Casting Simulation of Aluminum Alloy Piston Based on ProCAST

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Abstract: In view of the defects such as shrinkage porosity, shrinkage cavity and uneven grain size in the casting process of aluminum alloy piston, the numerical simulation of ZL108 aluminum alloy piston casting process was carried out by using Procast professional casting finite element analysis software. The three process parameters of pouring temperature, pouring speed and mold temperature were investigated by orthogonal test method, and the grain size and comprehensive scores of shrinkage porosity, shrinkage cavity distribution and mold filling rate. The results show that the optimal combination of process parameters is the pouring temperature of 700 ℃, the pouring speed of 0.3 kg/s and the mold temperature of 150 ℃. The numerical simulation of ZL108 aluminum alloy piston casting process provides theoretical guidance for the casting of important and complex parts with uneven wall thickness, and reduces the cost and time of part process optimization design

***Keywords*：** Aluminum Alloy Piston; Casting Process; Procast: ZL108; Numerical Simulation

1. Introduction

Aluminum alloy piston is mainly cast in metal mold [1], but defects such as shrinkage porosity and shrinkage cavity are easy to occur in the casting process. At the same time, the gap between piston wall thickness is relatively large, and defects such as uneven grain size are easy to be caused in the forming process [2–3]. These defects affect the service life of the casting. At present, there has been some progress in the research on the numerical simulation of the working process of aluminum alloy piston at home and abroad[4], and the research on improving the forming quality of aluminum alloy piston has also been carried out, but there are few studies on the combination optimization of casting process parameters of specific products [5–6].

Therefore, starting from the combination of casting process parameters, this paper uses the orthogonal test method to investigate the three process parameters of pouring temperature, pouring speed and mold temperature, comprehensively scores the numerical simulation results from the aspects of grain size, shrinkage porosity and shrinkage cavity distribution and mold filling rate, and obtains the optimal combination of casting process parameters.

2. Design of process parameters optimization scheme

During the casting process of aluminum alloy piston, the three process parameters of pouring temperature, pouring speed and mold temperature have a great impact on the forming quality. It is necessary to find out the optimal parameter combination for the forming quality of aluminum alloy piston. In this paper, ZL108 aluminum alloy piston is taken as the research object, and the composition is shown in **Table 1.**

Table 1. ZL108 aluminum alloy chemical composition

Chemical composition	Si	Cu	Mg	Mn	Fe	Al
Mass fraction（%）	11.0～13.0	1.0～2.0	0.4～1.0	0.3～0.9	≤0.7	allowance

According to the actual experience of the cooperative plant and the literature of piston pouring process[7–10], the pouring temperature of ZL108 aluminum alloy is 0.2~0.4 kg/s is 650~750 ℃, and the mold temperature is 150~250℃. The specific factor level setting is shown in **Table 2**.

Table 2. Level of numerical simulation factors

Factors	E pouring temperature (℃)	F pouring speed (kg/s)	G mold temperature （℃）
1	750	0.2	150
2	600	0.3	200
3	650	0.4	250

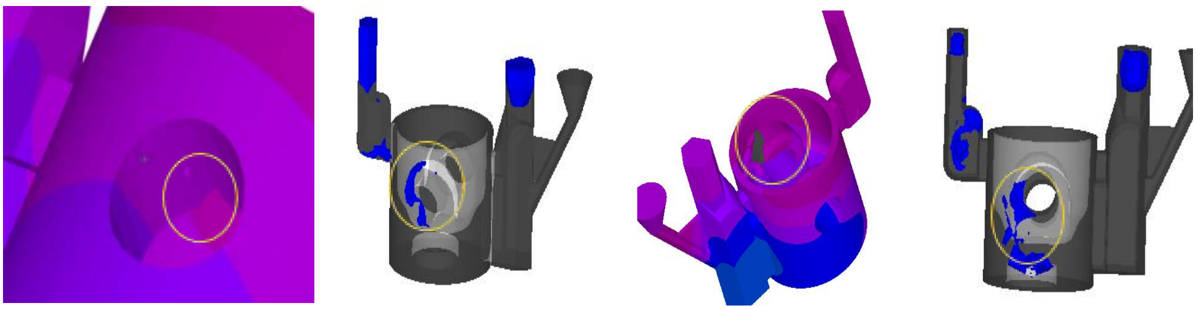
3. Numerical simulation of the casting process

Firstly, the solid modeling is carried out by Pro/E 3D software, and the surface mesh is divided by the mechanical module of Pro/E software. Considering the running speed of the computer, the maximum size of the surface mesh control of the piston blank is 5mm. The surface mesh model is imported into Procast finite element analysis software for surface mesh inspection, volume mesh generation and optimization.

The pretreatment is carried out in the precast environment of Procast finite element analysis software. The ZL108 aluminum alloy (AlSi12CuNiMg) in Procast can be used for flow and heat transfer analysis. Set the virtual mold and the mold material is common H13 steel. Set the virtual mold and calculate the virtual model with Computer Mold. The heat exchange coefficient between mold and casting is 1000 ω · m^{-2} · c^{-1}, and the pouring speed, mold temperature, pouring temperature and other process parameters are set by orthogonal test, as shown in **Table 3**.

4. Analysis of the simulation results

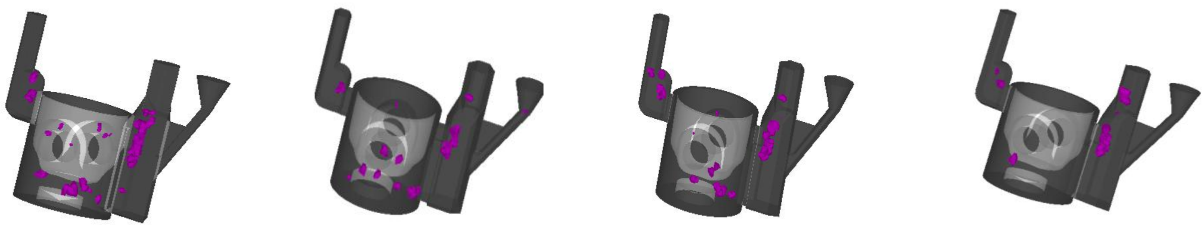
Through the simulation of each group of schemes, schemes 4 and 7 are unqualified, mainly due to insufficient pouring of the main body of the piston blank in casting. As shown in **Figure 1(a)** and **Figure 1(b)**, insufficient pouring and residual gas appear at the pin seat hole of the aluminum alloy piston, which has a great impact on the use of the piston.



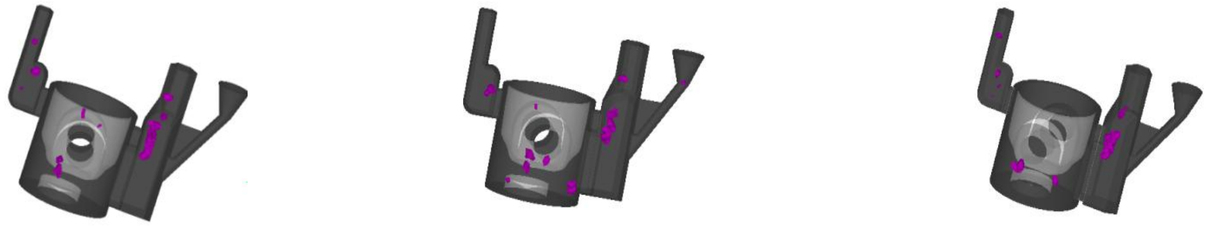
(a) scheme 4 (b) scheme 7

Figure 1. Insufficient pouring and gas mixing.

The evaluation of casting quality is based on the complete filling of mold cavity, as well as the inspection of casting defects and grain size. The shrinkage defects of schemes 1, 2, 3, 5, 6, 8 and 9 are shown in **Figure 2(a)** to **Figure 2(g)**.



(a) scheme 1 (b) scheme 2 (c) scheme 3 (d) scheme 5

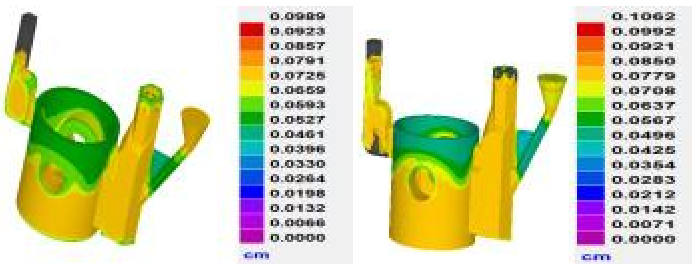


(e) scheme 6 (f) scheme 8 (g) scheme 9

Figure 2. Distribution of loose shrinkage holes for each scheme.

It can be seen that there are few defects in schemes 5, 6 and 9, and the shrinkage porosity of the main blank is significantly less than that of the other test groups. The shrinkage porosity of schemes 5, 6 and 9 mainly occurs on the main and auxiliary risers, while there are more shrinkage porosity and shrinkage cavities in the other groups, especially at the positions with relatively large wall thickness such as the head of aluminum alloy piston is easy to produce loose shrinkage holes and other defects.

The grain size of schemes 5, 6 and 9 is relatively small, and the grain size of the piston head is between 0.0669 cm and 0.0746 cm, while the grain size of schemes 1 and 3 is relatively large, and the grain size is between 0.0779 cm and 0.0791 cm. The grain size of piston skirt in schemes 5, 6 and 9 is 0.0417 cm ~ 0.0486 cm, the grain size of piston skirt in schemes 1 and 3 is 0.0527 cm ~ 0.0567 cm, and the grain size of schemes 1, 3, 5, 6 and 9 is shown in **Figure 3(a)** to **Figure 3(e).**



(a) plan 1 (b) plan 3

(c) plan 5 (d) plan 6 (e) plan 9

Figure 3. Simulation results of grain size of each scheme.

The filling quality is scored by comprehensively considering the above shrinkage porosity and grain size. The filling quality score of the experimental group with unqualified conditions is less than 50, and the scores of the other qualified experimental groups increase successively from 70 to 100, with a gradient of 5. The higher the score is, the better the forming quality will be. The results are shown in **Table 3**.

Table 3. Simulation results

Test number	Influencing factor level setting			E	F	G	Filling results	Filling quality
	E	F	G	Casting temperature （℃）	Casting speed （kg/s）	Mold temperature （℃）		
1	1	1	1	750	0.2	150	Qualified	70
2	1	2	2	750	0.3	200	Qualified	85
3	1	3	3	750	0.4	250	Qualified	75
4	2	1	2	700	0.2	200	Unqualified	50
5	2	2	3	700	0.3	250	Qualified	100
6	2	3	1	700	0.4	150	Qualified	95
7	3	1	3	650	0.2	250	Unqualified	50
8	3	2	1	650	0.3	150	Qualified	80
9	3	3	2	650	0.4	200	Qualified	90

Table 4. Analysis of various factors and level range

Parameter	E	F	G
Level result K1	230	170	245
Level result K2	245	265	225
Level result K3	220	260	225
ΔK	25	85	20
Result		F>E>G	

Using the range analysis method in orthogonal analysis, the scoring and range analysis of filling results are shown in **Table 4**. According to the factor level settings in **Table 2** and **Table 3**, E1 represents the casting process conditions with the influencing factor E (i.e. casting temperature) at level 1, i.e., E1 represents the casting temperature of 750 ℃, and the change trend of each factor at different levels is shown in **Figure 4**.

It can be seen from the results that factor F, i.e., casting speed, has the greatest impact on the forming quality of aluminum alloy piston, followed by factor E, i.e., casting temperature. Factor G, i.e., mold temperature, has the smallest impact on aluminum alloy piston. The factor level trend chart drawn according to the range value is shown in **Figure 4**. It can be clearly seen that factor F has the greatest impact on the quality of aluminum alloy piston.

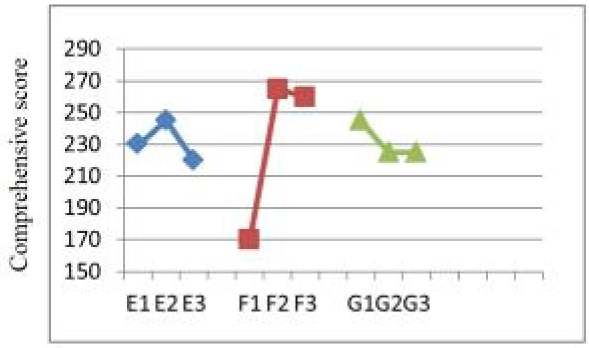
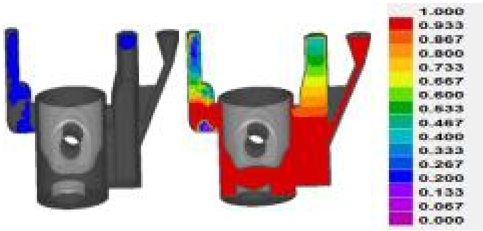


Figure 4. Influence trend chart of factor level.

According to the analysis of the influence trend chart of factor level, $E_2F_2G_1$ combination is the best combination of process parameters, which are 700 ℃ casting temperature, 0.3kg/s casting speed and 150 ℃ mold temperature respectively, and this plan is not in the above orthogonal combination, so it is necessary to verify and analyze the combination of process parameters and conduct numerical simulation with Procast simulation software. The simulation results are shown in **Figure 5(a)** to **Figure 5(d)**.

(a) Shrinkage cavity distribution (b) Grain size



(c) Filling rate (d) Gas inclusion distribution

Figure 5. The simulation results of the optimal combination of casting process parameters.

Conclusion

Through the simulated $E_2F_2G_1$ parameter combination results, it can be seen that there are few shrinkage cavities in the casting, and the shrinkage cavities are mainly distributed on the main and auxiliary risers; the grain size is more uniform, and the grain size changes from 0.0521cm to 0.073cm from the place with small wall thickness to the place with large wall thickness; the filling rate of the main part of blank is 100%, and gas inclusions also appear on the main and auxiliary risers. Considering the validation test and the above orthogonal test, the process parameter combination of $E_2F_2G_1$ (casting temperature of 700 ℃, casting speed of 0.3kg/s and mold temperature of 150 ℃) achieves the best filling quality. This paper provides some reference and guidance for the numerical simulation and optimization of casting process of important parts with uneven wall thickness.

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