, had significant drawbacks, not only increasing magnesium loss but also reducing the service life of the crucible and production efficiency. Currently, the commonly used modifiers for melting magnesium alloys include carbon-containing substances, C_2Cl_6, and high-melting-point additives (such as Zr, Ti, B, and V). Carbon can effectively refine the grains of Mg-Al or Mg-Zn series, but has a limited effect on the Mg-Mn series. Commonly used carbon-containing modifiers in industry include magnesite ($MgCO_3$), marble ($CaCO_3$), chalk, stone coal, and coke. $MgCO_3$ is added to magnesium–aluminum alloy melts to produce a large number of fine, insoluble, and suspended Al_4C_3 particles. It acts as a nucleation base during solidification. The addition amount is usually 0.5–0.6% of the melt mass, the melt temperature is 760 to 780 °C, and the modification time is 5–8 minutes. C_2Cl_6 is one of the commonly used modifiers, which can achieve both degassing and grain refinement at the same time. It can significantly refine the grain size of AZ31, and the modification effect of ZM5 is significantly better than that of $MgCO_3$. C_2Cl_6 and other modifiers can also be used for compound modification. Zirconium has a significant grain refinement effect on several series of magnesium alloys and is currently one of the most commonly used grain refiners in magnesium alloy smelting.

1.4 Strategic Position and Development Prospects of Magnesium Alloys in Industry

1.4.1 Strategic Position of Magnesium Alloys

Magnesium alloys, which are rich in resources and have excellent performance, are hailed as green structural materials of the 21st century in the context of the current scarcity of mineral resources and the dual carbon goals. Magnesium alloys are widely used in aerospace, military manufacturing, automotive, and other fields due

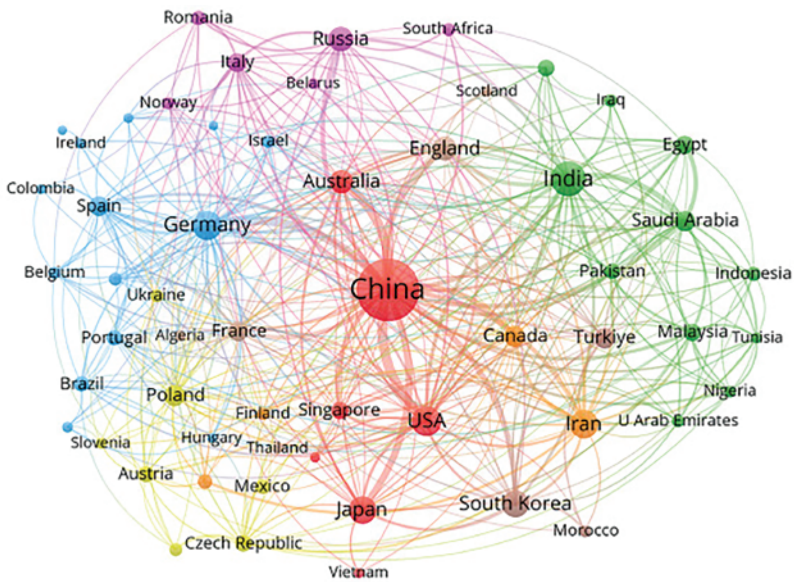

Figure 1.3 Statistical analysis of the distribution of countries with at least 5 Mg papers published in 2023: network visualization among different countries. *Source:* Adapted from [21].

to their excellent performance, low price of primary magnesium, significant weight reduction and energy-saving effects, and unique biological effects (Figure 1.3).

Magnesium has high specific strength and stiffness: its specific strength is much higher than that of aluminum alloys and steel, but slightly lower than that of fiber-reinforced plastics, which have the highest specific strength. The specific stiffness is comparable to that of aluminum and steel, but much higher than that of fiber-reinforced plastics. The use of magnesium alloys for structural components, while maintaining strength and stiffness, significantly reduces the quality of the parts, which is of great significance to multiple industries.

Under the same force conditions, magnesium alloys can consume more deformation work than aluminum alloys and steel, have good noise reduction and vibration damping functions, and can withstand greater shock and vibration loads. This is because magnesium alloys have a lower elastic modulus compared to aluminum alloys and steel, and thus magnesium alloys have better vibration-damping performance, which is 5–30 times that of aluminum alloys, 20 times that of plastics, and 50–1000 times that of steel. As a result, magnesium alloys are widely used in automotive, aircraft, and aviation damping components, improving comfort while enhancing product performance.

Magnesium alloys have excellent casting properties. On the one hand, magnesium hardly reacts with iron, and molten magnesium causes less erosion to crucibles and die-casting molds. On the other hand, magnesium alloys have a low specific heat capacity and latent heat of crystallization and have good fluidity. Compared with the aluminum alloy die-casting process, the service life of magnesium alloy die-casting molds is increased by 2–3 times, the die-casting efficiency is increased by 40–50%, and the wall thickness of magnesium products can be less than 0.6 mm, while the wall thickness of aluminum alloy for the same strength is 1.2–1.5 mm.

Magnesium alloys have high dimensional stability and a low volume shrinkage rate, so they have dimensional stability without the need for annealing and stress relief, and have the lowest shrinkage rate among cast metals. They have excellent machinability, with a much higher cutting speed than other metals, low tool consumption during cutting, no need for cutting fluid to improve the surface quality of parts, and a smooth and flat surface can be obtained without grinding and finishing.

Magnesium alloy has better shielding performance than aluminum alloy, which can better block electromagnetic waves and is suitable for making shells, covers, etc., of products that emit electromagnetic interference, especially mobile phones that are frequently touched by people. Electronic devices made of plastic products need to be coated with conductive paint or metal plating on the surface, which not only increases costs but also has a limited shielding effect.

Magnesium alloys, which have high heat dissipation, have better heat dissipation than plastics and aluminum alloys, but have much less heat storage than aluminum alloys. On the other hand, die-cast magnesium alloys have better formability than aluminum alloys, and the parts produced have thinner walls and more complex shapes. Taking all these factors into account, magnesium alloy die-castings tend to have better heat absorption and dissipation performance than aluminum alloy die-castings, making them suitable for the production of electronic products with dense components.

Recyclability: Used magnesium alloy castings can be remelted as secondary materials for AZ91 and AM50/AM60, with low energy consumption during smelting and impurities that can be removed through relatively simple metallurgical methods, making magnesium alloys more attractive than most plastic materials.

Weight reduction and energy-saving effect: Since the 21st century, reducing energy consumption, minimizing environmental pollution, and improving the human living environment have become common themes faced by all mankind. On the one hand, the use of magnesium alloys can enhance the performance of aircraft and reduce the cost of spacecraft launches. On the other hand, countries around the world are imposing more and more restrictions on energy consumption and exhaust emissions of vehicles, such as cars, and the requirements for energy conservation and emission reduction are almost exacting. Lightweighting of automotive structures is just around the corner. The use of magnesium alloys for automotive transmission system parts not only reduces self-weight and fuel consumption but also optimizes the mass distribution and improves the comfort and safety of automobiles. Magnesium alloys have become the focus of research in recent years due to their light weight and superior performance, and are widely used in aerospace, defense, and automotive manufacturing to achieve the goals of reducing costs, improving performance, reducing weight, and reducing energy consumption and to contribute to global carbon neutrality and carbon peaking.

Biological effects: Magnesium is an essential element for the human body and acts as a catalyst and activator in the human body. The average adult has about 20–25 g of magnesium in their body, of which 70% is involved in the formation of bones and teeth in the form of phosphates and carbonates; 25% of magnesium is present in soft tissues, mainly binding to proteins to form complexes. Magnesium, after being broken down in the body, participates in protein synthesis, activates various enzymes in the body, regulates neuromuscular and central nervous system activities, ensures normal myocardial contractions, participates in almost all metabolic reactions in the body, and promotes energy transport, storage, and utilization in the body; magnesium is the second most important intracellular positive ion in the human body after potassium, sodium, and calcium, and has a very low electrode potential. Magnesium ions in body fluids can be absorbed by surrounding body tissues under normal metabolic conditions and excreted through body fluids. In short, magnesium is degradable in the human body and has good biocompatibility. Also, magnesium is an essential element for bone growth, promoting calcium deposition, bone cell formation, and accelerating bone healing; magnesium alloys have a density and elastic modulus similar to that of human bone, providing a stable mechanical environment in the early stage of fracture healing and allowing the fracture site to gradually bear stress that increases to the physiological level.

1.4.2 Trends in Magnesium Alloys

1.4.2.1 Direction of Development

From the first acquisition of metallic magnesium to the commercial use of magnesium alloys, there is only a history of 200 years. In 1808, the British chemist Davy first produced metallic magnesium. Magnesium began to be used in the photographic industry around 1850 and started to have commercial value. During World War II, the magnesium industry developed rapidly and was used to make military equipment such as incendiary bombs, flares, signal flares, and aircraft parts. After World War II, the application of magnesium alloys in civilian industries was discovered. With the improvement of high-temperature creep resistance of magnesium alloys, AS, AE, and ZE series alloys were developed, and their application in the automotive and aircraft fields gradually expanded. In addition, the corrosion resistance of magnesium alloys has also become another research direction. Magnesium alloys have unique advantages but also inherent disadvantages. Magnesium alloys are not as widely used as aluminum alloys, mainly for the following reasons:

High chemical reactivity, prone to oxidation and combustion, and makes smelting and processing difficult.

It has low plasticity at room temperature and poor deformability.

It has poor corrosion resistance and lacks effective and proactive anticorrosion approaches.

Low absolute strength, especially poor high-temperature strength and high-temperature creep resistance.

In response to the shortcomings of magnesium alloys, the development directions of magnesium alloys are as follows:

Ultralight magnesium alloys: Magnesium–lithium alloys are by far the least dense alloy materials, with densities typically ranging from 1.35 to 1.65 g/cm^3.

The addition of lithium gradually transforms the close-packed hexagonal structure of magnesium into a body-centered cubic structure: when the lithium content is 5.7–10.3%, the magnesium–lithium alloy presents the β phase, which is a body-centered cubic structure; when the lithium content is greater than 10.3%, the α phase of the close-packed hexagonal structure disappears, and it is all β phase. This means that the magnesium–lithium alloy has more slip systems, better deformability, and even superplasticity. But magnesium–lithium alloys have lower strength, and the addition of elements such as Al, Zn, Si, Mn, and R can enhance the strength and microstructure stability of the alloys. Magnesium–lithium alloys will play a greater role in many fields, especially in aerospace and electronics, due to their excellent processing deformation ability and low density.

Flame-retardant magnesium alloys: Magnesium alloys are prone to intense oxidation and combustion during the smelting and casting process. Gas protection and flux protection, although effective in flame retardancy, will reduce alloy performance and seriously pollute the environment. Studies in Japan and the United Kingdom have shown that adding calcium can be flame-retardant and antioxidant, and adding beryllium can prevent further oxidation of magnesium alloys, but excessive addition of these elements can lead to poor quality of magnesium alloys, excessive calcium can deteriorate mechanical properties, and excessive beryllium can cause grain coarsening and increase the tendency to heat. So far, no ideal element has been found that can enhance the flame retardancy of magnesium alloys, improve their mechanical properties, and be nontoxic. Improving the flame retardancy of magnesium alloys is of great significance for the long-term development of magnesium alloys (Figure 1.4).

Deformed magnesium alloys: Although cast magnesium alloys are used more than deformed ones, deformed magnesium alloy materials can obtain higher strength, better ductility, and more diverse mechanical properties, which can meet the requirements of structural components on different occasions. Therefore, the development of deformable magnesium alloys is a longer-term trend in the future, and the development of new deformable magnesium alloys and forming processes has received great attention from materials workers in various countries.

Poor corrosion resistance of magnesium alloys is one of the major obstacles to their large-scale application, and improving the corrosion resistance of magnesium alloys has become an important scientific and technological problem that must be solved in the development and application of magnesium alloys. Current research shows that purification and surface treatment of magnesium alloys are effective ways to improve magnesium alloys. Strictly limiting the content of impurity elements such as Fe, Cu, and Ni in magnesium alloys, corrosion-resistant alloying, and surface treatment are all effective ways to improve corrosion resistance.

High-strength heat-resistant magnesium alloys: The strength and creep resistance of magnesium alloys decline significantly with increasing temperature, making them difficult to be widely used as key materials in industries such as aviation, aerospace, and automotive. At present, countries are focusing on the research, design, and development of heat-resistant magnesium alloys as an important

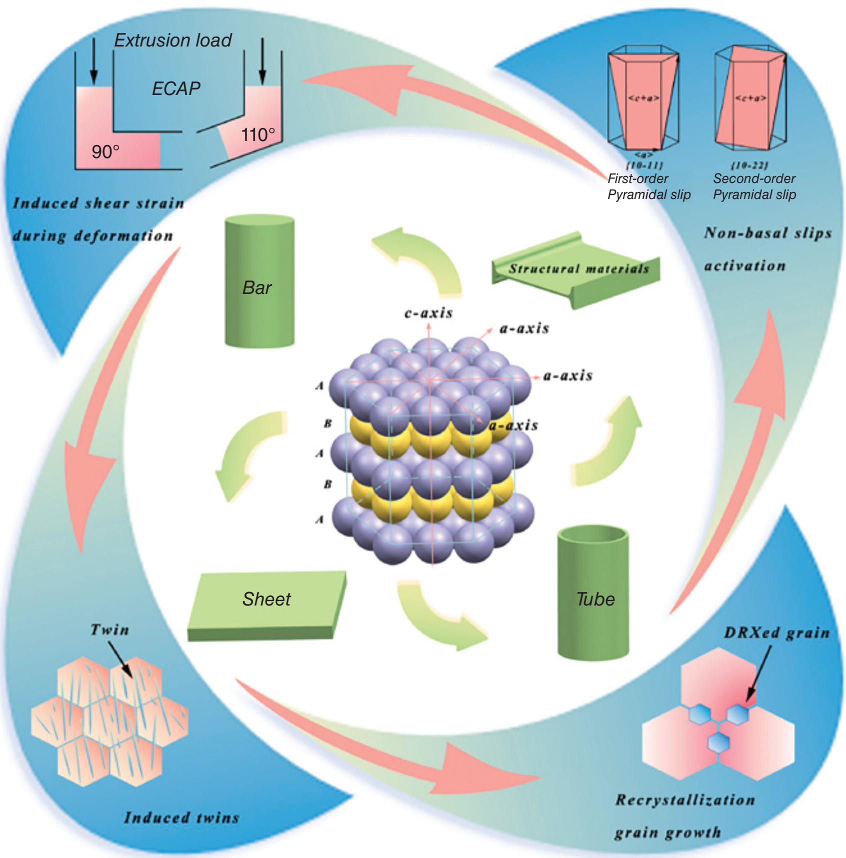

Figure 1.4 Schematic diagram of texture controlling methods of Mg alloy. *Source:* Adapted from [22].

direction, aiming to improve the high-temperature strength and creep resistance of magnesium alloys at 150–300 °C with the same cost or a slight increase. The main alloying elements used in the developed heat-resistant magnesium alloys are R, Si, Ca, Sr, etc.

High modulus and high-strength magnesium-based composites: Alloying is difficult to solve the problems of low elastic modulus and poor wear resistance of magnesium alloys. The method of composites significantly improves the mechanical properties, such as specific strength, specific modulus, and wear resistance of magnesium-based composites, as well as the high-temperature creep resistance, while maintaining the original advantages of magnesium alloys. In addition, magnesium-based composites have electrical shielding and hydrogen storage properties and are a class of excellent structural functional materials with great application prospects in aerospace, military product manufacturing, and other fields, and are one of the most promising types of composites in today's high-tech fields.

New functional magnesium alloy materials: Magnesium-based hydrogen storage materials have high hydrogen storage capacity, good hydrogen absorption and release platforms, abundant resources, low cost, and very attractive application prospects, but magnesium-based alloys have harsh hydrogen absorption and release conditions, slow speed, high operating temperature, and are prone to corrosion in alkaline solutions. In 2001, Japanese scientists discovered that MgB_2 becomes a superconducting material at 39 K, setting a new record for metal superconductors, which is currently the highest critical temperature for metal compound superconductors. Magnesium-based bio-hard tissue materials, which have properties similar to human bones and antibacterial properties, are popular in the field of biomaterials. Damping magnesium alloys have a wide range of application prospects due to the damping properties of metallic structural materials. Foam magnesium alloys, which combine structural and functional materials, have a variety of excellent physical properties and a wide range of applications.

1.4.2.2 Development Prospects

Magnesium alloys are the fastest-growing and most widely used light alloys in the world at present. Industry experts believe that in the context of global scarcity of nonferrous resources and rising prices, magnesium's resource, price, and product advantages will surely be fully exploited. Magnesium is one of the most abundant light metals in the world and the most promising green material for building a resource-conserving society in the 21st century. The development and application of magnesium and its alloys are of practical significance to human production and sustainable development. Unlike other metals, its development and application are not yet fully developed, indicating that all participants will have the opportunity to witness and participate in the development of this industry. Magnesium alloys are likely to be developed in several directions.

Ultralight Mg-Li alloy materials will have more in-depth and extensive applications in future automotive, computer, communication, and consumer electronics fields. High-performance, high-temperature-resistant magnesium alloys will be widely used in automotive powertrain components, aerospace vehicles, and other fields where there are strict requirements for material strength, high-temperature resistance, and material lightweighting. Magnesium-based composites are currently mostly produced by powder metallurgy for small-sized components, and the high-quality and efficient preparation of large-sized magnesium-based composites is an urgent problem to be solved in the industry.

Magnesium is the most promising lightweight material, and magnesium alloys have great potential for lightweighting in automotive, motorcycle, rail transportation, aerospace, information, and other fields. Magnesium alloys have a significant weight reduction effect. They can reduce weight by more than 60% when replacing steel under the same stiffness conditions, by more than 70% when replacing steel under the same strength conditions, and by more than 30% when replacing aluminum. According to US Department of Energy data, a 10% reduction in vehicle weight can improve fuel economy by 6–8%, and each vehicle traveling 200,000 km can reduce CO_2 emissions by 8 tons. The economic benefits of reducing the weight of commercial aircraft by the same mass are nearly 100 times those of cars and 10 times those of military aircraft lightweighting commercial aircraft, and the improved maneuverability of lightweighting can significantly enhance the combat effectiveness and survivability of fighter jets. The vigorous development of the magnesium industry and the large-scale application of magnesium alloys are of great significance for energy conservation and emission reduction and the realization of the dual carbon goals.

Magnesium-based hydrogen storage materials have great potential for development and are expected to disrupt the energy structure. Existing energy storage methods include pumped storage, electrochemical storage, hydrogen storage, thermal storage, and mechanical storage. At present, pumped storage is widely used for large-scale energy storage due to its low cost per kilowatt-hour, but it is constrained by low energy storage efficiency and environmental impact. Electrochemical energy storage, represented by lithium batteries, is favored in the fields of electric vehicles and portable electronic products for its convenience of storage. However, lithium-ion batteries have problems such as resource shortage, poor safety performance, and serious environmental pollution. At the same density, magnesium batteries are much safer than lithium batteries, and they have abundant strategic resources and a significantly reduced environmental burden. Their performance potential and development potential stand out among the new generation of energy storage batteries and power batteries. Some experts believe that once magnesium batteries break through, it will disrupt the battery industry. The hydrogen strategy is a global development strategy. Hydrogen has great potential in terms of environmental pollution and energy transition, but it also faces problems of efficiency and safety in storage and transportation. Magnesium solid-state hydrogen storage has a density of up to 5–7%, far higher than the 1–2% of current hydrogen storage technologies, and the safety of storage and transportation at normal temperature and pressure is greatly enhanced. The breakthrough of magnesium solid-state hydrogen storage technology is of great significance in fields such as hydrogen vehicles, the energy storage industry, the hydrogen chemical industry, and the hydrogen metallurgy [23].

Bio-magnesium alloy materials have excellent performance, good biocompatibility, degradability, good antibacterial properties, abundant resources, and low cost, and are a promising new generation of biodegradable and absorbable biomedical materials.

The development demands of magnesium alloys in industry are as follows:

High-performance magnesium-based lightweight structural alloys containing rare earth elements, with their excellent mechanical properties, superior impact resistance, and outstanding high-temperature and corrosion resistance, effectively overcome the performance bottlenecks that have long existed in the practical application of traditional magnesium alloys. Especially in the design of aircraft and vehicles that are highly sensitive to weight, the application of this type of alloy significantly improves the overall energy efficiency ratio and endurance.

New magnesium alloy systems with high strength and excellent thermal conductivity, along with their large-scale preparation processes, are becoming key technical paths to support the development of heat dissipation systems for high-end equipment. Such materials are widely used in the manufacturing of thermal management components in civil airliners, high-speed train units, electric vehicle power units, and high-performance computing devices.

At the same time, high-strength conductive magnesium alloys with electrical conductivity exceeding 17 (MS/m) are becoming an important direction for technological upgrading in the information appliance industry. These materials can significantly improve the electromagnetic shielding performance and current transmission efficiency of electronic products while ensuring sufficient mechanical strength. The use of such alloys in portable devices such as smartphones, laptops, and wearable devices helps to reduce the overall weight of the device, improve energy efficiency, and reduce the potential impact of electromagnetic radiation on the external environment and the health of users, which has significant ecological and social benefits.

Research and development of ultrahigh-strength magnesium alloys in response to future demands for high-end equipment manufacturing continue to attract attention. These materials are mainly used to manufacture structural components that withstand extreme loads, such as fighter landing gear assemblies, rocket propulsion module connection mechanisms, high-speed train bogie components, and electric passenger car chassis systems. With the advancement of material strengthening and toughening theories and the development of precision plastic forming processes, magnesium alloys, while maintaining their low-density advantage, have seen their comprehensive mechanical properties approach or even partially surpass those of traditional aluminum alloys, showing great potential for substitution.

New superplastic magnesium alloy materials have relatively low production costs and high profits, and have obvious competitive advantages in the production and application of magnesium alloy materials. The new type of superplastic magnesium alloy developed in China has high room temperature strength (tensile strength >350 MPa, yield strength >250 MPa) and strong superplastic deformation ability during stamping (elongation at medium and low temperatures 100–200%, elongation at high temperature 700–800%). This type of alloy is suitable for one-time stamping of complex-shaped parts, significantly reducing subsequent processing costs and having good industrialization prospects and market competitiveness.

In addition, the development of casting magnesium alloys with high fluidity, high strength (tensile strength >300 MPa), and high plasticity (elongation >10%) has also become a research hotspot in response to the demand for thin-walled complex castings such as aircraft engine casings and transmission cases. Ultra-lightweight Mg-Li alloys, due to their extremely low density, show broad application potential in consumer electronics, communication equipment, and portable tools. High-temperature-resistant magnesium alloys are expected to enter the peripheral components of automotive engines and the hot-end structures of spacecraft. Although magnesium-based composites currently rely mostly on powder metallurgy to produce small components, achieving efficient and stable production of large-sized, high-quality composites remains a technical challenge that the industry urgently needs to overcome.

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