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Automobile Lightweight Technology: Development Trends of Aluminum/Magnesium Alloys and Their Forming Technologies

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Abstract: This study reviews the development of aluminum and magnesium alloys, including new materials, forming technologies and application trends, and analyzes the obstacles of their application in the automobile industry. Possible solutions are given to promote the use of aluminum and magnesium alloys in the automobile industry of China.

Keywords: automobile; lightweight; aluminum alloy; magnesium alloy; forming technology; development trend

Vehicle lightweighting is an effective measure for reducing energy consumption and pollutant emissions. In recent years, owing to continuous increases in vehicle production and ownership, China is currently facing severe energy consumption, and safety and environmental problems. Vehicle lightweighting technology is therefore an important tool for driving the sustainable development of the automobile industry, increasing the fuel economy of vehicles, and reducing vehicle emissions. Vehicle lightweighting refers to the minimization of vehicle mass to achieve energy consumption and emissions reduction targets without compromising the vehicle function and safety. Lightweight designs, lightweight materials, and lightweight manufacturing processes are the three primary components of lightweighting technologies [1,2]. The viability of a new lightweighting technology for implementation depends on its cost versus benefit relationship: such technology will only be implemented if its benefits far outweighs the cost increase. Herein, newly developed lightweight aluminum and magnesium alloys, and the development of aluminum/magnesium forming technologies in automotive fields are viewed.

1 Aluminum alloys

The density of aluminum alloy is approximately 1/3 that of steel, and it is a widely used lightweight material in the automotive industry. Research has shown that the replacement of low-carbon steel, cast iron, or high-strength steel with aluminum alloys could reduce a vehicle weight by 30%–60%. Each kilogram of aluminum used in a vehicle reduces greenhouse gas emissions by 13–20 kg [3]. The replacement of steel with aluminum is therefore a popular trend in vehicle lightweighting technologies, and the use of aluminum has become typical in luxury cars.

The aluminum alloys for vehicle usage include wrought and cast aluminum alloys, with cast aluminum alloys accounting for 80%. Cast aluminum alloys are typically used to produce engine blocks, cylinder heads, clutch housings, bumpers, and wheels, while wrought aluminum alloys are used to produce automobile body panels, e.g., the aluminum car body in Audi A8. In addition, aluminum-based composites, aluminum foam, and aluminum powder metallurgy alloys are also used in automobiles. In

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this section, the research and application of lightweighting technologies on aluminum alloys inside and outside of China from the perspective of new materials, new forming technologies, and new applications are reviewed.

1.1 New materials

1.1.1 Non-heat-treated die-cast aluminum alloy

Shanghai Jiao Tong University has developed two aluminum alloys for die castings, which are denoted as JDA1 (Al-Si-Mn-Mg-RE) [4] and JDA2 (Al-Mg-Si-Mn) [5]. These alloys do not need high-temperature solution treatment and artificial aging. High levels of strength and plasticity can be achieved through natural aging alone after die casting. The tensile performance of these alloys at room temperature is shown in Table 1. JDA1 has excellent die casting properties and good mechanical properties, weldability, polishability, and malleability. The mechanical performance of JDA1 alloy is comparable with the T6-treated die cast Silafont-36 aluminum alloy (Germany alloy). JDA2 has a lower density than pure aluminum, and has excellent die casting properties, outstanding corrosion resistance, good weldability, polishability, and malleability. After conventional die casting and natural aging, the mechanical performance of JDA2 alloy is higher than T6-treated die cast Magsimal-59 aluminum alloys (Germany alloy). These non-heat-treated die-cast aluminum alloys are well suited for the thin-walled automotive parts.

The JDA1 aluminum alloy has already been used to fabricate the engine bracket (chassis system) in Cadillac CT6, as shown in Fig. 1.

1.1.2 Highly ductile die-cast aluminum alloys

The Fan Z Group in the University of Birmingham (UK) [6] developed a highly ductile die-cast aluminum alloy that contains 5.0 wt%–5.5 wt% Mg, 1.5 wt%–2.0 wt% Si, 0.5 wt%–0.7 wt% Mn, 0.15 wt%–0.20 wt% Ti, and < 0.25 wt% Fe, to improve the plasticity of die-cast aluminum alloys. After die casting, the alloy was found to have a yield strength of 150 MPa, a tensile strength of 300 MPa, and an elongation of 15% at room temperature, in the as-cast condition. This alloy is therefore able to satisfy the requirements of car bodies.

1.2 New forming technologies

1.2.1 Vacuum die-casting for large aluminum components

Conventional die-cast aluminum components tend to contain a large number of gas pores. To address this issue, Shanghai Jiao Tong University developed a vacuum die casting system, which consists of a vacuum casting system, vacuum valve, a sealed mold, and a set of venting lines. This system is a highly effective combination between a vacuum control system and a die casting controller, and it was implemented in a large 3550 t high-precision horizontal die casting machine in the Fengyang L-S Precision Metal Forming Co., Ltd. This system was subsequently used to die-cast aluminum V6 engine blocks (engine systems), as shown in Fig. 2. In the near future, high-vacuum die casting for large aluminum components is expected to become an important trend in the automotive industry.

1.2.2 Rheo-die casting for semi-solid aluminum alloys

Semi-solid metals have highly homogeneous microstructures. Owing to their inherent fluidity under shear stress, they do not tend to form defects or segregate. Furthermore, heat treatment can be used to improve the mechanical properties of parts that are casted using semi-solid metals. Semi-solid die-casting technologies therefore hold significant advantages over conventional liquid die-casting. To reduce the cost of semi-solid die casting

Table 1. Room temperature tensile properties of the JDA1 and JDA2 aluminum alloys.

Alloy	AlSi9Cu3 (as-cast)	A356 (as-cast)	Silafont36 (T6)	JDA1 (as-cast)	JDA2 (as-cast)
σ_b (MPa)	280–285	155–160	250–290	260–340	280–340
$\sigma_{0.2}$ (MPa)	150–165	85–90	120–150	160–196	180–220
δ (%)	2–3	6–7	5–9	6–10	10–20

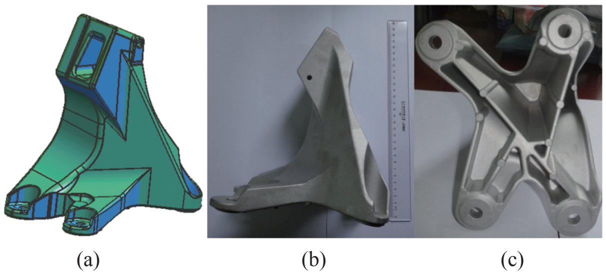


Fig. 1. Engine bracket (chassis system) made from the JDA1 aluminum alloy. (a) Design drawings; (b) and (c) photograph of the casted component.

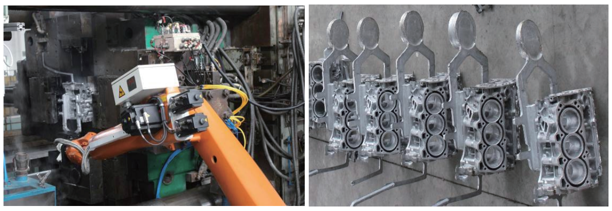


Fig. 2. Photographs of die cast aluminum alloy V6 engine blocks.

processes and to fully exploit the advantages of aluminum alloy rheo-die casting, the Beijing General Research Institute for Nonferrous Metals (GRINM) developed an online manufacturing system that produces semi-solid aluminum alloy slurries, which was successfully used to combine online semi-solid preparation with the die casting of automotive components in a dynamic manner. This system has been used to produce various components in the chassis system, e.g., aluminum calipers, air chamber brackets, torsion linkages, and left-middle bracket, which are 35%–48% lighter than their steel equivalents. Fig. 3 shows a photograph of a caliper that was die cast from semi-solid aluminum alloy, as well as its microstructure. As semi-solid aluminum alloy rheo-die casting costs only slightly higher than conventional die casting, this technology has excellent prospects in the automotive component manufacturing, especially for the mass production of components that weight 10 kg or less.

1.2.3 Flow forming technology for aluminum wheels

The replacement of steel wheels with aluminum wheels (chassis system) markedly reduces the energy consumption and emissions of commercial vehicles. Aluminum wheels have already become the norm in passenger cars. In 2016, the use of aluminum wheels in trucks grew explosively in China. Most aluminum wheels are currently being produced by a combination of forging and flow-forming techniques. Fig. 4 shows a photograph of the aluminum wheels produced by the Shandong Meika Wheel Co., Ltd. via forging & flow forming technology. Other than forging & flow forming, Shanghai Jiao Tong University has also developed a thick-plate flow-forming technique to produce truck wheels. In this method, 35-mm-thick aluminum plates are used as the metal blank, power spinning is used to form the wheel spokes using materials from the middle of the aluminum plates, whereas the materials on the sides of the aluminum plates are used to form the wheel rim. Split-flow forming is subsequently used to split the previously formed wheel rim into the front and back rim blanks. Finally, power spinning is used to form the front rim and back rim from the front and back rim blanks, respectively. As compared with the forging & flow forming, thick-plate flow forming does not require prefabricated forged blanks, uses only simple equipment and processes, has high material utilization rates, involves low processing costs, and has high production yields. Furthermore, this technique reduces the costs by as much as 60%. The thick-plate metal flow forming technique therefore has the potential to become a mainstream metal-forming technology for aluminum truck wheels.

1.3 New applications

1.3.1 Aluminum-composite brake rotors

With the development of lightweighting technologies, aluminum composite materials are gradually being incorporated in automotive brake rotors (chassis system). In 2014, the Grimsel electric racing car created by ETH Zurich and the Lucerne University of Applied Sciences and Arts set the record for the acceleration in electric cars by accelerating from 0 to 100 km/h in 1.785 s. The brake rotors of this electric car were constructed from a composite that consists of an aluminum matrix reinforced by SiC particles. As compared with conventional gray cast iron, the SiC particle aluminum-composite has a much lower density and a higher thermal conductivity. The composite brake rotors are 50%–60% lighter than conventional brake rotors.

1.3.2 Aluminum car bodies

Since the adoption of aluminum car bodies by the Audi A8, the use of these bodies in passenger cars has become increasingly popular. In January 2016, a lightweight aluminum body was adopted for the production version of the EX microelectric vehicle produced by BAIC BJEV. In February 2016, Cherry New Energy held the foundation-laying ceremony for a project to construct 60 000 aluminum-bodied electric passenger cars per year in the Wuhu Economic & Technological Development Area of the Anhui province, which will primarily produce the S51EV, S61EV, and A0-SUV EV electric passenger cars. In April 2016, the Cherry Land Rover Jaguar Automotive Co., Ltd. launched a purpose-built body shop for aluminum bodies in the Changshu factory. This body shop manufactures the long wheelbase version of the new Jaguar XFL saloon, 75% of which is made of aluminum. The car body is made of aluminum plates while its frame is made of aluminum extrusion alloy. The joint connections are die-cast/casted, and the total weight of the car body is only 297 kg. The Cadillac factory of the SAIC Motor

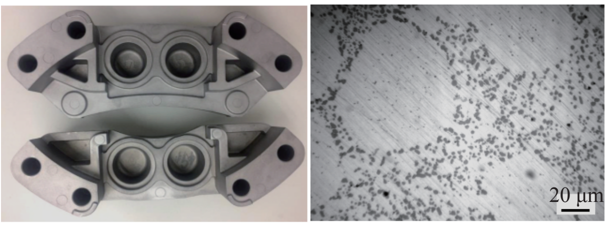


Fig. 3. Calipers (chassis system) produced by rheo-die casting of semi-solid aluminum alloy and their internal microstructure. The eutectic Si phases exhibits a fine and dispersed distribution after T6 treatment.

Fig. 4. Aluminum truck wheels produced via forging & flow forming by the Shandong Meika Wheel Co., Ltd.

Corporation Limited manufactures the Cadillac CT6, which has a lightweight car body design and is 57.72% made of aluminum. In January 2016, 18 new energy buses with aluminum frames manufactured by Guangxi Yuanzheng New Energy Vehicle Co., Ltd. began to service bus routes in Nanning City. The aluminum frame lightweighting technology of this company has already been successfully implemented in a series of 6–18 m city buses.

2 Magnesium alloys

As magnesium alloys are the lightest metallic structural material, they are expected to be used in automobiles in the future. Magnesium components could reduce the weight of components that are currently made of aluminum alloys by approximately 30%. Although magnesium alloys have been used in cars since the 1930s, their current usage in cars is extremely limited. Magnesium alloys are flammable and difficult to form by nature, and have relatively poor strength, plasticity, and corrosion resistance, which do not satisfy the requirements of automobile applications. In this section, the research and application of lightweighting technologies in magnesium alloys from the perspective of new materials, new forming technologies, and new applications are reviewed.

2.1 New materials

2.1.1 Development of high-performance magnesium rare-earth (RE) alloys

Shanghai Jiao tong University developed the JDM1–JDM4 series alloys [7–11] to address the lack of strength, plasticity, heat tolerance, and corrosion resistance of magnesium alloys, to satisfy the needs of the automobile industry for lightweight structural components. The typical tensile mechanical properties of these magnesium alloys are shown in Table 2.

JDM1 [7,8] is an Mg-Nd-Zn-Zr based alloy. It is synergistically strengthened by dispersed Zr-containing particles and metastable prismatic β″ (Mg_3Nd)-phase precipitates; trace amounts of Zn and Zr addition promote the activity of the non-basal dislocations at room temperature, which improve the ductility of the alloy. At room temperature, this alloy has a typical yield strength of 140 MPa, tensile strength of 300 MPa, and elongation of 10%.

JDM2 [9] is an Mg-Gd-Y-Zr based alloy, which is primarily strengthened by the precipitation of coherent Mg-heavy rare earth precipitates during the aging process. At room temperature, this alloy has a yield strength of 230 MPa, tensile strength of 340 MPa, and elongation of 3%. The incorporation of texture strengthening in wrought JDM2 alloys increases tensile strength, yield strength, and elongation of the alloy to >500 MPa, >450 MPa, and >10%, respectively, at room temperature.

JDM3 [10] is an Mg-Gd-Y-Zn-Zr based alloy, which was developed by the addition of Zn in JDM2 to form high-thermal stability, long period stacking ordered (LPSO) phases. JDM3 alloy is both strengthened by the basal LPSO phases and the prismatic precipitates. The prismatic precipitates are frequently observed in Mg-RE alloys. JDM3 alloy has more than 250MPa ultimate tensile strength at 300 °C.

JDM4 [11] is an Mg-Gd-Y-Ag-Zr based alloy, which is developed by micro-alloying of Ag based on JDM2 alloy. Ag addition can modify the morphology of precipitate phases, which leads to the simultaneous formation of prismatic and basal precipitates that jointly contribute to the strength of the alloy. The JDM4 magnesium alloy has a yield strength of >300 MPa and tensile strength of 420 MPa at room temperature.

2.1.2 High thermal conductivity die-cast magnesium alloys

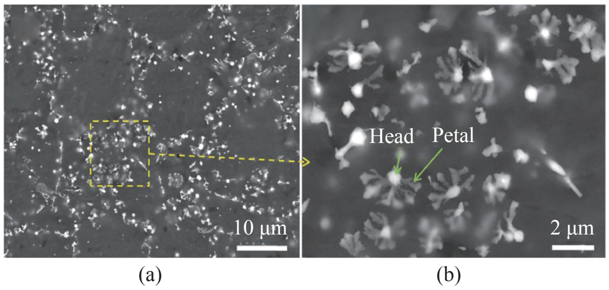
Owing to the demand of dissipating heat in lightweight components, Shanghai Jiao Tong University has developed a die-cast magnesium alloy with high strength and high thermal conductivity [12], which has a thermal conductivity of > 100 W/m·K, yield strength of > 120 MPa, comparable corrosion resistance to commercial AZ91D magnesium alloys. This alloy was used to produce car components that have high heat dissipation requirements.

2.1.3 Highly ductile die-cast magnesium alloys

As the current die-cast magnesium alloys tend to have low plasticity, Changchun Institute of Applied Chemistry (Chinese Academy of Sciences) [13] used Sm to replace mixed La and Ce rare earth in the AE44 magnesium alloy to prepare a Mg-4Al-4Sm-0.3Mn (wt%) magnesium alloy via die casting. At room temperature, this alloy has an elongation of 21%, a yield strength of 157 MPa, and a tensile strength of 245 MPa. The elongation of this new alloy is nearly two-fold that of the AE44 alloy. This increment in elongation is primarily caused by morphology change of the secondary phase as shown in Fig. 5.

2.1.4 Wrought magnesium alloys for high-speed extrusion

National Institute for Materials Science (NIMS, Japan) and Nagaoka University of Technology developed a high-strength wrought magnesium alloy (Mg-1.1Al-0.3Ca-0.2Mn-0.3Zn, wt%, AXMZ1000) [14]. The AXMZ1000 magnesium alloy is



(a) (b)

Fig. 5. Microstructure of the die-cast Mg-4Al-4Sm-0.3Mn alloy in the as-cast condition; the secondary phase exhibits a clumped distribution.

Table 2. The typical mechanical properties of JDM1–JDM4 magnesium rare-earth alloys.

Alloy	$\sigma_{0.2}$ (MPa)	σ_b (MPa)	δ (%)	Temperature (℃)
JDM1-cast T6	140	280–300	6–10	Room temperature
	130	200	15	200
JDM2-cast T6	230	320–340	3	Room temperature
	200	250	6	250
JDM3-cast T6	230	250–280	2	Room temperature
	210	250–300	5	300
JDM4-cast T6	300	380–420	2	Room temperature
	230	250	6	300

Note: "cast T6" indicates that T6 treatment was applied after the alloy was casted.

relatively insensitive to extrusion speed and can be extruded in very high speed, while maintains very high mechanical properties comparable with medium-strength aluminum alloys. Hence, high-speed extruded AXMZ1000 wrought magnesium alloys could be used in components such as car seats (car body system).

2.2 New forming technologies

2.2.1 Forming technologies for magnesium wheels

Magnesium wheels (chassis system) are light, consume less energy, and have excellent control characteristics and safety. These qualities render magnesium wheels a highly attractive option for car makers. However, owing to their high cost, low yield, and poor product stability, magnesium wheels are not sold on a large scale yet. Nonetheless, the extrusion lines invested by Linzhou Dingxin Magnesium Technology Co., Ltd. and Henan Dowell Co., Ltd. may promote the production of magnesium wheels into a commercial scale. The extrusion process is shown in Fig. 6 (photograph sourced from Dingxin Magnesium Technology Co., Ltd.), which begins with the cutting of continuously casted blanks, followed by the homogenization treatment, extrusion, machining, and finally surface coating. The extruded magnesium wheels made of AZ80 magnesium alloy are already being sold in small batches.

Additionally, Shanghai Jiao Tong University has developed a composite of low pressure die cast + flow forming (cast & flow forming) technology based on the currently existing low-pressure casting technologies for magnesium wheels. As compared with the earlier low-pressure casting process, cast & flow forming significantly improves the yield ratio of magnesium wheels. After undergoing the flow forming process, the microstructures of the wheel rim become much finer, which significantly improves the room temperature mechanical properties. Fig. 7(a) shows a 20-inch magnesium wheel that was produced by cast & flow forming technology, while the microstructures of the wheel rim before and after flow forming are shown in Figs. 7(b) and 7(c), respectively. It is shown that the flow forming process significantly refines the microstructures of the wheel rim.

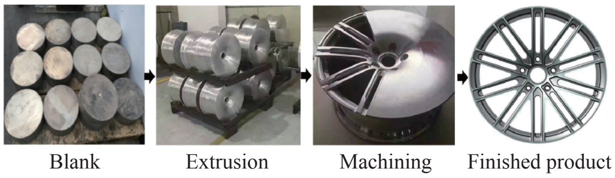


Fig. 6. Production of magnesium alloy wheels via extrusion process.

2.2.2 Vacuum die-casting technology for large and complex thin-wall magnesium parts

Compared with aluminum alloys, magnesium alloys are more suitable for high-speed casting, especially well-suited for large thin-wall parts. In 2016, a die-cast automotive door panel made of AM60B alloy produced by Wanfeng Meridian was awarded the Award of Excellence by the International Magnesium Association (IMA), and is thus an exemplary work for large and complex thin-wall magnesium alloy die-cast parts. This door panel was previously made by seven stamped steel components. After being redesigned into magnesium alloy, its weight was reduced by approximately 50%, and the number of joints (weld points and rivets) was reduced from 62 to 10. This product demonstrates the potential of magnesium alloys in automotive parts.

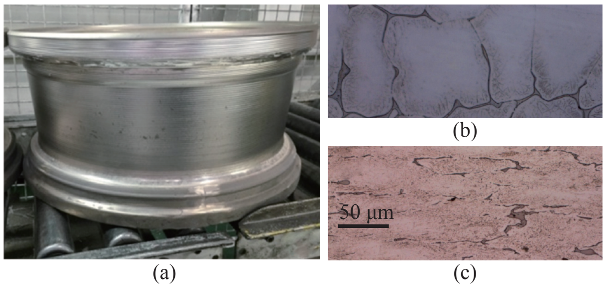


Fig. 7. (a) JDM1 magnesium wheel produced by cast & flow forming technology; (b) the microstructure of the wheel in the as-cast condition, which has a yield strength, tensile strength and elongation of 85 MPa, 138 MPa, and 4.8%, respectively; (c) the microstructure of the wheel rim after flow forming. In as-flow formed condition, the wheel has a yield strength, tensile strength, and elongation of 278 MPa, 317 MPa, and 8.4%, respectively.

With the support of National Key Research and Development Program of China, Shanghai Jiao Tong University has collaborated with Dongfeng Automobile Co., Ltd. to design shock tower and subframe by using magnesium alloy, in hopes of achieving breakthroughs in magnesium alloy forming technologies and application of magnesium alloys on these large and complex thin-wall parts.

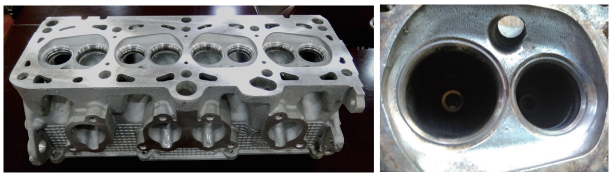
2.3 New applications

2.3.1 Magnesium engine cylinder head

The engine cylinder block and cylinder head have highly demanding material requirements as they operate in harsh thermo-mechanical environments. Shanghai Jiao Tong University first collaborated with General Motors to establish a low-pressure casting technology to cast JDM1 cylinder blocks. Subsequently, Shanghai Jiao Tong University collaborated with the Zhejiang Kaiji Automobile Spare Parts Manufacture Co., Ltd. to cast JDM1 cylinder heads and install these components in cars for road tests. Based on the casting of aluminum cylinder head, adjustments were made for magnesium alloy and then JDM1 magnesium cylinder head was ultimately prepared using the tilt-pour casting process (Fig. 8(a)). After T6 heat treatment and machining, this cylinder head was installed in a car for road tests. After working for more than 9000 km, the cylinder head was dismantled and measured. After the combustion chamber and exhaust passages were cleaned, there were no changes in the dimensions of these parts which had experienced the highest temperatures in the cylinder head. Their surfaces are clean and smooth, as shown in Fig. 8(b). The dimensions of the camshaft bore and tappet hole were measured before and after the road tests. The results show that no wear occurred in the camshaft and tappet during the road test. Hence, the JDM1 cylinder head can be used under the complex thermo-mechanical environment of car engines over a long time period.

2.3.2 Magnesium car bodies

In September 2016, Shandong Yixing Electric Auto Co., Ltd. developed an 8.3-m-long lightweight electric bus using magnesium alloys. The entirety of its chassis was made of magnesium alloy, while the panels were made of aluminum plates. Further, 226 kg of magnesium alloy was used in each bus, and its chassis was 70% lighter than an equivalent steel chassis. This showcases the advantage of magnesium alloys in reducing the weight of car bodies.



(a) (b)

Fig. 8. (a) Engine cylinder head made of JDM1 magnesium alloy and (b) surface morphology of the combustion chamber after road tests over 9000 km.

3 Obstacles against the usage of aluminum/magnesium parts and suggestions

Although the use of aluminum and magnesium alloys in automotive parts is an inevitable trend, major obstacles against the large-scale usage of these parts still remain.

3.1 Increased materials costs

The use of aluminum and magnesium alloys to manufacture steel parts inevitably results in substantially higher parts procurement costs. For example, 6011 and 6016 aluminum alloy car panels have a market price of 38000 CNY per ton, whereas the market price of steel body plates is only 8000 CNY per ton. Even with the difference in density, aluminum alloys are still much more expensive than steels. Hence, the use of aluminum car bodies was limited to high-end vehicles, as the price of low-to-mid end vehicles cannot withstand the cost pressures associated with this lightweighting technology.

3.2 Increased R&D and production costs

When a steel product is being replaced by a component made of aluminum or magnesium alloys, the structure of the product needs to be redesigned according to the characteristics of the new material. In addition, new product trials and tests are necessary, and the associated equipment, molds, and production lines also need to be updated. These R&D costs significantly increase the production costs of the new product and R&D risks borne by the manufacturer. High R&D costs and the uncertainty of R&D profits are the primary drivers for the reluctance of car makers to adopt aluminum/magnesium alloy lightweighting technologies.

3.3 Increases in maintenance costs

As aluminum and magnesium alloys are relatively soft, they are more susceptible to deformation and damage in usage. Furthermore, the repair of these alloys cannot be performed using simple processes such as sheet metal repair, as this typically requires specialized technologies and equipment, or even replaces the parts. These issues significantly increase the usage costs borne by consumers.

3.4 Insufficient maturity in anticorrosion and jointing technologies for magnesium alloys

Magnesium alloys are susceptible to corrosion as their oxide films are not dense. Although various protective coatings have been developed by scientific research, most of these technologies have only been tested in laboratory conditions. As magnesium alloys are rarely used in cars, the problems that may arise in joints between magnesium alloys and aluminum or steel parts have not been adequately investigated. Studies regarding this aspect are also relatively scarce.

Given the aforementioned obstacles against the usage of aluminum and magnesium alloys in automobiles, it may be surmised that aluminum/magnesium alloy lightweighting technologies are still in the early stage of development. A number of problems related to the materials, R&D, production, and after-sales repair of aluminum/magnesium parts remain unsolved, while certain key technologies require further optimization. This stage of development represents an opportunity for the Chinese automotive industry to improve its capacity for aluminum/magnesium alloy-based lightweighting technologies, and it is a challenge that must be jointly confronted by every party in the materials and automotive industries. We propose the following suggestions for the development of aluminum and magnesium alloy and processing technologies:

(1) Improve the ability of China's automotive industry to adopt new materials. Chinese automotive industry has developed at a rapid pace over the last 30 years and gained significant improvements in the manufacturing capacity and industrial scale. However, the industry is not adept at adopting new materials as the original designs used by the industry primarily originate from overseas sources. It is therefore necessary to enhance the capacity of the automotive industry for original design work, to fundamentally address China's demands for aluminum/magnesium alloy lightweighting technologies.

(2) Optimize industrial chains and manufacturing bases to reduce the cost of lightweight aluminum/magnesium alloy parts. The industrial chains for aluminum and magnesium alloy parts are still inadequate because of the currently insufficient relevant vendors, which has resulted in high raw materials costs. Insufficient competition in the market also contributes to high material costs as the manufacturing of automotive aluminum alloy plates can only be reliably performed at industrial scales by a small number of multinational companies currently. To solve this problem, the automotive industry of China should establish industrial chains and manufacturing bases in a targeted manner, such that the cost of aluminum and magnesium alloy parts can be reduced via market competition and mass production, thus reducing the cost of lightweighting technologies.

(3) Conduct in-depth and individualized basic research to overcome the limitations of aluminum/magnesium alloys. Some of the difficulties in aluminum/magnesium alloy lightweighting technologies could be solved using different approaches. For example, the poor corrosion resistance of magnesium alloys could be handled by incorporating anticorrosion treatments in practical applications.

(4) Use the application of die-casting processes as a breakthrough. As the automotive industry is extremely sensitive to component costs, the mass production of aluminum/magnesium alloy parts must be established based on low production costs. The die-casting process has high yields, and the amortization costs of the manufacturing equipment can be lowered through mass production. Therefore, car makers could use standardized aluminum/magnesium parts to reduce the part production costs.

(5) Capitalize on the usage of magnesium wheels as a breakthrough. New energy vehicles (NEVs) have become important for the development of the automobile industry. However, the replacement of conventional gasoline cars by NEVs will be determined by breakthroughs in the endurance of these vehicles. In addition to battery parameters, endurance is also determined by the vehicle weight. It has been shown in road tests that the replacement of aluminum wheels with magnesium wheels of the same diameter in rental cars increases their endurance by > 8%. Therefore, the use of magnesium wheels in electric vehicles could become a breakthrough point that drives the growth of magnesium alloy usage in automobiles.

4 Conclusions

In 2016, the *Energy-Saving and New Energy Vehicle Technology Roadmap* published by China mandates that new passenger cars should be able to achieve a fuel consumption rate of 5.0 L/100 km by 2020, 4.0 L/100 km by 2025, and 3.2 L/100 km by 2030. To achieve these objectives, each car will use more than 350 kg of aluminum, and 45 kg of magnesium by 2030. Therefore, the usage of aluminum and magnesium alloys in automobiles will grow explosively in the next 10 to 15 years. National Engineering Research Center of Light Alloy Net Forming of Shanghai Jiao Tong University, which is one of China's primary research centers for aluminum and magnesium alloys and forming technologies, is willing to work with upstream and downstream industries, both in China and abroad, to face this historical challenge and seize the opportunity to promote the vehicle lightweighting technologies in China.

References

[1] Guo Y Q, Zhu X F, Yang Y, et al. Research state of lightweight material and manufacture processes in automotive industry [J]. Forging & Stamping Technology, 2015, 40(3): 1–6. Chinese.

[2] Gong Y Y, Wang Z, Zhang Z P. New energy vehicles lightweight approach and its evaluation [J]. Automobile Applied Technology. 2017 (1): 5–6. Chinese.

[3] Ingarao G, Gagliardi F, Anghinelli O, et al. Sustainability issues in sheet metal forming processes: An overview [J]. Journal of Cleaner Production, 2011, 19(4): 337–347.

[4] Zhang P, Li Z M, Liu B L, et al. Effect of chemical compositions on tensile behaviors of high pressure die-casting alloys Al-10Si-yCu-xMn-zFe [J]. Materials Science and Engineering: A, 2016 (661): 198–210.

[5] Zhang P, Li Z M, Liu B L, et al. Improved tensile properties of a new aluminum alloy for high pressure die casting [J]. Materials Science and Engineering: A, 2016 (651): 376–390.

[6] Ji S, Watson D, Fan Z, et al. Development of a super ductile die cast Al-Mg-Si alloy [J]. Materials Science and Engineering A, 2012 (556): 824–833.

[7] Fu P H, Peng L M, Jiang H Y, et al. Effects of heat treatments on the microstructures and mechanical properties of Mg-3Nd-0.2Zn-0.4Zr (wt. %) alloy [J]. Materials Science and Engineering: A, 2008 (486): 183–192.

[8] Fu P H. Study on the microstructure, mechanical properties and strengthen mechanism of Mg-Nd-Zn-Zr alloys [D]. Shanghai: Shanghai Jiao Tong University (Doctoral dissertation), 2009. Chinese.

[9] He S M. Study on the microstructural evolution, properties and fracture behavior of Mg-Gd-Y-Zr (-Ca) alloys [D]. Shanghai: Shanghai Jiao Tong University (Doctoral dissertation), 2007. Chinese.

[10] Gao Y. Microstructure, properties and creep behavior of Mg-YGd-Zn-Zr alloys [D]. Shanghai: Shanghai Jiao Tong University (Doctoral dissertation), 2009. Chinese.

[11] Zhang Y, Wu Y J, Peng L M, et al. Microstructure evolution and mechanical properties of an ultra-high strength casting Mg-15.6Gd-1.8Ag-0.4Zr alloy [J]. Journal of Alloys and Compounds, 2014 (615): 703–711.

[12] Su C Y, Li D J, Ying T, et al. Effect of Nd content and heat treatment on the thermal conductivity of MgNd alloys [J]. Journal of Alloys and Compounds, 2016 (685): 114–121.

[13] Yang Q, Guan K, Qiu X, et al. Structures of Al2Sm phase in a high-pressure die-cast Mg-4Al-4Sm-0.3Mn alloy [J]. Materials Science & Engineering A, 2016(675): 396–402.

[14] Bian M Z, Sasaki T T, Suh B C, et al. A heat-treatable Mg-Al-Ca-Mn-Zn sheet alloy with good room temperature formability [J]. Scripta Materialia, 2017 (138): 151–155.