Design of Low-Pressure Sand Casting Process for Water-Cooled Motor Shell in Electric Vehicle

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Abstract. Aluminium alloy motor shell is the core part of the new energy vehicle powertrain. It has a complex structure with an average wall thickness of 4-5mm, a side wall with 6-7mm spiral water jacket, and the bottom of the shell inlaid with cast steel bearing bushing. Because of its complex structure characteristics, as well as higher internal quality requirements and air tightness requirements, the casting process of motor housing is very difficult. This paper introduces the structural characteristics and common casting defects of the motor shell. On this basis, the typical casting process scheme of motor shell with sand core casting technology and the application of computer simulation technology in the development of motor shell casting process are discussed and shared.

Keywords. Aluminium alloy, motor shell, low pressure sand casting, casting process.

1. Introduction
In recent years, by the demand of energy saving, emission reduction and environmental protection, the research and development focus of automobile manufacturing enterprises is shifting from traditional fuel vehicles to new energy vehicles \cite{1}. The motor shell is the core casting of new energy vehicle powertrain. The top of the motor shell (open side) is connected with the inverter, the bottom is connected with the reducer, and the spindle bearing is connected with the embedded bearing bushings. The suspension on the side wall is connected with the sub-frame \cite{1-3}.

The structure of the motor shell is complicated. The side wall of the motor shell surrounds the cooling water jacket \cite{4, 5}. Ensuring the sealing of the water jacket is an important technical requirement of the product, as well as the biggest casting difficulty of the product \cite{6}. At the same time, the shrinkage of the upper and lower end faces and side walls of the motor shell are also casting defects that need to be avoided in the process development \cite{3, 6-8}.

This paper introduces the structural characteristics and common casting defects of the motor shell. On this basis, the casting process design of motor shell and the application of computer simulation technology in the rapid trial production of motor shell castings are discussed and shared.

2. Motor Shell Information

2.1. Product Overview
The motor shell is one of the important castings of the new energy vehicle. One end of it is connected with the reducer and the other end is connected with the inverter \cite{1-6}. The structure of the aluminium
alloy motor shell in this paper is shown in the figure 1. The side wall is equipped with 6.5mm spiral water jacket, the wall thickness around the water jacket is 5mm, the bottom of the casting is inlaid with bearing sleeve (made of 45 steel). The outline size of the motor shell is: 320mm×298mm×283mm, and the net weight of the product is 8.1kg. The casting material is: AlSi7Cu3Mg (heat treatment scheme: T6). The nominal chemical composition is listed in table 1.

2.2. Technical Specifications for Products
The main technical requirements of motor shell in this paper are as follows: the casting surface and the processed surface are not allowed to have porosity, shrinkage, cold isolation, cracks, slag inclusion and other casting defects; Mechanical properties of castings: hardness of the top flange surface≥90HbW, tensile strength($R_m$)≥275MPa and elongation($A_a$)≥2% at the sampling part of the body. Casting internal defects shall be controlled to ASTM E155 Class III; The air tightness shall meet the requirements of water test at 0.6Mpa for 10 minutes after the product is blocked, and there is no gas leakage around the water jacket.

![Figure 1. Motor shell in the power assembly; (b) Motor shell construction.](image)

| Table 1. The Chemical composition of AlSi7Cu3Mg alloy (wt.%). |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Si  | Cu  | Mg  | Fe  | Mn  | Zn  | Ti  | Al  |
| 6.5-8.0 | 3.0-4.0 | 0.3-0.6 | ≤0.08 | 0.2-0.3 | ≤0.65 | 0.2-0.25 | Bal  |

2.3. Risk Analysis of Casting Defects
The structure of motor shell products is complex and it is very difficult to cast. Once the casting process design is ill-considered, it is very hard to produce accepted products [6-8]. According to the previous production experiences, the common casting defects of the same type of motor shell products are shown in figure 2: Due to the deficiency of feeding, it is easy to appear the casting defects such as shrinkage cavity (figure 2(a)) or microporosity (figure 2(b)). In the process of filling, because the liquid aluminium temperature is too low and the cavity exhaust is not smooth, it is easy to appear bubbles on the top of the sub-castings (figure 2(c)), and it is easy to produce cold shut (figure 2(d)). These casting defects are also the main cause of leakage in the pressing of the motor shell (figure 2(e)).
In addition, there are other defects, such as severe sand stickiness (figure 2 (f)), poor fitting of bearing bushing (figure 2 (g)), and broken core of water jacket core (figure 2 (h)), also need to be considered.

In the casting process of motor shell blank, the defects caused by poor feeding are the most important ones. Therefore, casting process selection is the main focus of the casting feeding problem. There are three typical hot spot regions of motor shell predicted by numerical simulation are shown by figure 3. These shrinkage risk areas should be considered during the cast process design.

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3. Casting Process Design and Assess

3.1. Microstructure Analysis
The low pressure sand casting process is used in this motor shell case. Generally, the casting Process design includes the design of the gating system, the feeding system, the casting process parameters and the mold parting scheme [6]. According to the analysis above, some special areas should be paid attention. In addition, the risk of other casting defects, such as sticky sand, pores, etc., needs to be considered during process design.

3.2. Gating System
The design of the gating system not only needs to ensure the smooth flow of the metal liquid during the mold filling process, but also needs to realize the feeding of the ingate to the adjacent positions of the casting (Region C in figure 3) during the solidification process. Based on the above considerations,
the inner gate is directly opposite the bottom thickness of the casting. The runner is designed as an annular structure and is connected to the sprue by a cross structure. The proportion of the minimum cross-sectional area of inner gate \( F_{\text{gate}} \), runner \( F_{\text{runner}} \) and sprue \( F_{\text{sprue}} \) is as follows: \( F_{\text{gate}}: F_{\text{runner}}: F_{\text{sprue}} = 1:1.6:2.1 \). The sketch of gating system is shown in figure 4.

![Figure 4. Gating system design.](image)

3.3. Feeding System
The hot spot region A and B, which are shown in figure 3, would be fed by hot feeders and side feeders, respectively. The feeders design is shown in figure 5.

![Figure 5. Feeding system design.](image)

3.4. Casting Process Parameters
In order to avoid the casting defects of cold shut and burn on sand in the filling process, filling temperature is controlled in the ideal range of 720–740°C. The pressure-time curve is shown in figure 6. The filling time is 10 s, and the pressure holding time is 210 s.

![Figure 6. Pressure-time curve for pouring and solidification.](image)
3.5. Cores Fabrication and Assembly Process
For the mass production of motor shell, the water jacket core is made by hot core box, and the outer contour cores are made by cold core boxes, which is shown in figure 7(a). For the sample production and small batch production of motor shell, the cores can be 3D printed due to its complex structure. The die drawing can be ignored in the direction of 3D printed sand cores, thus, part of the sand cores can be integrated (as shown in figure 7(b)).

![Figure 7](image_url)

**Figure 7.** Core combination modes of (a) the mass production and (b) the small batch production.

3.6. Numerical Simulation
In order to verify the reasonability of the casting process and to forecast the risk of casting defects, simulation was made by means of ProCAST software. The liquidus temperature of the aluminum alloy is about 602°C, and the eutectic temperature is about 503°C. And, thus the pouring temperature is 730±5°C according to experience of other motor shells.

The simulation of filling process is shown in figure 8. During the whole filling process, the liquid metal flows smoothly without turbulence or air-entrapment. And, until the end of filling, there is no serious loss of temperature of metal liquid.

The fraction-solid field during solidification is shown in figure 9. The metal liquid in the mold cavity is solidified in an ideal solidification sequence, and no isolated liquid region appears.

By analyzing the shrinkage criterion of ProCAST software, the porosity of the casting were predicted. As is shown in figure 10, the shrinkage and cavity defects exist in the feeders, and there is no serious shrinkage cavity and porosity in the casting, only a little light and micro shrinkage porosity appears.

Based on the above simulation analysis, the casting process design is feasible.
**Figure 8.** Simulation of filling process.

**Figure 9.** Simulation of solidification process.
3.7. Production
The final motor shell is shown in figure 11. There is no casting defect in the motor shell. Through pressure leakage test to verify the product sealing to meet the technical requirements of the product.

![Figure 10. Simulation of shrinkage.](image)

![Figure 11. Motor shell of (a) as-cast; (b) assembly.](image)

4. Conclusion
(1) For the motor shell, the low-pressure sand casting process can be used for the mass production and small batch production.

(2) For the complicated motor shell, the gating system and feeding system need to be carefully thought when the casting process design.

(3) In order to avoid the appearance of casting defects as much as possible, it is necessary to make full use of simulation methods.

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