Micro-structure and Air-tightness of Squeeze Casting Motor Housing for New Energy Vehicle

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Abstract: In order to improve the performance of automobile parts, the influence of squeeze casting process parameters on casting defects, material structure and air-tightness of aluminum alloy motor housing for new energy vehicle was studied. The results show that the density of the castings increases with the increase in pressure and mold temperature. With increase in pouring temperature, it increases first and then decreases. Pressure has the greatest influence on the density of the castings. Under a certain pressure, with moderate increase in casting temperature and mold temperature, the grain growth begins to increase; the dendrites become less, the new $\alpha$-Al grains are spherical and granular, the micro-structure is uniform. Also, with increase in pressure, this effect is more pronounced, the air-tightness of castings improve. In conclusion, when the pressure is 110MPa, pouring temperature is 680° C, mold temperature is 280° C, pressure holding for 30s, and punch speed of 0.1m/s, there is no clear shrinkage in the casting, the structure is uniform, the qualified rate of air-tightness of production reaches 86%, and the performance is excellent.

1. Introduction

Relevant data shows that the number of private cars in China have reached 137 million[1]. As the key component of the motor module, excellent air-tightness is necessary for the safe and efficient operation of the motor housing. The mainly material of motor housing is aluminum alloy, which not only improving the self cooling effect, but also reducing the weight of the automobile. The literature pointed out that the car's weight reduce 100kg, the fuel consumption will reduce 0.3-0.5L per 100 kilometers[2]. The aluminum alloy motor housing manufacturing main processes are low pressure casting and pressure casting, etc. As a kind of near net forming technology, squeeze casting is getting more attention[3]. This process is characterized in that a high mechanical pressure is applied to the metal liquid which is poured into the
mold cavity with low speed and high flow rate, and the metal liquid is solidified under high pressure to obtain the casting with complicated shape, high density and good air-tightness. This technology is widely used in automobile, motorcycle, mechanical, aerospace and other fields\cite{4,6}. However, there are many casting defects in the castings, and low air-tightness, which is difficult to meet the needs of customers.

This paper aims at the existing problems of automobile motor housing. Through orthogonal test, the optimum extrusion casting process parameters of aluminum alloy motor housing are obtained. Under the optimal process parameters, obtained the motor housing products with excellent air-tightness.

2. Experiment procedure

2.1 Design of casting gate and overflow system for motor housing

The structure of motor housing is very complicated, and it is difficult to produce the casting by direct extrusion casting. As the channel of the metal liquid flowing into the mold, the design of the channel should ensure that the metal liquid flow into cavity smoothly and continuously. The design of gating system has a direct influence on the quality of the production\cite{7,8}. Unreasonable shape and size of the channel will cause metal liquid collision, forming a vortex, roll gas, which will result in low air-tightness after forming. The position, shape and size of the inner gate which are directly connected with the flow rate and flow direction of the molten metal into the mold cavity, which influences the forming quality of the product. According to the structure characteristics of the motor housing, the inner gate is opened in the center hole position, and the inner gate diameter is set to 60mm. From the gate to the material handle, the sectional area of layers increases, the longitudinal angle is 8 degrees. In order to ensure that the castings are fully filled, the thickness of the handle is controlled between 25-40mm. The design of the drainage system should contribute to the smooth discharge of gas and the collection of oxide in the filling process. The overflow grooves of the motor housing is provided on the parting surface, and metal liquid reaches the position finally. The concrete pouring system modeled by Pro-E is shown in Figure 1.

![motor housing casting model](image1.png)

![detection position of motor housing](image2.png)

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2.2 Test method

The test material is ADC12 aluminum alloy. The alloy melting process is that when the temperature of aluminum liquid is 720-730 degree, the nitrogen gas is used to remove the gas which into liquid. Then, a certain amount of Al-Ti-B and Al-10Sr are added to make aluminum liquid more refined. In the end, deslagging agent is used to remove impurities. Squeeze casting equipment consists of SCV-2000T vertical squeeze casting machine, motor housing mold and ancillary equipment. The
orthogonal test with three factors and three levels is adopted in squeeze casting experiment. According to the principle of orthogonal test, The specific combination of process parameters are shown in Table 1, the pressure holding time of 30s and punch velocity of 0.1m/s are remained unchanged.

| Numbe | Pressure/Mp a | Casting temperature/°C | Mold preheating temperature/°C |
|-------|---------------|-------------------------|-------------------------------|
| A     | B             | C                       |
| G1    | 1 (70)        | 1 (660)                 | 1 (220)                       |
| G2    | 1 (70)        | 2 (680)                 | 2 (250)                       |
| G3    | 1 (70)        | 3 (700)                 | 3 (280)                       |
| G4    | 2 (90)        | 1 (660)                 | 2 (250)                       |
| G5    | 2 (90)        | 2 (680)                 | 3 (280)                       |
| G6    | 2 (90)        | 3 (700)                 | 1 (220)                       |
| G7    | 3 (110)       | 1 (660)                 | 3 (280)                       |
| G8    | 3 (110)       | 2 (680)                 | 1 (220)                       |
| G9    | 3 (110)       | 3 (700)                 | 2 (250)                       |

After the test, A position (Figure 2, which is modeled by Pro-E) which should have good tightness requirement. For this, by use XG-1604L/C type X-ray real-time imaging equipment for internal detection, then calculate the area density and analysis microstructure by OLYMPUS metallographic microscope, perform the air-tightness test finally.

3. Results and discussion

3.1 Analysis of Process Parameters on filling

The effect of process parameters on the filling of the casting is shoot by the camera, as shown in Figure 3. In figure 3-(a), 70MPa/660°C/220°C, respectively expressed as the ratio of pressure, casting temperature and mold temperature, others empathy. As shown in Figure 3, G1 casting has obvious appearance defects. The lower pressure, pouring temperature and mold temperature, result in cold liquid alloy reduce liquidity, casting will appear cold lap, flow marks, and even less casting defects. With the pouring temperature and mold temperature increasing, the motor housing casting cooling slowly. Keep pressure at the same time, casting can not completely solidified. When taking out the casting, it is easy to have a casting injury. As shown in figure 3- (b).

G1(70MPa 660°C 220°C)  G3(70MPa 70°C 280°C)

Fig. 3 Effect of process parameters on filling pattern
Because the G1 and G3 castings have obvious defects, X-ray test was detected at A group only for the rest of the castings. Figure 4 is obtained by an X-ray inspection apparatus. Test results show that the shrinkages of G2, G4, G6 groups are in the pipeline with gas tight requirements, as shown in figure 4- (a). It can be concluded that the air-tightness of these castings is not qualified. The shrinkages of G7 group is far from the pipe, and has little effect on the air-tightness. For the rest of the castings, at the appropriate temperature, with the increasing of the pressure, castings don’t have shrinkage porosity and other defects, meeting the requirements of air tightness, as shown in figure 4- (b).

Defective castings  
Defect free castings  
Fig. 4 Effect of process parameters on the inner of the motor housing casting

3.2 Effect of process parameters on density

To a certain extent, the density of the casting can reflect the air tightness of the casting. In order to reflect all influence of the selected parameters on the density, the total density of the 9 groups of castings was measured. For different process parameters, the test results of the motor housing density are shown in table 2.

| Number | Pressure/MPa | Casting temperature/°C | Mold preheating temperature/°C | Density/g·cm⁻³ |
|--------|--------------|-------------------------|-------------------------------|----------------|
| G1     | 70           | 660                     | 220                           | 2.7293         |
| G2     | 70           | 680                     | 250                           | 2.7380         |
| G3     | 70           | 700                     | 280                           | 2.7358         |
| G4     | 90           | 660                     | 250                           | 2.7342         |
| G5     | 90           | 680                     | 280                           | 2.7432         |
| G6     | 90           | 700                     | 220                           | 2.7372         |
| G7     | 110          | 660                     | 280                           | 2.7403         |
| G8     | 110          | 680                     | 220                           | 2.7386         |
| G9     | 110          | 700                     | 250                           | 2.7436         |
| I      | 8.2031       | 8.2038                  | 8.2051                        |                |
| II     | 8.2146       | 8.2198                  | 8.2158                        |                |
| III    | 8.2225       | 8.2166                  | 8.2193                        |                |
| K1     | 2.7344       | 2.7346                  | 2.7350                        |                |
| K2     | 2.7382       | 2.7399                  | 2.7386                        |                |
| K3     | 2.7408       | 2.7389                  | 2.7398                        |                |
### 3.3 Effect of process parameters on Microstructure

Microstructures of the A region in the casting under different process parameters are shown in figure 5. Figure 5 is obtained by an optical microscope. At low pressure, pouring temperature and mold temperature, the majority of $\alpha-Al$ microstructures present dendrite, only a handful is ball and granular, distribution is very loose, irregular grain shapes and sizes, relatively small, poor mechanical properties, as shown in figure 5- (a). Keep the same pressure, increasing pouring temperature and mold temperature, the fine grain structures disappeared obviously, grain begin to grow, the number of dendrite morphology begin to decrease. Enhance the pouring temperature to 700°C and mold temperature to 280°C, the average cooling rate of metal solidification and casting solidification rate slowed down, the solidification time became longer. It can be seen that the $\alpha-Al$ grain is further grown up, the dendrite coarsening, the dendrite space decreases, as shown in figure 5- (b). In figure 5- (c), The microstructure of the casting is almost without dendrites, $\alpha-Al$ grains present spherical and granular. The microstructure is uniform, and its shape and size are roughly equal. Because of at a suitable pouring temperature and mold temperature, increasing the pressure, the casting and the mold cavity fit more closely, and the heat transfer coefficient between the housing and the wall increases. The increase effective area between the two make the alloy cooling rate accelerated and the nucleation rate increase. In addition, the pressure inhibits the diffusion of atoms and the growth of the crystal nucleus, so that the grain is refined, and the microstructure become uniform$^{[9-11]}$. 

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| R     | 0.0065 | 0.0053 | 0.0047 |
|-------|--------|--------|--------|
| Primary factor → secondary | A B C |

Optimal scheme | A<sub>3</sub> B<sub>2</sub> C<sub>3</sub>

Among them:

I = The sum of the results on the level number 1 on the J column;
II = The sum of the results on the level number 2 on the J column;
III = The sum of the results on the level number 3 on the J column;
K<sub>1</sub> = I /3, K<sub>2</sub> = II /3, K<sub>3</sub> = III /3; K<sub>1</sub>, K<sub>2</sub> and K<sub>3</sub> respectively represent the average of the sum.

R = The disparity between the maximum and minimum of K<sub>1</sub>, K<sub>2</sub> and K<sub>3</sub> on the J column.

The results presented in Table 3, groups 5 and 9 correspond to the high density, which correspond to the process parameters A<sub>2</sub>B<sub>2</sub>C<sub>3</sub> and A<sub>3</sub>B<sub>3</sub>C<sub>2</sub>. The greater the density, the better the air-tightness. Corresponding parameters combination are more reasonable. In Table 3, the effect of the factors on the density of squeeze casting is maximum. Through the analysis of the experimental results, it can be concluded that the casting density increase with the increase of the specific pressure and the temperature of the mold. With the increase of the casting temperature, the density of the motor housing increase firstly and then decrease. Overall, the optimal process parameters are A<sub>3</sub>B<sub>2</sub>C<sub>3</sub>, the pressure is 110MPa, pouring temperature is 680°C, the mold temperature is 280°C.
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G1(70MPa /660℃ /220℃)  G3(70MPa /700℃ /280℃)G5(90MPa /680℃ / 280℃)

Fig. 5 microstructure of A

It can be drawn from the figure 3 and table 5 that the microstructure of the casting is mainly present dendrite, and the gap is larger, the density is the smallest, so the air-tightness is poor in the G1 group; Keeping the pressure, increasing the casting temperature and mold temperature, the dendrite structure of the G3 group reduced significantly, grain growth, casting density increase, air-tightness is also good; At appropriate pouring temperature and mold temperature, improve the pressure, microstructure of G5 basically presents spherical shape, uniform round, the shape and size of roughly equal. So the G5 group have larger density and better air-tightness. In general, at proper pouring temperature, increasing the pressure of squeeze casting, the microstructure of production become denser and the grains uniform distribution, so the air-tightness is bound to increase.

3.4 Air-tightness test

The air-tightness of the casting is not only determined by the macroscopic filling of the casting, but also the density and microstructure of the casting. By analyzing the filling result, density and microstructure of the casting, it is found that at proper pouring temperature and mold temperature, improve pressure, the casting will get better air-tightness. Thus, the best process parameters are A3B2C3. The pressure is 110MPa, pouring temperature is 680℃, mold temperature is 280℃, holding pressure time is 30s, the injection rate is 0.1m/s.

Fig.6 Air-tightness testing device

Producing castings under optimum process parameters, then the air-tightness test is carried out, and the experimental device as shown in Figure 6. Place the casting into the water, then fill the casting with nitrogen gas, when the pressure gauge reach 1.8MPa, close the gas source, and keep 3min. To observe whether the bubble is formed and the pressure gauge is reduced. Finally, the experimental results show that the qualified rate of air-tightness reached 86%.

4. Conclusion

In the case of low specific pressure, pouring temperature and mold temperature, the fluidity of the aluminum alloy liquid is reduced, the casting will appear cold interval, flow marks and other defects; Improved the casting temperature and mold temperature, while increasing the pressure, casting defects are significantly reduced, and the air-tightness of castings increases.

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The results show that the pressure has the greatest influence on the density of the castings, and further analysis shows that the density of the castings increases with the increase of the pressure and the mold temperature, while increasing the pouring temperature, the density of the motor housing increases first and then decreases; Under the same condition of the pressure, as the casting temperature and mold temperature increases, the fine grain structures disappeared obviously, grain begin to grow, the number of dendrite morphology begin to decrease and $\alpha-Al$ grains present spherical, granular, and the microstructure is uniform. With the pressure increases, this effect is more obvious, the airtight of castings improve inevitably. Therefore, at a proper casting temperature and mold temperature to increase squeeze punch pressure, the air-tightness of castings will be improved.

The optimum process parameters of new energy vehicle motor housing produced by squeeze casting is: the pressure is 110MPa, the pouring temperature is 680℃, the mold temperature is 280℃, the pressure holding time is 30s, and the punch speed is 0.1m/s. Under the above conditions, there is no obvious shrinkage into the motor housings, it has excellent mechanical properties, and the air-tightness rate exceeds 86%.

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