Thin-walled and large-sized magnesium alloy die castings for passenger car cockpit: Application, materials, and manufacture

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Abstract: In order to effectively reduce energy consumption and increase range mile, new energy vehicles represented by Tesla have greatly aroused the application of integrated magnesium (Mg) alloy die casting technology in automobiles. Previously, the application of Mg alloys in automobiles, especially in automotive cockpit components, is quite extensive, while it has almost disappeared for a period of time due to its relatively high cost, causing a certain degree of information loss in the application technology of Mg alloy parts in automobiles. The rapid development of automotive technology has led to a higher requirement for the automotive components compared with those traditional one. Therefore, whatever the components themselves, or the Mg alloy materials and die casting process have to face an increasing challenge, needing to be upgraded. In addition, owing to its high integration characteristics, the application of Mg alloy die casting technology in large-sized and thin-walled automotive parts has inherent advantages and needs to be expanded urgently. Indeed, it necessitates exploring advance Mg alloys and new product structures and optimizing die casting processes.

This article summarizes and analyzes the development status of thin-walled and large-sized die casting Mg alloy parts in passenger car cockpit and corresponding material selection methods, die casting processes as well as mold design techniques. Furthermore, this work will aid researchers in establishing a comprehensive understanding of the manufacture of thin-walled and large-sized die casting Mg alloy parts in automobile cockpit. It will also assist them in developing new Mg alloys with improved comprehensive performance and new processes to meet the high requirements for die casting automotive components.

Keywords: Mg alloys; thin wall; large size; automotive part; die casting

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1 Introduction

It is well known that the outstanding characteristics of magnesium (Mg) alloys, such as low density, good castability and high strength-to-weight ratio, make them as potential candidates for original equipment manufacturer (OEM) in reducing vehicle weight and improving fuel efficiency characteristics [1-3]. Since 1918, as an engineering material, Mg alloys have been used in automotive components for over 100 years [4-5]. During this period, Mg alloys have been continuously attempted to be applied in various automotive parts due to its excellent lightweight effect [6-15]. To further promote the application of Mg alloys in automobile, research on materials, parts and manufacturing processes of Mg alloys is becoming increasingly in-depth. Over a period of time, the application of Mg alloys in automobiles has faced significant resistance owing to its high material and manufacturing costs. Recently, Mg alloys have once again attracted considerable attention for the new energy and intelligent vehicles. That is mainly attributed to the two reasons, i.e., (1) new energy vehicles, especially battery electric vehicle (BEV), are constantly focusing a longer continued driving mileage, requiring less energy consumption for the same driving distance; and (2) the intelligentization of vehicle greatly increases its energy consumption. In view point of the technology, the energy density of battery and the energy storage of the vehicle cannot simultaneously meet the requirements of both long driving mileage of vehicle and high-power consumption of intelligent products in automobile. As a result, lightweight technology has become one of the effective ways to solve the issue of the energy consumption of the new energy vehicle, leading to an opportunity for the application of Mg alloys in automobiles.

At present, most research on the application of Mg alloys in passenger car is focused on the interior parts with lager sizes, such as seat frame, cross car beam (CCB) of instrument panel, as well as center console frame. These parts are in a semi-closed state due to being wrapped with some non-metallic materials, possessing a relatively good working condition compared with the exterior parts and power system components, which have to contact directly with the atmosphere and rainwater or work in the high temperature environment. This means that there are no special corrosion resistance requirements for the parts in cockpit. Furthermore, the lightweight effect of the Mg alloy parts will be more prominent when the parts with a large size in cockpit is selected. According to the related studies [6-7, 10-16], these thin-walled and large-sized Mg alloy parts are mainly manufactured by die casting technique, and the final parts greatly depends on the materials, die casting processes, and dies. Consequently, to deeply explore and promote the application of Mg alloys in automobile, the key points of thin-walled and large-sized Mg alloy parts, including material selection, die casting process, post-treatment and dies, are reviewed in detail. It also looks forward to the future prospects of Mg alloy application in automotive cockpit parts with large sizes.

2 Application of thin-walled and large-sized Mg alloy parts in automotive cockpit

Basically, in automotive cockpit, those parts with a contour size exceeding 500 mm could be considered as the large-sized parts. Following the hint, four typical Mg alloy parts are included, i.e., seat frame, CCB, center console frame, and door inner. According to the relationship between part size and die locking force, a die casting machine with large capacity is required for the manufacture of these parts [17]. For instance, a die casting machine with die locking force of 13,000 kN should be used for the seat backrest frame at least.

Among these parts, CCB of instrument panel is the biggest one with the most complex structure, and Mg alloy has been used by the majority of OEMs because of the reduced weight and its superior stiffness and strength [6]. The first high-volume one-piece die cast Mg alloy CCB was introduced by General Motors (GM) in 1996 for its full-size van (Fig. 1) [18-19]. Although a 12.3 kg part with a nominal thickness of 4 mm, it used to be the world's largest Mg die casting, which provided 32% mass saving compared to the steel design and significant performance improvements and cost savings due to parts consolidation [18]. In recent years, the development of the die casting technology has resulted in more efficient CCB parts design, achieving even greater mass savings (40%–45%) and high level of part integration [20]. Until now, more than 20 models, such as Ford GT 2005, Dodge Caliber, LandRover LR3, Mini Cooper, etc., have ever been equipped with Mg alloy CCB, each weighing 4–7 kg. In China, some OEMs, including Chery, Shanghai Automotive Industry Corporation, Geely, etc., have claimed the use of Mg alloy CCB in some car models to improve the performance of the middle and senior cars, while the related reports are limited. From the perspective of the global automotive industry, the application of Mg alloy CCB in automotive cockpit has been the mature technology currently. The primary obstacle to its widespread adoption may be the high cost of products.

Besides the CCB of instrument panel, center console frame is also an important part which could be changed from the steel structure to Mg alloy one. Traditionally, center console has not received the same attention as instrument panel owing to its relatively simple function as a cover of the gear lever and handbrake mechanism. It is usually consisting of the plastic cover and plastic structure parts with some stamped steel brackets [21] (Fig. 2).

Recently, the development of new energy and intelligent vehicles has driven the center console to be more complex, and some functions have been ported to the center console, such as cup holder, storage box, picnic table and wireless charge. The addition of the functions results in the high requirements for the structure strength and stiffness of the center console, bringing an opportunity for the application of Mg alloys in the center console frame. Although, there are relatively few reports on the application of Mg alloy center console frame [6, 22], the Mg alloys have been commercially used for the center console frame in several vehicles, such as Audi A8, Porsche Cayman, Porsche PO series, Volvo XC60, XC90 and Hongqi H7 (Fig. 3). Clearly, the current application of Mg alloys in the center console is only concentrated in premium cars, which are not cost sensitive. According to the related reports [6, 23], the weight of center console frame could be reduced from 6 kg to 2 kg by using Mg alloy parts, bringing an obvious effect of lightweight. Instead of the plastic structure, the Mg alloy center console frame does not need to be designed with thicker sections (Mg die castings could be cast to a section thickness of 1 to 2.5 mm), but the rib features should be kept on the part to enhance the structure stiffness. Thin-walled die castings promote the Mg alloy part design efficiency and offer a higher degree of integration than corresponding plastic one, superior mechanical properties, the capability to integrate several functional features, and material recyclability.

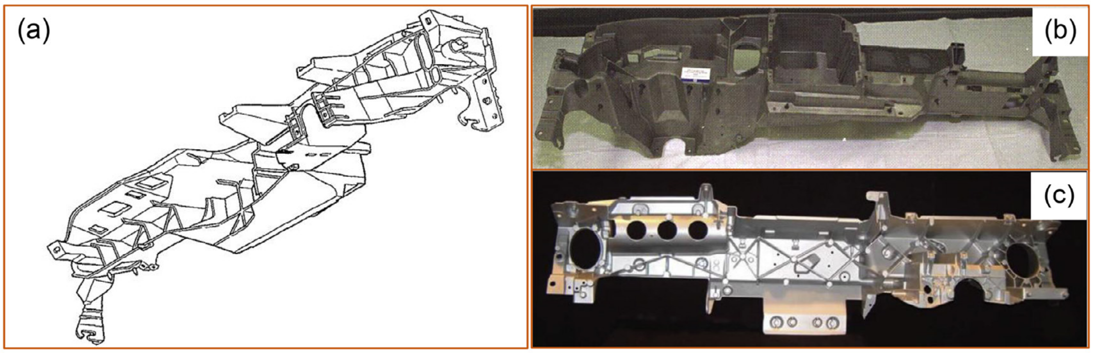

Fig. 1: First high-volume one-piece die cast Mg alloy CCB: (a) 3D data [18]; (b) CCB for GMC Savana and Chevrolet Express; (c) CCB for Buick LaCrosse [19]

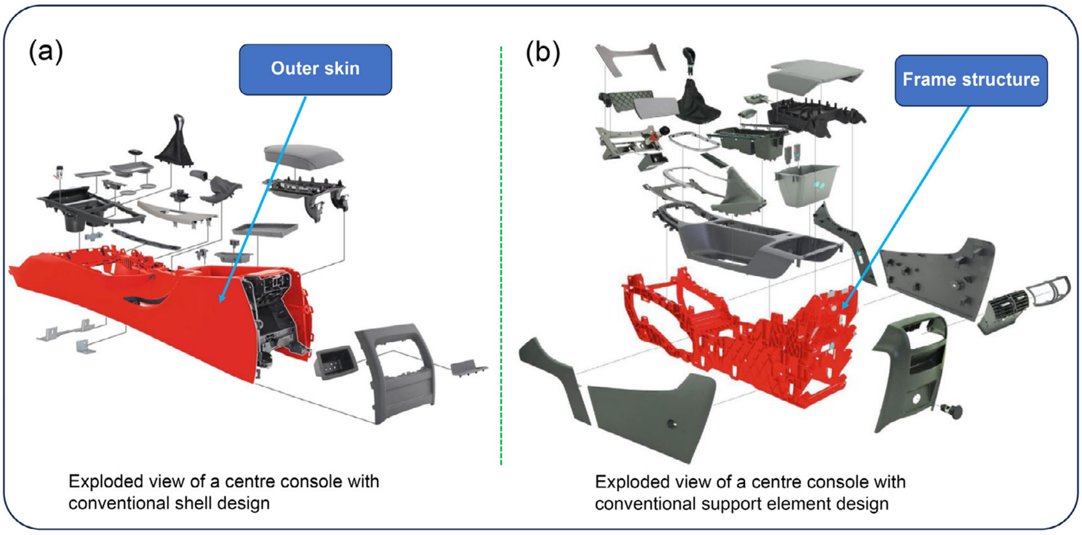

Fig. 2: Exploded view of the center console with conventional structure: (a) the shell itself is outer skin; (b) with a structural component inside [21]

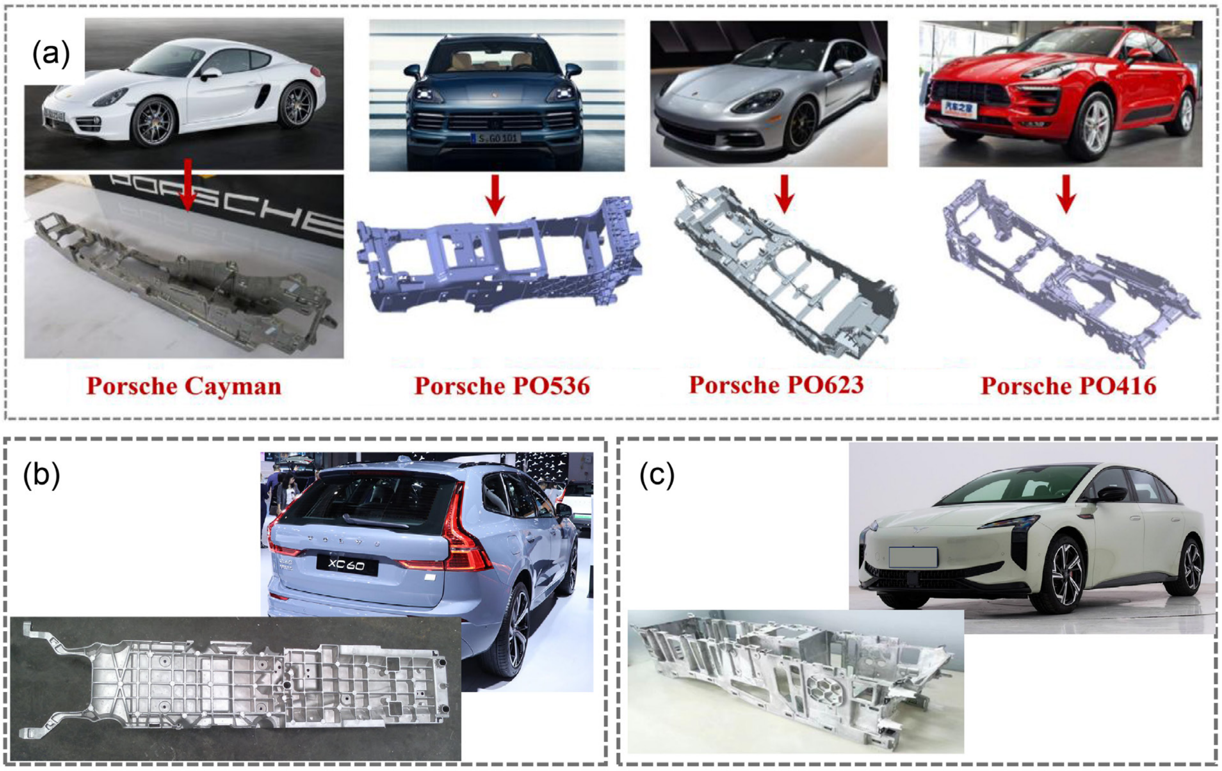

Fig. 3: Application of Mg alloys center console frame in automobile: (a) Porsche [6]; (b) Volvo; (c) Hongqi

The third important automotive cockpit component can be produced by Mg alloys is seat frame, which is the only component that supports the human body. Automotive seat systems generally consist of many different components and materials, making them enough support strength, good looking, comfortable feeling and safety. Usually, the passenger car is equipped with two sets of front seats and one set of rear seats in cockpit. The front seat is generally more functional with a complex structure, while the rear seat has relatively fewer functions and a simpler design. For traditional front seat, the frame is composed of backrest frame and cushion frame along with some adjusting mechanisms. The backrest frame is typically designed as a trapezoidal structure with 4 pcs stamped steel parts being welded together (Fig. 4). Although the ultra-high strength steel with a thickness of 0.9–1.2 mm is used, the weight of the backrest frame still reaches 2.2–2.4 kg without recliners.

For cushion frame, two stamping steel side members and a cushion pan are assembled with two steel tubes at front and rear to form a quadrilateral constructure with a weight of 2.8 kg (Fig. 5). Obviously, both the two components could be potentially integrated by Mg alloy die castings. Until now, the application of Mg alloys in seat frames has attracted increasing attention whatever in research or in production [12-13, 24-30].

Mercedes Benz firstly developed Mg alloy front seat frame in their sports car with a high integrated structure of the backrest and cushion frame in 1990 (Fig. 6) [11]. Subsequently, many OEMs, including Alfa Romeo, Daimler Chrysler, Hyundai, Mercedes Benz, etc., replaced their steel structure seat frame by Mg alloy ones, achieving a weight reduction of 40%.

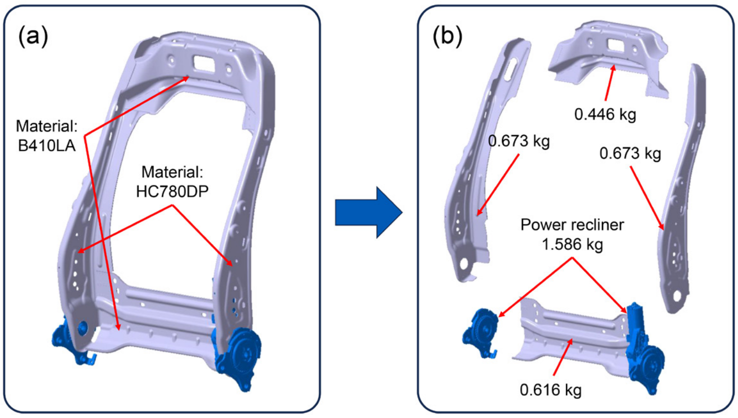

Fig. 4: Traditional seat back frame structure: (a) main material; (b) corresponding weight for each part

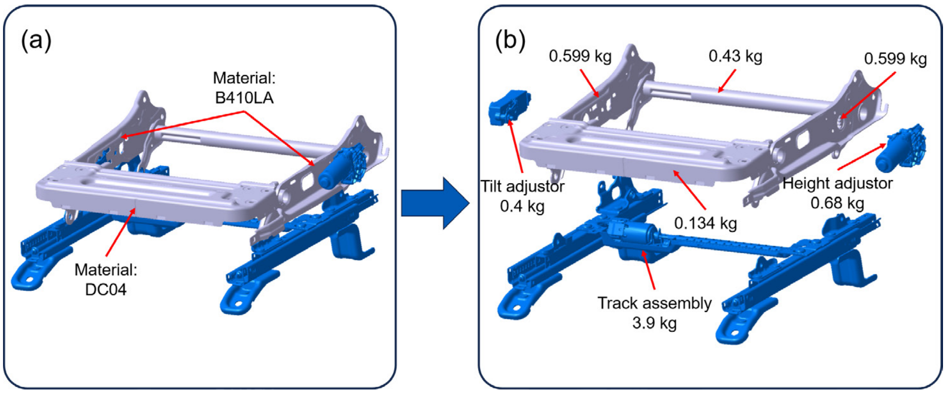

Fig. 5: Traditional seat cushion frame structure: (a) main material; (b) corresponding weight for each part

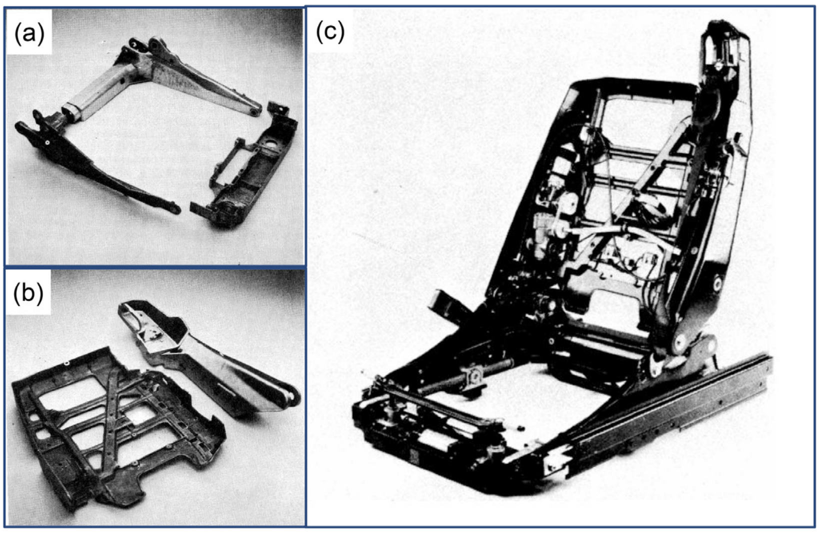

Fig. 6: Seat frame consisting of 5 Mg die casting parts: (a) backrest; (b) cushion; (c) assembly [11]

Domestically, there are few reports about the high-volume Mg alloy seat frame in production, but Changan Automobile has reportedly the use of a Mg alloy seat frame for the Oushang E01 model [6]. In addition to the replacement of steel structure seat frame, aesthetic can also be taken into account for the Mg alloy seat frame. The Mg alloy seat frame can be integrated with the plastic back panel to form a new type of Mg alloy seat frame after a surface painting with matched colors, as shown in Fig. 7 [24], further reducing the weight of the complete seat as well as the production cost. Nevertheless, the connection between the Mg alloy seat frame and the mechanisms, such as recliner, height adjustor and track, could bring some issues related to corrosion and strength of the materials, needing to be further studied and discussed later.

For rear seat, its structure greatly depends on the vehicle models, corresponding to the different backrest and cushion frame proposals for Sedan, SUV and MPV passenger cars. Usually, the structure of the rear seat frame is relatively simple with a tubular or hybrid structure (tubular and stamped parts) for Sedan vehicles. While the rear seats of SUV and MPV vehicles require some functions of adjustment, such as folding and stowing, resulting in a more complex seat frame structure similar to the front seats. Considering the feasibility of the product, current research for the application of Mg alloys mainly focuses on the rear seat frame of Sedans. That is, based on its traditional hybrid structure, the Mg alloy rear seat frame is also designed as an integrated structure. According to the literature available, there are two proposals for the Mg alloy rear seat frame, i.e., stamping panel structure and die casting structure (Fig. 8) [13]. Through the related analysis, it is found that the rear seat frame with stamping panel structure is difficult to shape, meaning that the die casting structure would be the better selection for the rear seat frame. Additionally, it is concluded that if a cast Mg back frame is within the limits of a program (mass, appearance, cost and effort targets), the benefits outweigh the negatives [10]. In practical, Ford Motor company has successfully applied Mg alloy rear seat frame in Lincoln MKT and Explore models.

Fig. 7: Images showing Mg alloy seat frame applications in 2015 Mercedes-Benz SLK seat [24]

In automotive cockpit, the metal door inner or rear liftgate inner, as the typical thin-walled and large-sized parts, have also recently received widespread attention. Traditionally, the door inner has historically been manufactured with steel stampings, although there has been a slight increase in the use of lightweight materials such as aluminum. Since the 1990s, there has been an increase in research on Mg alloy door inner [31-35]. One recent example is the application of a Mg die casting for the structural liftgate inner in the 2017 Chrysler Pacifica, replacing nine parts in the previous generation and resulting in a liftgate assembly weight reduction of nearly 50% [31]. For the door inner, the most prominent feature is its ultra-thin structure. The reported Mg alloy door inner was only 2–5 mm in wall thickness [31]. Practically, the door inner contributes to occupant protection and resists loads from aerodynamic wind, door slam, and hold open forces, as well as general use/abuse loads, resulting in a higher requirement on the structure strength as well as stiffness. Nevertheless, the limited packaging space available in both side door and rear liftgate and the limitations of designing an open section for part ejection in a die casting could not allow the Mg alloy door inner to be designed as a thick-walled part, meaning that the strength and stiffness of the part cannot be improved by increasing its wall thickness. To ensure good strength and stiffness of the parts, two methods were usually used, i.e., bonding the door inner with an aluminum/steel beam and adding some ribs or variable cross-section on the door inner structure, as shown in Fig. 9. Currently, the biggest challenge faced by Mg alloy door inner is how to reduce defects during the die casting process due to their large external dimension and ultra-thin wall thickness. It is worth noting that despite the significant weight reduction of the Mg alloy door inner, there have been few production examples of Mg inner castings in closure applications. This may be due to both the product design and cost challenges.

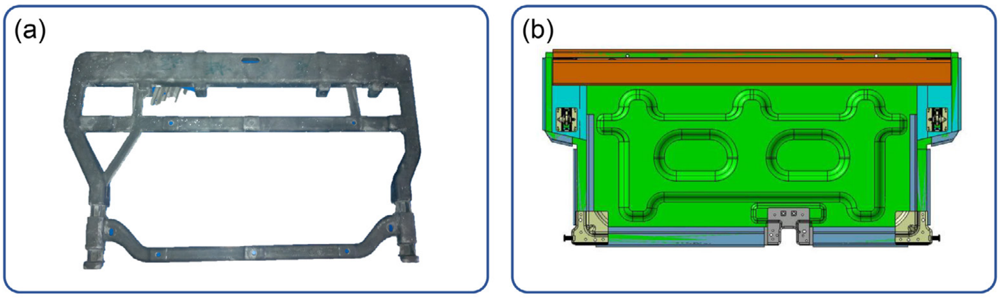

Fig. 8: Typical Mg alloy seat back frame: (a) die casting structure; (b) stamping panel structure [13]

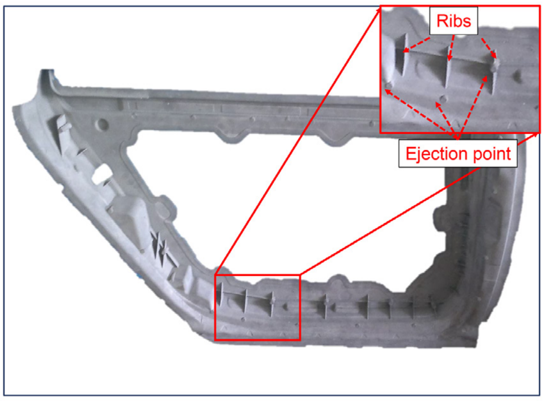

Fig. 9: Prototype of Mg alloy door inner die casting

The above analysis indicates that the application opportunities of thin-walled and large-sized Mg alloys in automotive cockpits are constantly expanding due to the advantages of high integration. Comparatively, the technologies of Mg alloy front seat frame, CCB and center console frame are more mature than those of rear seat frame and door inner. Despite the advantages of the high integration and weight reduction, the relatively high cost of raw materials, unsound supplier systems, existing material issues and the difficulty of integrated design are the main challenges which Mg alloy parts have to face.

3 Material selection

For the thin-walled and large-sized Mg alloy die-casting parts, the material selection should primarily focus on the material castability, mechanical properties, and cost, meaning choose among commercial Mg alloys. At present, the commercial casting Mg alloys are mainly included Mg-Al-Zn, Mg-Al-Mn and Mg-RE series alloys, typically corresponding AZ91, AM50, AM60, WE43 and WE54 alloys, respectively [36-40]. Actually, the selection of Mg alloys for the manufacture of thin-walled and large-sized parts in automotive cockpit is quite comprehensive and largely depends on the practical requirements of the different parts, including structure strength, rigidity, high temperature resistance, corrosion resistance, impact resistance, etc. Taking the seat as an example, the main requirements for the part are as follows:

(1) Working temperature: The parts working temperature should be –40–80 °C.

(2) Static and dynamic strength:

(i) The minimum rearward loads for seat frame deformation and failure are 1,470 N and 1,764 N, respectively.

(ii) The minimum forward loads for seat frame deformation and failure are 1,058 N and 1,274 N, respectively.

(iii) After a front impact at a speed of 50 km·h^{-1} and a rear impact at a speed of 35 km·h^{-1}, the seat frame is not allowed to crack or damage, but deformation is allowable.

(3) Rigidity: The elastic deformation of the front seat frame should not exceed 4.0 mm under a load of 500 N.

(4) Durability: After vibration of 50,000 cycles and 100,000 cycles for seat cushion and backrest, respectively, no cracking on the seat frame.

According to these requirements of the seat frame, some basic performances for the selected Mg alloys are necessary as follows:

(1) Good and stable mechanical properties are necessary for Mg alloys under both low and high temperature conditions. This means that the degradation of mechanical properties in Mg alloys is undesirable during their service under low or high temperature conditions.

(2) According to the equivalent strength theory, when the thickness and yield strength of low-carbon steel used for seat frame are 1.2 mm and 420 MPa, respectively, the substitute Mg alloys must have a minimum thickness of 3 mm and a yield strength of 168 MPa at least.

(3) The die casting manufacturing of thin-walled and large-sized parts means that Mg alloys must have excellent castability.

(4) A good fatigue strength is necessary for the Mg alloys to prevent parts failure when cyclic loads are applied.

(5) The Mg alloys need to have good corrosion resistance, as they are not prone to galvanic corrosion when connected with other metal components.

Therefore, the physical properties of Mg-Al-Zn, Mg-Al-Mn and Mg-RE series alloys, mentioned above, need to be well understood.

3.1 Mg-Al-Zn alloys

Mg-Al-Zn series alloys (including AZ91, AZ31 and AZ61 alloys, etc.) have once been the well-known materials in the past and widely investigated [41]. The typical AZ91 alloy has the lower raw material cost comparing to other alloys and has been applied in automobile for a long time. However, the shortcomings of AZ91 alloy, such as limited elongation and relatively lower corrosion resistance, limit their application in automotive cockpit. The material properties of commercial AZ91 Mg alloys are given in Table 1 [1, 36, 42, 47]. As indicated, the tension strength and elongation of as cast AZ91 alloy are relatively low, far from meeting the material strength and toughness requirements of the parts in automotive cockpit. After T4 or T6 treatment, the material strength has been evidently improved, but the elongation varies a little. In fact, the elongation of Mg alloys is crucial for automotive parts due to the fact that the fracture or cracking of the parts is not allowed after a low-speed collision. Obviously, for such a requirement, Mg alloys appear somewhat brittle due to their lower ductility.

Currently, the addition of alloying elements, such as Ce, Sr, B, Nd and Y, is the primary method to improve the elongation of AZ91 alloys. According to the related research, the addition of Ce, Nd, Ti, Sr and B to the AZ91 alloy produces a modest improvement in mechanical properties, but a trace of Y or RE could increase the tensile strength and elongation of AZ91 alloy greatly [36, 43-46]. In addition, the heat and aging treatment along with the forming process have also demonstrated to be effective for the improvement of the mechanical properties of the AZ91 alloy [47-48]. In view point of die casting process, AZ91 alloy could be readily the material for the automotive components due to its excellent castability, but it still cannot

Table 1: Material properties of commercial AZ91 magnesium alloys

Alloy	Condition	YS (MPa)	UTS (MPa)	Elongation (%)	Ref.
AZ91	As cast	95	135	2	[1]
	T4	80	230	4	
	T6	120	200	3	
AZ91	As cast	77	130	3.4	[42]
	T4	79	162	4	
	T6	130	154	1.9	
AZ91+1.0Ce	HPDC	158	248	6.8	[36]
AZ91+1.0Nd	HPDC	164	258	5.6	
AZ91+0.5Y	HPDC	162	270	10	
AZ91+0.8Pr	HPDC	137	228	6.8	
AZ91+1.0Y+1.0Ca	HPDC	168	232	3.7	
AZ91	As cast	118	180	4	[47]
	Pre-heating 375 °C/3 h 415 °C/18 h, air cooling	125	280	20	
	Pre-heating 375 °C/3 h 415 °C/18 h, water cooling	125	282	22	

completely meet the requirements of seats, CCB and door structures, which require materials with better toughness. However, it is still a good selection for those parts with complex shapes and relatively good working conditions, such as the center console frame. For other Mg-Al-Zn alloys (AZ31 and AZ61), there are few reports on the practical applications in automotive cockpit parts, needing to be further studied and developed.

3.2 Mg-Al-Mn alloys

Mg-Al-Mn series alloys are another commonly studied and used lightweight material in automotive cockpit parts, and AM50 and AM60 alloys have received considerable attention due to their relatively higher strength and elongation compared with AZ91 alloy. It is well known that the increase in corrosion resistance and toughness of the AM series alloys mainly attributes to the addition of Mn and the reduction of Al content in materials, which would worsen the material strength and castability [49-51]. At present, AM50 and AM60 alloys have been the predominantly materials of the auto seat frame and CCB parts, while the limited material mechanical properties of such AM series alloys are still the barrier for their application in automotive parts. In addition, these alloys are generally unsuitable for use above 150 °C, and a certain degree of degradation in strength are evidence [52]. Taking advantages of relatively low cost of the AM series alloys, a lot of modified AM50 and AM60 casting Mg alloys with various element additions have been developed, mainly focusing on the tensile properties, strengthening mechanism and/or corrosion resistance. For instance, Ti, Sn, Y, Nd, B, RE, Sr, Ce and so on, have been chosen to further improve the mechanical properties of AM60 alloys [36, 53, 57-60]. Among these alloying and microalloying elements, Ti, Nd, Sn and Ce elements are found to be relatively effective in further enhancing the mechanical properties of AM60 alloy. Similarly, the addition of Ca, Sb, Cu, Ce, Pr or RE is also confirmed to be effective for improving mechanical properties and corrosion resistance of AM50 alloy [61-68]. Typically, the addition of Ce can remarkably improve the tensile and compressive properties of AM50 alloy at both room and elevated temperatures due to the formation of Al-Ce phases and the grain refinement [63]. The addition of Cu into AM50 alloy has stronger grain refinement effects in comparison with that of Sb [62]. The as-cast room temperature tensile properties of modified AM50 and AM60 alloys with various additions are shown in Table 2. Clearly, the yield strength of AM50 and AM60 alloys is generally lower than that of AZ91 alloy, but their elongation is relatively better. It is worth noting that Fe element contained in AM50 alloy is detrimental to the corrosion resistance of the material. The corrosion rate of AM50 alloy depends on the impurity concentration in the alloy, and increases with Fe/Mn ratio [69]. Apart from the addition of some elements in alloys to improve material properties, methods such as heat treatment can also improve material performance. Yang et al. [70] reported that T6 treatment improves not only corrosion resistance of AM50 alloy because of the solid solution of Al elements in the α-Mg phase but also the tensile strength of the materials because of the solution treatment and aging strengthening.

Although a lot of modified AM series alloys have been developed, most of them have not yet been produced with high

Table 2: Properties of commercial AM50 and AM60 magnesium alloys

Alloy	Condition	YS (MPa)	UTS (MPa)	Elongation (%)	Ref.
AM50	HPDC	125	210	10	[1]
AM50	As extruded	168	268	18	[51]
AM50	As cast	48	157	8.3	[54]
AM50+0.15B	As cast	94	215	12.3	[54]
AM50	HPDC	87	145	2.8	[55]
AM50+1Ce	HPDC	98	168	4.8	[55]
AM50	As cast	87	190	7.7	[56]
AM50+0.6Sb	As cast	110	257	9.9	[56]
AM50+1Y	As cast	101	226	8.4	[56]
AM60	HPDC	115	205	6	[22]
AM60+0.2Ti	As cast	–	284	11.2	[36]
AM60+1Sn+0.3Ti	As cast	115	190	9.3	[36]
AM60+0.9Y	As cast	62	192	12.6	[36]
AM60+0.9Nd	As cast	127	230	14.0	[36]

volume or abundantly used in automotive cockpit parts. These types of Mg alloys remain the most promising materials for application in automobiles, requiring robust design and cost reduction. Furthermore, considering the operation conditions, in addition to the material strength and corrosion resistance, the other properties, such as fatigue properties and cyclic deformation behavior, need to be investigated deeply.

3.3 Mg-RE alloys

Generally speaking, the research and application of Mg-Al series alloys in automotive cockpit parts are quite extensive, mainly due to their high strength, good castability. However, the formed coarse brittle Mg-Al intermetallic compounds ($Mg_{17}Al_{12}$) in Mg alloys greatly decrease the mechanical properties of the materials, limiting their application. Mg-RE series alloys, as another important commercial Mg alloys, have attracted significant interest in auto industry in recent years. Rare earth (RE) elements can enhance corrosion resistance and mechanical properties of Mg alloys, especially high-temperature performance by forming precipitates with high melting points and high stability. Furthermore, RE also can purify Mg alloy melts, refine grains and improve castability [71-74]. Mg-RE alloys, albeit high cost, have been widely used in many key fields such as aerospace and defense industries, but few in auto industry. Among the Mg-RE alloys, WE43 and WE54 alloys are the two most well-known commercial Mg alloys and receive considerable attention. Nowadays, WE43 and WE54 alloys have been defined as the high-strength casting Mg alloys that can be used in temperatures of up to 250 °C [75]. Traditionally, such level of performance could be achieved by the use of some expensive elements such as Ag, Y and combination of other RE mixtures, only being accepted in aerospace and other high-performance applications, which are cost insensitive. However, the current largest market for the use of Mg alloys is in the high volume commercial automotive sector owing to the maximum fuel economy and minimum emissions. To achieve further weight reduction for the passenger cars, the application of Mg alloys in automotive cockpit should be expanded. Therefore, an opportunity is given to WE43 and WE54 alloys for the design and manufacture of the thin-walled and large-sized automotive cockpit parts. Table 3 summaries the typical mechanical properties of WE43 and WE54 alloys at different temperatures [76]. As can be seen, both WE43 and WE54 alloys maintain exceptional properties at temperatures as high as 250 °C, completely meeting the requirement of the maximum operating temperature of 105 °C (It refers to the temperature generated after prolonged exposure to sunlight) in automotive cockpit. To further improve the mechanical properties of the materials, similar to Mg-Al series alloys, element alloying and heat treatment are the commonly used methods for WE43 and WE54 alloys. Heat treatment is found to be effective for improving the tensile yield and ultimate strengths of WE43 alloy [77]. Zr, Zn and Sm are confirmed to be beneficial for the grain refinement of Mg-RE alloys due to the promotion effect in nucleation, eventually leading to a distinct combination of strength and ductility of WE43 and WE54 alloys [78-80]. It worth noting that the heat treatment strengthening effects for Mg-RE alloys would be significantly weakened if the porosities is high in materials [81]. In fact, WE43 and WE54 alloys are currently used for the power systems and gearboxes of sports cars and missiles by taking advantages of their specific high-temperature mechanical properties but not in automotive cockpit parts,

Table 3: Typical properties of WE54 and WE43

Alloy	Condition	YS (MPa)	UTS (MPa)	Elongation (%)	Ref.
WE54	As cast	146.7	173	1	[79]
	Solution-treated	148	200	4.8	
	Peak-aged	222	242.5	0.8	
WE54+0.45Zr	As cast	149.7	211.7	5.1	
	Solution-treated	153.5	223	12.5	
	Peak-aged	194	274.5	8.2	
WE54	T5	200	300	10	[77]
WE54	T6-ambient temp.	205	265	4	[76]
	T6-150 °C	191	245	5	
	T6-250 °C	177	234	10	
WE43	T6	187	256	4.1	[78]
WE43	T6	160	245	6	[77]
WE43	T6-ambient temp.	190	252	7	[76]
	T6-150 °C	175	243	7	
	T6-250 °C	160	227	18	

which are operated in a low-temperature condition and sensitive to material costs. Therefore, it is of significance to develop a new low-cost and high strength Mg-RE alloy.

Based on the above analysis, it can be concluded that in real production, the commercial used Mg alloys for automotive cockpit parts are limited. The insufficient ductility of AZ series alloys is their main disadvantage, and the strength and toughness of AM series alloys need to be further improved. The application of Mg-RE series alloys still faces price barriers although they have excellent mechanical properties. Comparatively, AM series alloys (AM50 and AM60) are still the preferred material for die casting automotive cockpit parts at present. For the parts with good working conditions, such as center console frame, DVD support bracket, AZ series alloys are better for application. Actually, the application of Mg alloys in automotive cockpit parts has to face a big challenge from the development of ultra-high strength steel (UHSS). Recently, the seat frames have been produced using UHSS with the tensile strength of 780 and 980 MPa, achieving a 20wt.% reduction in weight but not causing a significant change in product cost [82-83]. Furthermore, transformation-induced plasticity (TRIP) steel with tensile strength of 1,180 MPa has also been attempted to use for the automotive seat track, possibly resulting in about 1 kg weight reduction [84]. This means that the advantage of Mg alloys in weight reduction is greatly weakened. Therefore, Mg alloys with higher strength and lower cost, especially Mg-RE series alloys, need to be developed to make their applications more competitive.

4 Manufacturing and post-treatment of Mg alloy parts

Due to the hexagonal lattice of Mg, the deformation of the Mg alloys is difficult at room temperature. Therefore, casting has been the dominant manufacturing process for Mg components, including high-pressure die casting (HPDC), gravity casting, low-pressure casting (LPC), etc. For Mg alloy automotive parts, especially thin-walled and large-sized parts, the most commonly used manufacturing process is HPDC since it offers much flexibility in design and manufacturing and its excellent die filling characteristics, enabling large, thin-walled, and complex castings to be economically produced [85]. Although the heat treatment has been confirmed to be beneficial for improving mechanical properties of Mg alloys [86-89], it is rarely applied in Mg alloy die casting parts because trapped gas pores tend to expand after heat treatment, causing surface blistering and bulk distortion [86].

4.1 Manufacturing of die casting Mg alloy parts

It is well known that two types of HPDC processes can be used for the manufacturing of Mg alloy components in automobile, i.e., hot chamber die casting and cold chamber die casting [90]. Most thin-walled and large-sized Mg alloy parts, including CCB, seat frame, center console frame and door inner, are produced by the cold chamber die casting process due to the limited castability of hot chamber die casting. Generally, the cold chamber die casting process consists of six steps with different injection pressures (Fig. 10 [91]). The whole cycle of HPDC takes usually around 2 minutes. Macroscopically, due to their characteristics of thin walls and large size, these Mg alloy parts often face three main issues during manufacturing: (1) insufficient filling, (2) differences in mechanical properties of the parts in different positions, and (3) part deformation. Therefore, the key to manufacturing the thin-walled and large-sized Mg alloy die casting parts lies in the appropriate part structure design and the selection of die casting process parameters. The low heat content of Mg alloy materials leads to the rapid solidification of molten Mg alloys with the solidification time of 5 ms–100 ms depending on the wall thickness. It thus makes the molten Mg alloys prone to insufficient filling during the die casting process, especially for those thin-walled and large-sized parts. Based on the ideal injection molding profile [91], the rapid pre-fill and fill steps are necessary to avoid premature freezing. Also, the process parameters, including casting and die temperatures, filling time, plunger and gate velocities, injection and intensification pressures and so on, can remarkablely influence on the product quality and mechanical properties [92-93]. For instance, the material mechanical properties of the thin-walled and large-sized parts are related to the distance between the gate and the material position. The mechanical properties of the material decrease with increasing distance from the gate, meaning the lower mechanical properties of the materials at the final filling position [91]. This means the gate should be designed as close as possible to the center of the part, ensuring that the distance between each area of the part and the gate is consistent. Alternatively, the critical stress-bearing areas of the parts should not be positioned far from the gate, which will be shown in Section 5. In addition, both the lower gate velocity and the lower melt temperature could reduce the number density and area fraction of the gas pores [94]. The increase in plunger pressure would increase the material strength, while decrease its elongation [95]. Therefore, to achieve a die casting part with good quality, the casting process should be made under high injection and intensification pressures, with a low casting temperature and high die temperature and with minimum flow velocities. It should be pointed out that for thin-walled parts, the effectiveness of packing pressure in improving part integrity is not as significant as for thick-walled parts. Additionally, the deformation of the thin-walled and large-sized Mg alloy parts is also a major issue during their manufacturing, which is difficult to avoid. To effectively control the deformation of parts, meticulous attention to detail is imperative, including optimization of part structure, appropriate material selection, reasonable die design, and strict control of the manufacturing process.

For the manufacturing of the automotive cockpit Mg alloy parts mentioned above, the cold chamber die casting machine with locking force of 30,000 kN is sufficient to meet their requirements. However, cold chamber suffers from lower economic performance than hot chamber. To address it, integrating more parts can be beneficial for the cost saving. Therefore, ultra-large cold chamber die casting machines have been developed in recent years and used for the manufacturing of thin-walled and large-sized Mg alloy parts for automobiles. Since 2020, ultra-large cold chamber HPDC machines (locking force>60,000 kN) have been rapidly developed with the introduction of integrated die casting technology into the manufacturing of rear floor by Tesla. At present, many car manufacturers, including Tesla, XPENG, ZEEKR, Xiaomi, AITO, etc., use ultra-large die casting machines (The locking force even exceeds 100,000 kN) for the design and manufacturing of oversized thin-walled die casting parts of vehicle body on their main models. It should be noted that the application of ultra-large die casting machine on the integrated rear floor mainly focuses on Al alloy materials, and there are relatively few reports on the Mg alloy integrated die casting rear floor of vehicle body. This may be related to the fact that the mechanical properties of Mg alloy currently cannot meet the requirements of collision strength for automotive bodies, which emphasize not only the high strength but also the good toughness of the materials. In the future, the oversized thin-walled vehicle body parts such as rear floor are also expected to be designed and manufactured using Mg alloy integrated die casting to achieve a greater weight reduction.

At a microscopic level, two key issues also need to be addressed for the manufacturing of thin-walled and large-sized Mg alloy parts. Namely, gas porosity formed in the die casting parts and formation of externally solidified crystals (ESCs) in the shot sleeve. The gas porosity caused by gas entrapment

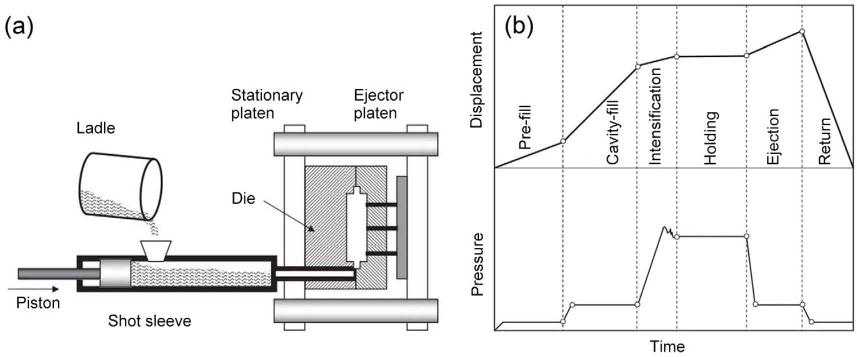

Fig. 10: Schematic of a cold chamber die-casting machine (a), and stages of the shot profile for die casting process showing changes of melt pressure and plunger displacement versus time (b) [91]

during high-speed injection of molten Mg alloys into the mold cavity seems inevitable in die casting, greatly affecting the mechanical properties of thick-walled parts, including their durability and fatigue strength. Vacuum-assisted HPDC is an effective way in reducing the gas porosity level in castings [96-97]. Compared with conventional HPDC, vacuum-assisted HPDC can indeed reduce the porosity in Mg alloy die castings and improve the mechanical properties of the Mg alloys, as shown in Fig. 11 [98]. Until now, only the company of Gibbs Die Casting (Henderson, KY), in North America, was reported that their die casting Mg alloy components have been in production by using vacuum high pressure die casting process [18]. Additionally, to further modify the material properties of Mg alloys, similar to high vacuum die casting process for aluminum, a super vacuum die casting (SVDC) process has been developed for Mg alloys [99]. The results show that the ductility and ultimate tensile strength of the both AZ91D and AM60B alloys produced by SVDC are significantly improved compared to the conventional HPDC properties due to the reduced porosity in these castings. In addition, the adjustment of the pouring speed and injection parameters and control of cavity filling degree could also reduce the porosity in the die casting Mg alloy parts. For cold chamber die casting, the filling degree should be greater than 50%, preferably 70%–80%, to ensure that the molten Mg alloy flows fully in the pressure chamber and reduce the air entrapment caused by waves and reflected waves.

Besides the porosity issue, ESCs is also identified as a kind of defect of the Mg alloy die casting parts. Ideally, the solidification of molten Mg alloy should start after die cavity is full. However, during pouring and filling, some molten Mg alloy already solidifies outside, forming ESCs. Some fraction of ESCs may travel into the die cavity during cavity filling and reside as part of the final casting (Fig. 11). ESCs remaining in the material can bring a negative impact on the mechanical properties of the part. Furthermore, the formation of ESCs could also affect the melt flowability, die cavity filling, and microstructure of castings. Therefore, minimizing or eliminating the content of ESCs as much as possible is particularly important for improving the performance of Mg alloy die casting parts. Obviously, the formation of ESCs is closely related to the pouring temperature of Mg alloy melt and shot speeds. A relatively higher pouring temperature, a higher slow shot speed and a shorter delay time of pouring would lead to a decrease of the size and percentage of the ESCs. Additionally, the use of ultrasonic treatment of the Mg alloy melt during the die casting process can also reduce the percentage of ESCs [91].

4.2 Post-treatment of Mg alloy parts

After ejection from the die cavity, the Mg alloy parts need to be post-treated, including trimming, deburring, surface treatment, painting and so on, to ultimately become a commodity. In general, the ejected Mg alloy part needs to be

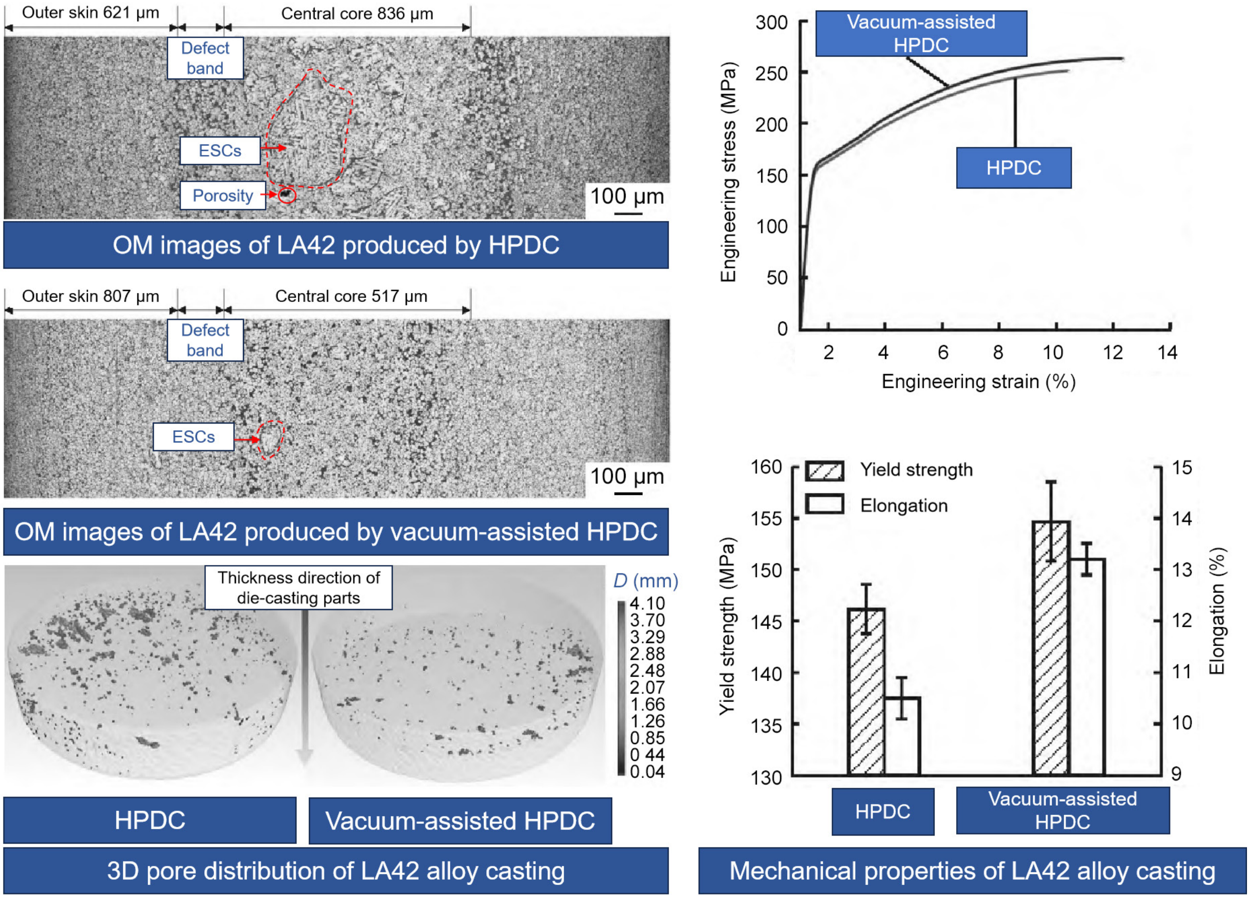

Fig. 11: Comparison of the LA42 alloy casting of HPDC and vacuum-assisted HPDC [98]

firstly punched to remove the redundant materials on the part, such as gating system, overflow launder, burrs, flash and so on [Fig. 12(a)]. For the sake of cost, the reduction of the redundant materials volume as much as possible is necessary through the optimization of the die and die casting processing [100-103].

After trimming treatment, the Mg alloy die casting parts would be sent for the surface treatment. Surface treatment is mainly used to prevent further oxidation or corrosion of the Mg alloy parts. The detailed flow chart for the surface treatment of the Mg alloy parts is shown in Fig. 13, approximately including 3 stags with total 9 steps.

The first stage includes 6 steps and aims at removal of contaminants and activating the surface. At this stage, the treatment of Mg alloy parts is relatively regular, but the process is tedious and time-consuming. After the first stage treatment, the part surface is completely cleaned and then the part can be passivated, aiming to formation of a dense oxide film on the surface of Mg alloy, which can delay or prevent corrosion of the Mg alloy parts. Depending on the requirements, there are three methods for passivation treatment, including electrochemical plating, conversion coatings and anodizing. The electroplating and electroless techniques are the most promising methods for the surface treatment of common metals but are still at developing stage and not mature enough for Mg alloys [104]. It should be noted that no matter electroplating and electroless plating, the waste disposal generated during the pre-treatment and plating baths is a serious issue. Recently, some environmentally-friendly methods have also been developed but not widely applied for the magnesium alloy parts [105-106]. Another passivation treatment method is chemical conversion coating, which could enhance paint adhesion to the coatings and provide improved corrosion protection to the Mg alloys due to its low cost and simplicity in operation [107]. There are various types of conversion coatings used for surface treatment of Mg alloys, including chromates [108-109], phosphates [110-111], permanganates [112], molybdates [113], and rare-earths-based systems [114-116]. In earlier days, the most widely used conversion coating for Mg alloys is chromate process, but it has gradually been abandoned in automotive parts in recent years due to the carcinogenic effects of Cr^{6+}. Phosphate and rear earth-based conversion coatings attract more attention as the alternative to conventional chromate conversion coatings for the surface treatment of Mg alloy parts [117-118]. The third most frequently used method for the passivation treatment of Mg alloys is anodizing, which has been successfully used over many decades. The obvious advantage of this process is the formation of a thick, stable anodized layer with desirable protective, decorative or functional properties. Up to now, various commercial anodizing technologies have been developed to protect Mg alloys, including galvanic anodizing

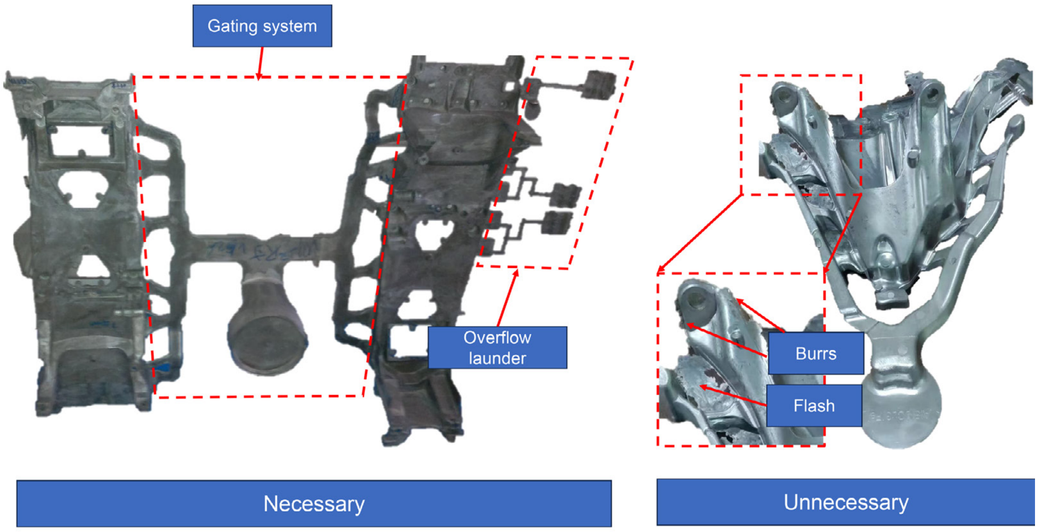

Fig. 12: Typical redundant materials on the part of Mg alloy die casting

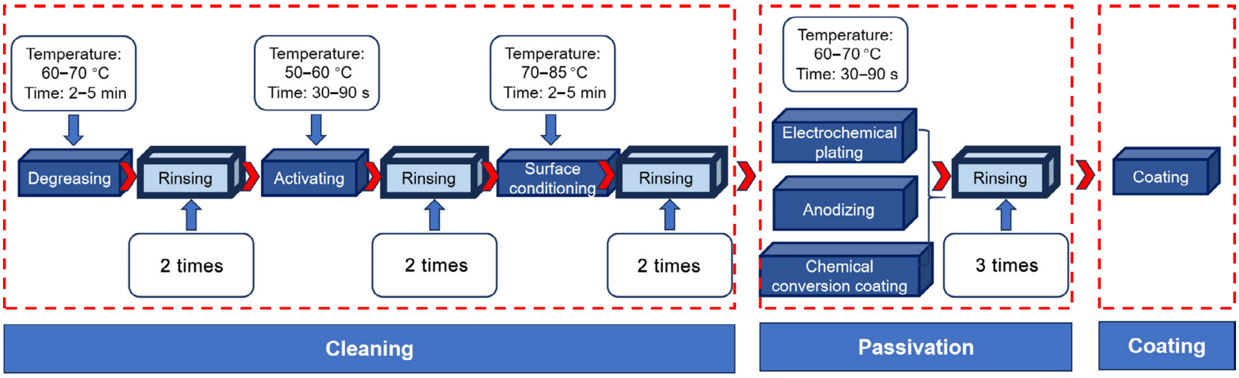

Fig. 13: Surface treatment process flow for Mg alloy die casting parts

(called Dow 9 process), Dow 17 process, HAE process, anomag process, tagnite treatment, magoxide-coat treatment and so on [119-120]. The related research indicated that the anodizing process parameters have a significant influence on the properties of the anodic films formed on Mg alloys. For instance, the anodizing potential could greatly influence the surface morphology and corrosion property of the anodic film formed on AZ31 Mg alloy [121] (Fig. 14), and the thickness of the anodic films shows a trend of firstly increasing and then decreasing with a maximum value of 2.3 μm at an anodizing time of 30 s [122]. Although anodizing could provide a film of hard, dense, electrically insulating and wear resistant, this process also faces many challenges, such as eletrochemical inhomogeneity in coating, effect of localized heating on fatigue strength of Mg alloys. Due to its high operational costs, the use of anodizing in the automotive industry is rather limited in comparison to conversion coatings, which are inexpensive and simple, meaning that further development is required to reduce the costs of anodizing.

Practically, the Mg alloy parts used in automotive cockpit are usually semi enclosed, such as seat frame and CCB, etc., which are wrapped with non-metallic materials for decoration on the outside and are not directly exposed to the atmospheric environment. Therefore, most OEMs do not require coating treatment for these Mg alloy parts. After passivation treatment, the Mg alloy parts will be directly used in automotive cockpit. In order to achieve higher quality, some premium cars require the coating treatment for the Mg alloy parts. The painting of Mg alloy parts does not differ substantially from that of other metals. It should be pointed out that the painting cannot be directly applied to bare Mg alloys, and a pretreatment is necessary prior to painting process to form a thin film, such as chromate film, for enhancing the adhesion between the coating and substrate.

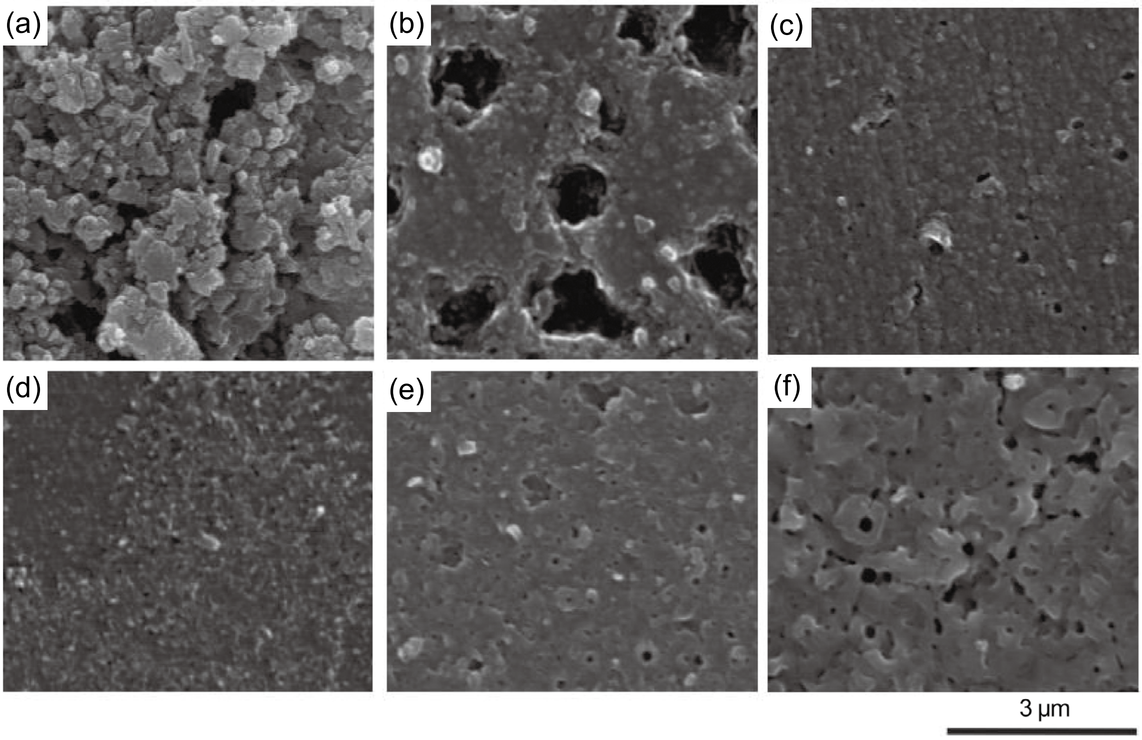

Fig. 14: Surface morphologies of AZ31 Mg alloy after anodizing at 3 V (a), 10 V (b), 20 V (c), 70 V (d), 80 V (e), and 100 V (f) [121]

5 Die casting die for thin-walled and large-sized Mg alloy parts

Die casting dies are crucial for the manufacturing of Mg alloy die castings. Whether the die casting process can be carried out smoothly and whether the casting quality can be guaranteed greatly depend on the design of the die casting die [123]. Basically, there are some requirements for die casting dies:

(1) The die needs to be repeatedly used for the part manufacturing.

(2) The die should ensure the consistency between the formed parts and the designed 3D data.

(3) The die should ensure the completely filling of molten Mg alloys in the die cavity.

(4) The heat transferred from molten Mg alloys can be quickly removed during the alloy solidification stage.

(5) The die should allow easy ejection for the formed parts from the die cavity.

To meet the related requirements, the die structure, materials, die cavity, and gating system, etc. should be taken into consideration comprehensively. Among them, the die cavity and gating system mainly determine the forming of the parts.

5.1 Die cavity design

The design of the die cavity is strongly related to the parts, including the external dimensions, wall thickness, and structure of the parts. The external dimensions of the parts determine not only the size of the die but also the required tonnage of the die casting machine. According to the size of the Mg alloy parts to be manufactured, there are related formulas for calculating the die size and locking force, which will not be described in detail here. For thin-walled and large-sized Mg alloy die casting parts, the most important factor is the forming ability of thin walls. It is well known that Mg alloys have lower latent heat of crystallization compared with aluminum alloys. During the flow process of molten Mg alloys in die cavity, they come into contact with the cavity wall, causing a rapid decrease in temperature and reduced fluidity, which has a certain hindering effect on the subsequent alloy liquid. If the wall thickness of the part is designed too thin, the flow of molten Mg alloys in die cavity will be poor, causing defects such as blisters, flow lines and premature freezing on the surface of the casting, as shown in Fig. 15(a) [91]. Normally, the wall thickness of Mg alloy parts is 2–4 mm, and there are also reports that the minimum wall thickness of Mg alloy die casting parts can reach 0.5 mm [124]. Of course, the wall thickness of Mg alloy parts cannot be designed too thick, as it may cause inconsistent solidification rates of Mg alloy melt in different areas, leading to an issue of internal porosity, as shown in Fig. 15(b) [125]. Commonly, the thickness of parts, which are made by commercial Mg alloys, could be determined through the equation as follows [126]:

$$T_{\min} = 0.8 + (0.004 - 0.005)S$$

where, T is the minimum thickness of the Mg alloy parts, S is the distance between the wall and the inner runner.

To avoid defects, reduce stress concentration and achieve good part quality, the wall thickness of thin-walled and large-sized Mg alloy die casting parts needs to be designed as uniform as possible in different areas. Therefore, some design techniques need to be used for the Mg alloy parts. For example, in areas where structural thickness is required, hollow design can be used to make the wall thickness uniform, as shown in Fig. 16. Additionally, for thin-walled and large-sized Mg alloy die casting parts, the reinforcing ribs is necessary to improve the strength and stiffness of the parts. Figure 17 [127] displays some suggestions about how to layout the ribs on the die casting parts, which can provide a guideline for the design of both the Mg alloy parts and die cavity.

Actually, the shape and size of ribs are more crucial for their design on the Mg alloy parts. Related studies have shown that the rib thickness has a relatively small impact on the part, but the notch radius of the rib behaviors considerably effect on the part. Comparatively, a large notch radius is more detrimental to the part strength [128]. The effect of the notch radius on the fatigue strength is caused by the difference in the highly stressed volume, rather than by the stress concentration associated with the notch factor. With the larger notch radius, a large volume is subject to stress because of the low stress gradient. As the volume subjected to stress increases, the probability of larger and more defects within that volume also increases.

Regardless of parts structure, the design of the die cavity needs to follow some requirements:

(1) The draft angle designed on the die casting part is necessary for its easy ejection from the die cavity. The draft angle of the Mg alloy parts does not need to be designed to be as large as that of injection plastic parts and aluminum alloy die casting parts. The draft angle of 2°–5° is usually recommended for the design of the die casting Mg alloy parts, sometimes can be designed to 0°–3° due to the low affinity between Mg and Fe [126].

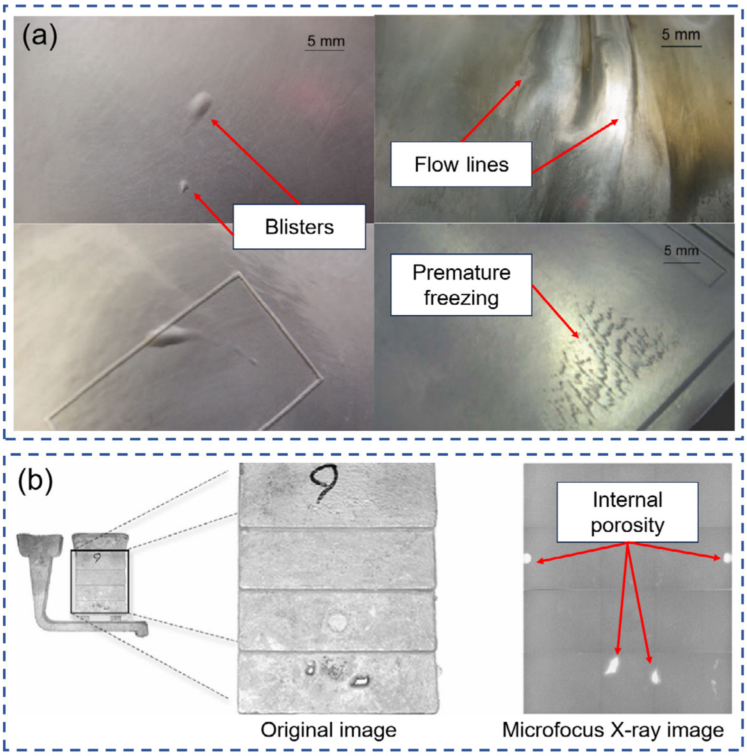

Fig. 15: Typical surface defects of thin wall Mg alloy parts: (a) blisters, flow lines, and premature freezing [91]; (b) internal porosity [125]

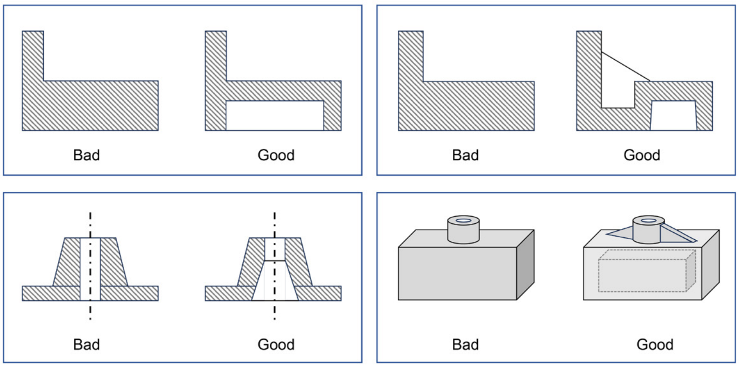

Fig. 16: Suggestions for the design of the die casting parts with uniform wall thickness

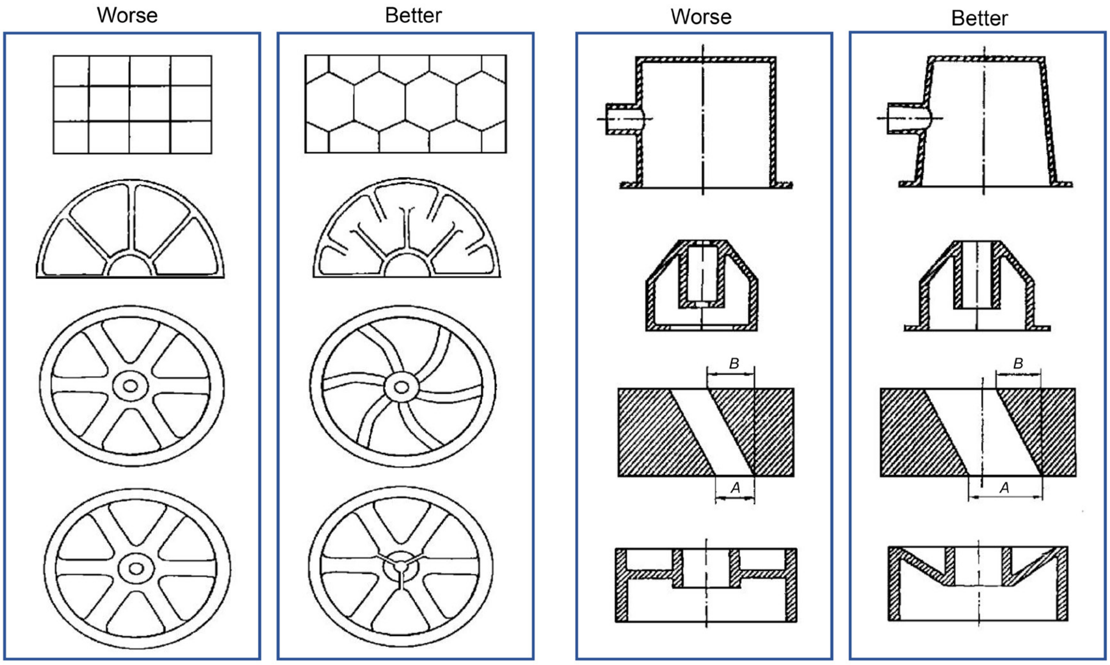

Fig. 17: Some suggestions about how to layout the ribs on the die casting parts [127]

(2) The undercut design for the die cavity should be avoided as much as possible in any area. The undercut structure on the parts can lead to the ejection difficult, and even cause Mg alloys to be torn or damaged owing to the poor material toughness.

(3) The intersection of two features on the part needs to be designed as a circular arc transition, which can reduce or eliminate stress concentration and cracks, and improve filling. Within the permissible limits of the part structure design, the radius of these circular arcs should be as large as possible.

(4) Features, such as sharp corners, edges, narrow grooves and small cores, etc. on die casting parts should be avoided. The corresponding structures in the die cavity for these features are easily damaged during the die casting process. After long-term use, these features are also prone to wear and tear, resulting in a decrease in the quality of the parts. If these features must be present on the parts, machining is recommended to achieve them.

(5) Ejector pins should be considered for the design of the die casting die. The location of ejector pins is strongly related to the location and magnitude of metal shrinkage on the parts during the cooling. Generally, the distance between the axis of the ejector pins and the casting wall cannot be less than 0.75 times the diameter of ejector pins.

5.2 Gating system design

For the die casting die design, the gating system plays an important role for the control and adjustment of the flowing direction of molten metal, temperature distribution of the die, pressure transmission, filling time, and so on [129-132]. An ideal gating system reduces the turbulent flow of molten metal inside the die cavity, holds gas to a minimum level, limits impurities and avoids various part defects. At the same time, an ideal gating system can also balance the relationship between meeting the requirements of die casting filling and minimizing material consumption.

Typically, the gating system consists of biscuit, sprue, runner, gate, and overflow launder, as shown in Fig. 18. With the development of the die casting technology, the sprue has been optimized due to cost reduction, and even are removed in some cases. For the die casting die, the design of the runner, gate and overflow launder greatly influence the final part quality. The sizes of the runner and gate could be calculated by using classical formulas and the size and quantity of overflow launder could be determined according to the wall thickness and volume of the parts [133]. However, the type of the runner and gate largely depends on the specific structure and shape of the parts. Basically, there are three types of runners for the Mg alloy die casting parts: Y shape design, T shape design, and radiation shape design, as shown in Fig. 19. Comparatively, Y shape design is better than T shape design. Timelli et al. [125] studied the filling process of the parts with different types of runners through numerical simulations. The results showed that during the filling process of molten AM60B alloy, the bumper designed on both sides of the T shape runner is not useful to prevent the back-wave of molten metal, and the debris are quickly reversed out of the bumpers and enter the die cavity, which can easily lead to some casting defects. On the contrary, the design of Y shape runner bumper could effectively absorb the impact energy generated by the molten metal during high-speed die casting, and smoothly introduces the molten metal into the die cavity, resulting in better filling effect. For thin-walled and large-sized die casting parts, the design of the gate is closely determined by the part shape. For the long strip shaped parts such as center console frame and CCB, the gate is usually designed on one side of the parts. However, for those square shaped parts such as seat frame or door inner frame, the gate usually needs to be designed at the center of the part, as shown in Fig. 20 [25, 29, 134]. According to the gate system of the seat frame, the center gate can lead to a shorter filling time and prevent cold shots compared to the bottom gating system, due to the lower heat content of the Mg alloys.

Of course, the die casting die is a complex system composed of many components. The design of other parts, such as core pulling, pushing plate, pushing pole, fixed die bed plate, moving die bed plate and so on, is also important for the manufacture of the die casting parts, needing to be valued.

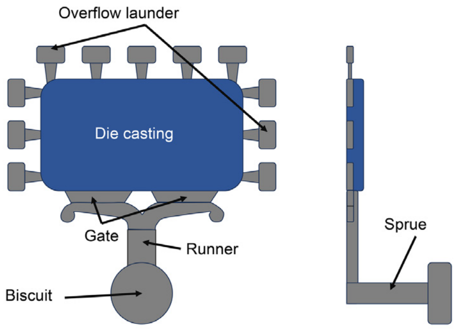

Fig. 18: Gating system of Mg alloy die castings

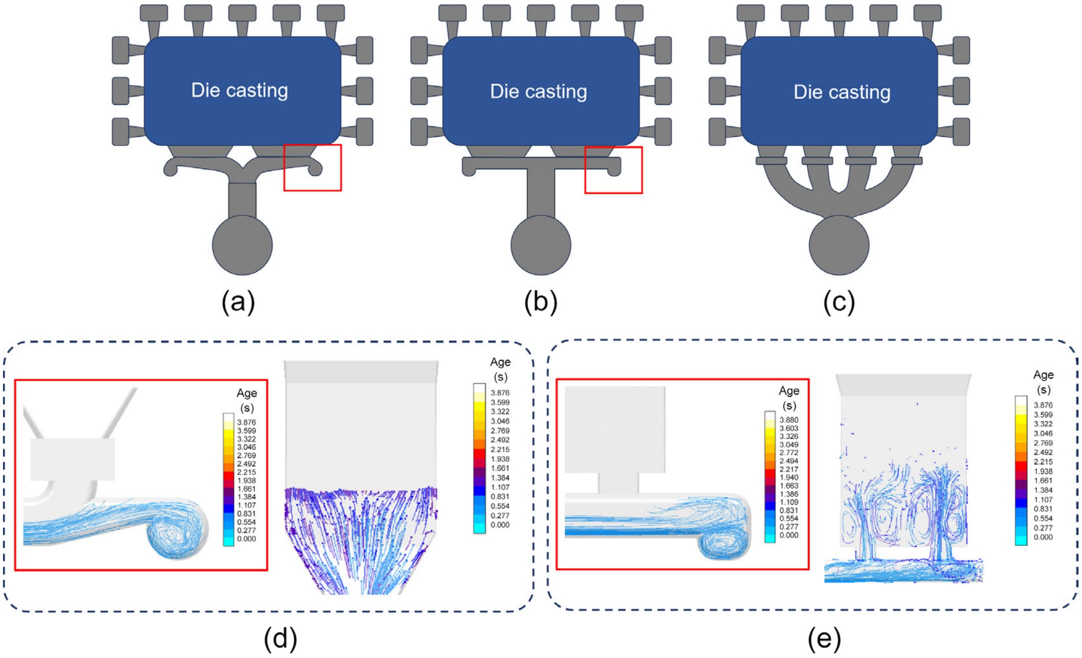

Fig. 19: Different runner designs of Mg alloy die casting dies and their impact on filling process: (a) Y shape runner; (b) T shape runner; (c) radiation shape runner; (d) tracer particles during the filling simulation of the Y shape runner; (e) tracer particles during the filling simulation of the T shape runner [125]

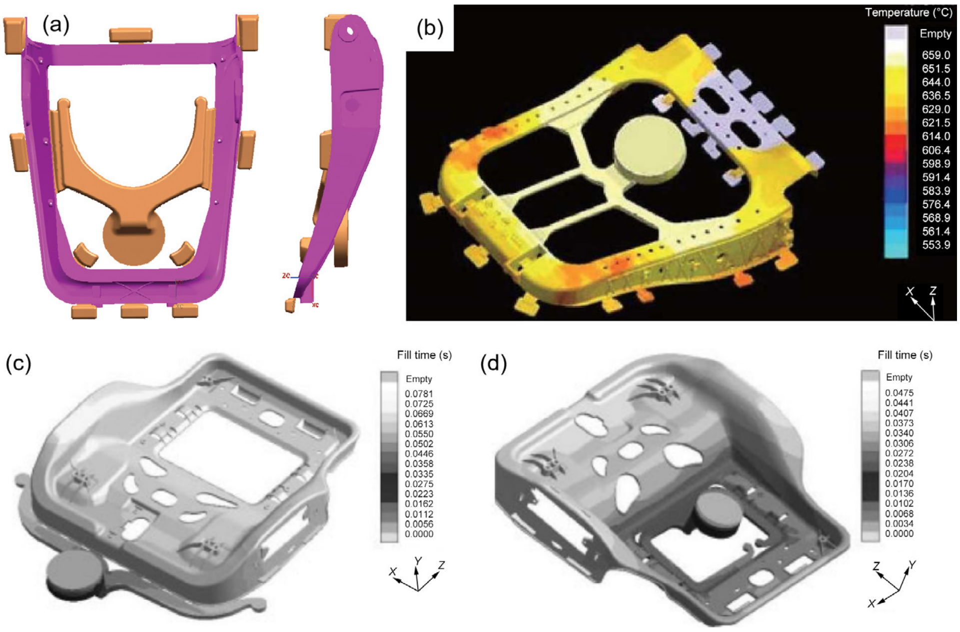

Fig. 20: Different gate system designs of Mg alloy die casting seat frame: (a) [134] and (b) [29] for backrest; (c) and (d) for cushion [25]

6 Summary and prospect

The popularization of new energy vehicles has greatly promoted the development of lightweight technology, and the application of Mg alloys die casting is desirable in many lightweight technologies. Due to its relatively high integration, die casting technology is more suitable for the integrating of numerous small parts to form the thin-walled and large-sized parts, making a significant effect on the components lightweight. Technically, the suitable components, selection of Mg alloy materials, die casting process, and the design of die casting molds will greatly impact the quality of the final parts. Through the related research, following conclusions could be obtained:

(1) Compared with those exterior components, the Mg alloys components located in automotive cockpits received inherent advantages. Therefore, the application of Mg alloy die casting technology in seat frames, CCB, and center console frames has been relatively mature for a long time. At present, the Mg alloy die casting door inner and rear tailgates have also attracted more attentions, expanding the application of Mg alloy die casting in automotive cockpits. With the development of integrated die casting technology, thin-walled and large-sized parts such as the rear floor of car bodies made of aluminum alloys are also expected to be changed to Mg alloy die castings. The resistance to the application of Mg alloy in automobiles will be transferred from high costs to integrated designs of thin-walled and ultra large parts. Solving technical issues such as how to integrate more parts to one piece, how to achieve a part with complex structures, and how to ensure the parts quality will be the key for the application of thin-walled and large-sized Mg alloy parts.

(2) Currently, the available commercial Mg alloys for thin-walled and large-sized automotive components are limited, and AM series Mg alloys are favored due to their good comprehensive mechanical properties. It should be clear that the requirements for parts within the automotive cockpits are constantly increasing with the development of the automobiles. Therefore, the current mechanical properties of commercial Mg alloys are no longer sufficient, and the Mg alloys with higher mechanical properties urgently need to be commercialized. The addition of some alloying elements such as RE is only one of the methods to improve the mechanical properties of Mg alloys, while the modified Mg alloys have to face the challenges from the ultra-high strength steels. Some technical methods such as extrusion and heat treatment might be the good choices to improve the properties of Mg alloys and reduce material costs.

(3) The commercialization of ultra large cold chamber die casting machines (100,000 kN locking force) is a new milestone for the application of Mg alloy parts in automobiles, greatly promoting the development of thin-walled and large-sized Mg alloy parts. However, the larger the part size, the more difficult it is to manufacture the part in a multiple cavity die, meaning that the production efficiency is relatively lower than that of small parts. Additionally, the thin-walled and large-sized Mg alloy die casting parts mean that the structure, die design, and manufacturing process of the parts are more complex. Therefore, the whole process should be considered more comprehensive and meticulous to improve the success rate of the final product.

(4) Thin walled and large-sized Mg alloy parts are more prone to defects, including porosity, ESCs, flash and other issues. For issues of flash and burrs, they can be removed through the post-treatment, but for porosity and ESCs, their occurrence can only be reduced or prevented in the main structure of the parts through reasonable product design, die design, and process parameters; they cannot be completely eliminated. For the Mg alloy parts located in automotive cockpits, they can be used after passivation surface treatment without painting, which can readily reduce the parts cost.

(5) Due to the lower latent heat of crystallization, the solidification of Mg alloys is fast. Therefore, the formability of thin-walled and large-sized parts is the key to the die casting Mg alloy parts, which mainly depends on the product structure and the design of the die casting die. Currently, the wall thickness of 2–4 mm is recommended for the Mg alloy cockpit parts and wall thickness should be as consistent as possible. The quality of the parts is not sensitive to ribs thickness, but to sensitive the ribs notch radius. A relatively smaller notch radius is more conducive to the quality of the part. For the die casting die of the thin-walled and large-sized parts, a radiation shape runner combined with the fan gate or wedge gate is recommended. The runner and gates must be smooth and rounded, and their area must be ever-decreasing from sleeve or sprue to gate.

At present, thin-walled and large-sized Mg alloy parts are increasingly demonstrating their advantages in performance and lightweight, and will be more widely used in automotive cockpit components with the development of automotive technology. There are four main challenges they have to face: (1) how to reduce part costs, (2) how to improve the performance of the parts, (3) how to achieve higher integration of parts while reducing part defects, and (4) how to repair Mg alloy parts damaged during use. In fact, the application of materials such as ultra-high strength steels and high-strength toughness Al alloys has brought greater pressure to the application of Mg alloys in terms of both cost and material properties. Therefore, those Mg alloys with excellent mechanical properties, such as WE series alloys, should be realized at low cost and commercialized as soon as possible. In addition, thin-walled and large-sized Mg alloy parts need to leverage their advantages of high integration and high part precision to achieve more significant lightweight effects, promoting the application of Mg alloy integrated die casting on large body parts.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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