Numerical simulation of 7050 aluminum alloy semi-solid squeeze casting

Lidong Yang1,a, Cunliang Pan1,b, Lingjiao Wang1,c, Zhifeng Zhang2,d, Xia Huang3,e, Shengguan Qu1,f, Xiaoqiang Li1,g*

1National Engineering Research Center for Near-Net-Shape for Metallic Materials, South China University of Technology, Guangzhou,510640, P. R. China
2GRIMAT Engineering Institute Co.,Ltd. Beijing,100088, P. R. China
3AVIC Manufacturing Technology Institute, Beijing,100024, P. R. China
aemail: 1124053782@qq.com, bemail: 746683662@qq.com, cemail: wanglj1108@163.com, demail: zhangzf@grimm.com, eemail: huangxia1600@163.com, femail: qusg@scut.edu.cn
*gemail: Lixq@scut.edu.cn

Abstract. The semi-solid squeeze casting numerical simulation study of 7050 aluminum alloy was carried out using ProCAST software, and the forming properties of the alloy were investigated by adjusting the process parameters appropriately. The results show that the filling process of semi-solid aluminum alloy is relatively stable, and it is not easy to splash. The optimal process parameters after optimization are: pouring temperature 620℃, mold temperature 300℃, forming pressure 80MPa. Under this process parameter, the defect of the part is the least.

1. Introduction

Compared with liquid casting and solid forming technology, semi-solid metal processing technology has the advantages of improving product performance, prolonging the service life of molds and reducing production costs. Since its appearance in the 1970s, it has received extensive attention from the scientific and industrial circles. Since the 21st century, semi-solid metal processing technology has made great progress in theoretical foundation, technical research and industrial application. Among them, aluminum alloy semi-solid forming technology is widely used in many industrial fields because of its stable process and easy manipulation[1-3].

Numerical simulation technology can effectively reduce experimental research costs and improve work efficiency, especially when faced with technology development in the complex process of coupling multiple physical fields. Numerical simulation technology has unparalleled advantages over physical experimental research. Through the numerical simulation analysis of the semi-solid forming process of metal materials, the evolution process of each physical field during the forming process and the location and quantity of possible defects can be predicted, which has very important guiding significance for the process design of semi-solid metal processing technology[4-6].

Based on the previous research work, this paper used numerical simulation technology to carry out semi-solid 7050 aluminum alloy squeeze casting technology research. The filling and solidification process of parts were simulated based on the ProCAST software. Orthogonal experiment were used to study the influence of squeeze casting process parameters on filling process and quality of parts, so as
to optimize process parameters and obtain nearly defect-free semi-solid squeeze casting parts. Provide reference for in-depth research and development of semi-solid aluminum alloy squeeze casting.

2. Pre-simulation processing
According to the geometric characteristics of the parts, the parts mold was drawn using Solidworks software. ProCAST casting simulation software was used to numerically simulate the semi-solid forming process. In ProCAST, the parts and molds were assembled and meshed. In order to ensure the simulation accuracy of the slurry filling process, the mesh size of the parts needs to be as small as possible, 1mm. At the same time, in order to improve the calculation efficiency, the grid size of the mold can be enlarged to 2mm. There are various thermophysical parameters of the material in the ProCAST database. For the aluminum alloy used in the experiment, most of the thermophysical parameters were calculated by ProCAST software. However, the relationship between the liquid phase rate and temperature and the semi-solid viscosity model, which have a greater influence on the slurry flow filling, were obtained through experiments.

In the semi-solid squeeze casting simulation forming process of the parts, pouring temperature (T_p), mold temperature (T_m) and forming pressure (P_f) are the main process parameters that affect the filling and solidification process of the parts. It was preliminarily determined that the pouring temperature T_p=580-620°C, mold temperature T_m=300-400°C and forming pressure P_f=0-80MPa.

In the ProCAST software, the influence of the forming pressure is reflected indirectly by changing the heat transfer coefficient between the parts and the mold interface. The relationship between the heat transfer coefficient between the parts and the mold interface and the forming pressure is shown in the formula (1) [7].

$$h = 1990.5 + 94.8P$$  

$h$ is the heat transfer coefficient (W/m²·K), and $P$ is the forming pressure (MPa).

3. Analysis of filling and solidification process
Figure 1 shows the filling process of the parts. The corresponding pouring temperature is 620°C, mold temperature is 400°C and forming pressure is 80MPa. It can be clearly seen that due to the unique flow characteristics of the semi-solid slurry, the viscosity is significantly increased compared to ordinary molten metal, so the filling of the semi-solid slurry is relatively stable without splashing. The semi-solid slurry is filled sequentially from bottom to top from the bottom of the mold, and the slurry filling time is very short, so the temperature of the slurry is not significantly reduced during the filling process.

![Fig.1](a) Fill 70%;(b) Fill 78.9%;(c) Fill 90.1%;(d) Filled completely

The distribution of the slurry flow velocity field during the filling process of the parts is shown in the figure 2. It can be seen that the filling speed of the slurry is small (<0.08 m/s), and the distribution is relatively uniform, and the fluid flow is in a laminar state. Laminar slurry is not prone to defects such as curl and oxidation inclusions.
The semi-solid slurry has a lower viscosity at a higher pouring temperature and shear rate, which manifests as a better fluidity, that is, a better filling ability. Since squeeze casting is a slow pressurization process, the lower press speed of the upper die is slow, so the shear rate has less influence on the filling process. Therefore, the filling ability of the slurry mainly depends on the pouring temperature. Figure 3 and 4 shows the schematic diagram and viscosity diagram of the parts after being fully formed at different pouring temperatures. It can be seen from the figure 3 and 4 that at a higher pouring temperature, the viscosity of the slurry is lower and the distribution is more uniform, the filling ability is better, and parts with good formability can be obtained. At a lower pouring temperature, the viscosity of the semi-solid slurry increases significantly and the distribution becomes more uneven, resulting in a rapid decline in the filling ability of the semi-solid slurry, and even the situation that it cannot be completely filled.

Fig.3 Schematic diagram of the parts after being fully formed at different pouring temperatures (a) 580℃ (b) is the partial schematic diagram of the top part of the a); (c) 600℃; (d) 620℃;

Fig.4 viscosity diagram of the parts (a)580-300-0.1 (b)580-350-40 (c)580-400-80 (d)620-300-40 (e)620-350-0.1 (f)620-400-80

It can be seen from the figure 5 that when the parts filling is completed, the temperature of the parts decreases with the increase of time, the temperature distribution is less uniform, the temperature on the outside of the parts is lower, and the temperature at the center of the parts is higher. This results in the central position of the parts being the final solidification position, and the final solidification position is more prone to defects such as shrinkage porosity and the performance of the parts is reduced.
4. Defect analysis

In the process of semi-solid squeeze casting of parts, some defects will inevitably appear, especially shrinkage porosity and so on. ProCAST can effectively predict the shrinkage porosity in the parts, as shown in the figure 6. It can be seen that the center of the parts is the place with the largest shrinkage. This is because these areas are the final solidified position of the parts and are located in the center of the parts, which is difficult to feed. Therefore, the shrinkage porosity are mainly concentrated in these areas.

The number of shrinkage porosity is an important index to evaluate the quality of parts. It can be seen from the table 1 that pouring temperature, mold temperature and forming pressure are the main factors that affect the quality of parts. According to the range R in the last row of the table 1, it can be seen that the range of factor A is the largest, indicating that the pouring temperature has the greatest impact on the shrinkage porosity. The difference between factor B and factor C is not much, and the difference relative to factor A is relatively small. Therefore, the influence of mold temperature and forming pressure on shrinkage porosity is relatively small. It can be seen from the table 1 that in the 9 tests completed, the results of L9 have the least shrinkage porosity. Therefore, the preliminarily determined optimal process parameters are L9, that is, pouring temperature of the semi-solid slurry is 620°C, mold temperature is 400°C and forming pressure is 80MPa.

| Test number | Pouring temperature | Mold temperature | Forming pressure | Result |
|-------------|---------------------|------------------|------------------|--------|
| L1          | 1(580)              | 1(300)           | 1(0.1)           | 29.9   |
| L2          | 1(580)              | 2(350)           | 2(40)            | 32.7   |
| L3          | 1(580)              | 3(400)           | 3(80)            | 34.4   |
| L4          | 2(600)              | 1(300)           | 3(80)            | 8.6    |
| L5          | 2(600)              | 2(350)           | 1(0.1)           | 21.3   |
| L6          | 2(600)              | 3(400)           | 2(40)            | 23.3   |
| L7          | 3(620)              | 1(300)           | 2(40)            | 5.9    |
| L8          | 3(620)              | 2(350)           | 1(0.1)           | 7.5    |
| L9          | 3(620)              | 3(400)           | 3(80)            | 3.0    |
| I           | 97                  | 44.4             | 58.7             |        |
In the table, \( I \) = the sum of the shrinkage porosity volume corresponding to the middle level 1 in column J

\[ \begin{align*}
\text{II} & : 53.2 & 61.5 & 61.9 \\
\text{III} & : 16.4 & 60.7 & 46 \\
\text{R} & : 80.6 & 17.1 & 15.9
\end{align*} \]

II = Sum of shrinkage porosity volume corresponding to middle level 2 in column J

III = Sum of shrinkage porosity volume corresponding to middle level 3 in column J

R = The difference between the maximum value and the minimum value of II, III, and R in column J

It can be seen from the table that the best process parameter is A3B1C3. Using the above optimal process parameters for simulation, the final shrinkage porosity volume is 1.9 cm³. It shows that A3B1C3 is indeed the best process parameter, that is, pouring temperature is 620°C, mold temperature is 300°C, and forming pressure is 80 MPa.

5. Conclusion

ProCAST software is used to simulate the semi-solid squeeze casting of aluminum alloy parts. The optimized process parameters are: pouring temperature 620°C, mold temperature 300°C, and forming pressure 80 MPa.

Based on the three parameters of pouring temperature, mold temperature and forming pressure, a three-factor and three-level orthogonal experiment was established to analyze the influence of the three factors on the volume of shrinkage porosity in the parts. The results show that the degree of influence on the volume of shrinkage porosity in descending order is: pouring temperature, mold temperature, and forming pressure.

Acknowledgments

The authors gratefully acknowledge the Military Products Supporting Scientific Research Project(x2jqA2200270); Foshan City's Core Technology Research Project(1920001000412) and Defense Industrial Technology Development Program(JCKY2018205B024).

References

[1] Shuai P, Qiang L, Baoyi Y, et al. (2019) Research progress of Mg alloy semisolid forming. Rare Metal Materials and Engineering, 48(7): 2379-2385.
[2] Joly P A, Mehrabian R. (1976) The rheology of a partially solid alloy. Journal of Materials Science, 11(8): 1393-1418.
[3] Kim W Y, Kang C G, Kim B M. (2007) The effect of the solid fraction on rheological behavior of wrought aluminum alloys in incremental compression experiments with a closed die. Materials Science and Engineering: A, 447(1-2): 1-10.
[4] Lu S L, Xiao F R, Zhang S J, et al. (2014) Simulation study on the centrifugal casting wet-type cylinder liner based on ProCAST. Applied Thermal Engineering, 73(1): 512-521.
[5] Jie Z, Dongqi Z, Pengwei W, et al. (2014) Numerical simulation research of investment casting for TiB2/A356 aluminum base composite. Rare metal materials and Engineering, 43(1): 47-51.
[6] LU Z, ZHANG H, JIANG H. (2012) Pouring Processing Simulation of Low Alloy Steel Track Plate Based on PROCAST. Foundry Technology, 33(01): 41-44.
[7] Zhang D L, Cantor B. (1995) A numerical heat flow model for squeeze casting Al alloys and Al alloy/SiCp composites. Modelling and Simulation in Materials Science and Engineering, 3(1): 121.