

Numerical simulation and optimization of Al alloy cylinder body by low pressure die casting

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Abstract: Shrinkage defects can be formed easily at critical location during low pressure die casting (LPDC) of aluminum alloy cylinder body. It has harmful effect on the products. Mold filling and solidification process of a cylinder body was simulated by using of Z-CAST software. The casting method was improved based on the simulation results. In order to create effective feeding passage, the structure of casting was modified by changing the location of strengthening ribs at the bottom, without causing any adverse effect on the part's performance. Inserting copper billet at suitable location of the die is a valid way to create suitable solidification sequence that is beneficial to the feeding. Using these methods, the shrinkage defect was completely eliminated at the critical location.

Key words: aluminum alloy; cylinder body; numerical simulation; optimization

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In recent years, precision casting technology is favored by corporations for its less processing procedures, low cost and short production period^[1-5]. In LPDC, casting solidification under pressure is beneficial to the mold filling; leak tightness and pressure resistance of the casting are both promoted by the homogeneous microstructure and less segregation. So these castings are widely used nowadays^[6-7].

E80 cylinder body is the shell of certain special electrical engine. Excellent leak tightness and pressure resistance are required and shrinkage is not allowed in critical location. The casting was prepared by LPDC; the casting material is ZL102 alloy which has good thermal conductivity and high specific strength. A home-made Al-alloy coating material was painted on the mold's inner surface. The cylinder body has a minimum of 4 mm and a maximum wall thickness of 38 mm. Owing to irregular outline dimensions and complex inner structure, shrinkage will be generated during solidification process, and thus reduced the overall yield greatly. Z-CAST software was used to simulate the mold filling and solidification of the casting. Casting method was optimized based on the simulation results in order to get rid of casting defect.

1 Initial conditions and boundary conditions

The cylinder body casting is shown in Fig.1. The 3-D geometry models were established according to casting design

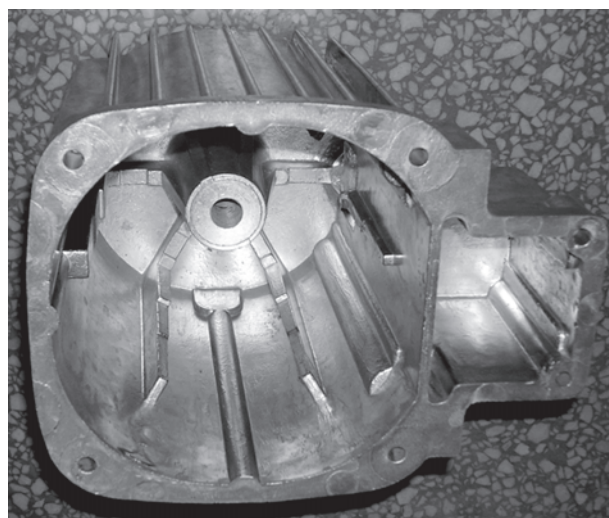


Fig. 1 Cylinder body casting

and saved as *.STL format. Then the 3-D models (STLformat) were imported into Z-CAST software. The importing sequence is: cylinder body – chills – moulds. The imported geometry solids are shown in Fig. 2.

The mesh was generated according to two principles:

- In order to avoid generating point contact in the thinnest position, the step size should be less than 2 mm.
- When using Z-CAST software for simulation calculation, each mesh occupies 80 byte physical memory.

So it should be assured that the number of mesh \times 80 is less than the memory of computer used. In the experiment, the service computer has a 1G memory. The dimension of the cylinder body is 362 mm \times 300 mm \times 342 mm ($L_x \times L_y \times L_z$). The step size was set as 2 mm and the total number of mesh was 4,642,650.

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Table 1 lists the initial conditions and materials used in casting, loose piece and die. The melt overflowed the whole lift pipe and gate runner during mold filling of LPDC, so the flowing of melt in gate runner was only considered when simulation calculation. The actual applied pressure on the gating position is shown in Fig.3. And I is the lifting stage, II is the mould filling stage, III is the pressure boosting stage, IV is the pressure maintaining stage, V is the pressure relief stage, and VI is the delayed cooling stage.

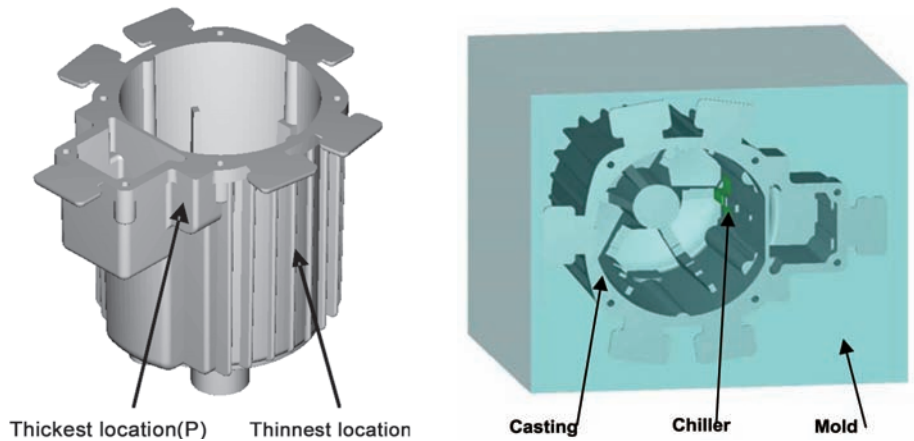


Fig. 2 Casting and gating system

Table 1 Initial conditions of casting, loose piece and die

	Cylinder body	Loose piece	Die
Material	AC3A	SKD61	SKD61
Initial temperature	700 °C	40 °C	200 °C

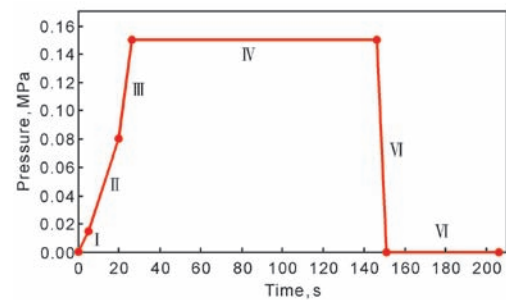


Fig. 3 The pressure curve of LPDC

2 Simulation results of original casting technique

2.1 Mold filling

Figure 4 shows the velocity field of mold filling. Figure 4(a) to

4(e) are velocity fields of the mold filled with 10%, 30%, 50%, 70% and 90%, respectively. The color changing from dark to

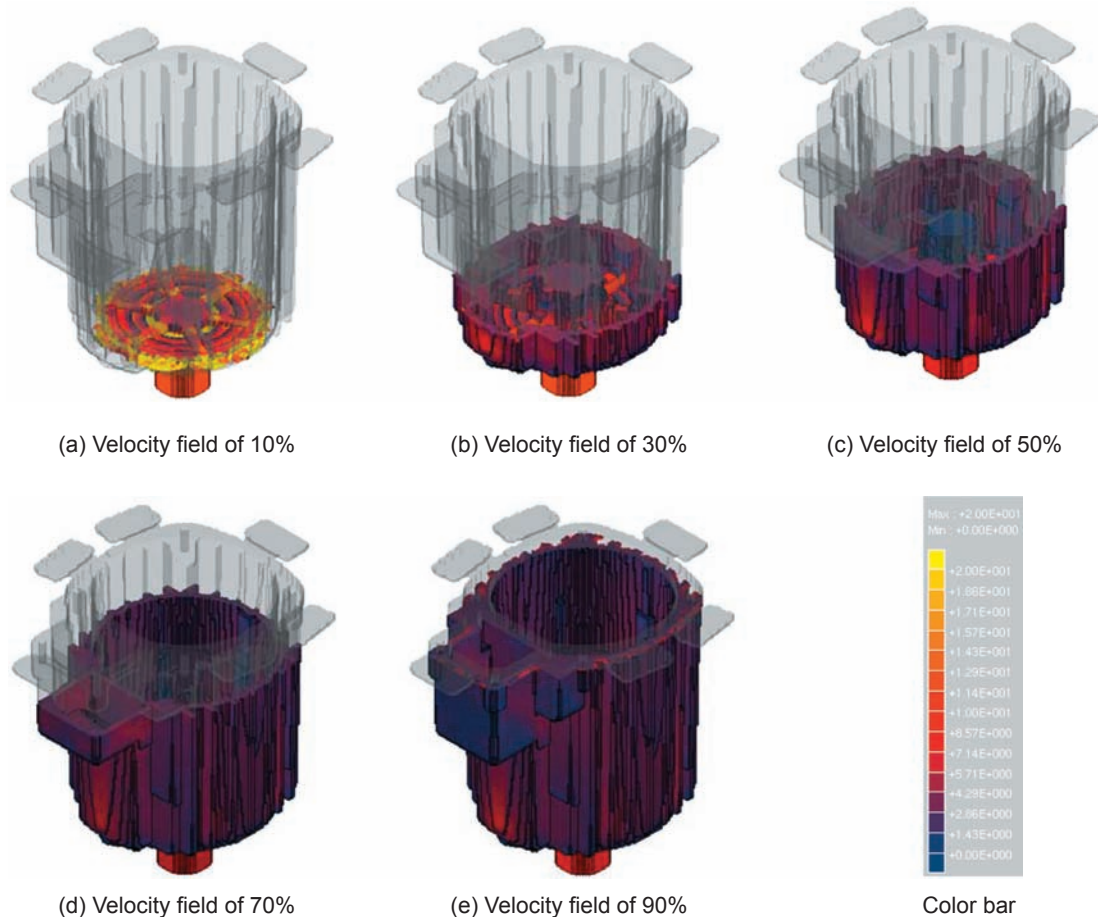
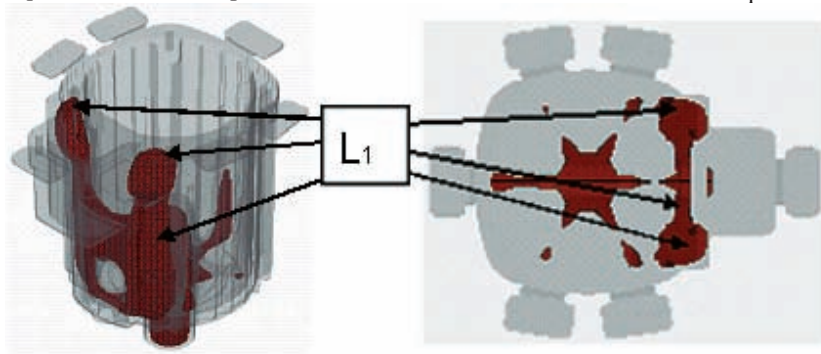


Fig. 4 Simulation results of filling process

light stands for the velocity varying from 0 to 20 cm/s. The simulation results show that at the beginning of mold filling, the velocity was fast and the liquid flowed from ingate to horizontal direction, no liquid crossing. After the bottom was filled up with liquid, the melt lifts along the cavity wall and fills smoothly without gas entrapment and splash. The mould filling process is acceptable.

2.2 Solidification procedure

Solidification times at different locations of the casting were obtained according to the simulation results. At $t = 96.82$ s, isolated liquid island L_1 was generated on account of the feeding passage between the thickest location P and gate runner was blocked, as shown in Fig. 5; at $t = 158.62$ s, isolated liquid island L_1 was split to island L_2 and island L_3 , as shown



(a) Side view
(b) Top view
Fig. 5 Liquid phase in the casting at $t = 96.82$ s

in Fig.6. Since machining is needed at location L_2 , shrinkage is not allowed to occur there. Whereas, L_2 disappeared at $t = 179.22$ s. The critical location P can be fed when $t < 96.82$ s due to the liquid metal at the location P acted upon by pressures from both gravity and antigravity, and antigravity pressure $>$ gravity, and then the feeding passage opened. However, at 96.82 s $<$ $t <$ 158.62 s, the feeding passage was completely blocked, then isolated liquid island L_1 only acted upon by gravity because the liquid metal at the location P would meet the demand of contraction at isolate inland L_2 . So during this process, a rather large shrinkage would generate in the location P. At 158.62 s $<$ $t <$ 179.22 s, the contraction in the location P was solidification shrinkage and the shrinkage mass would be far less than that at 96.82 s $<$ $t <$ 158.62 s. When $t >$ 179.22 s, the liquid in the location P completely solidified.

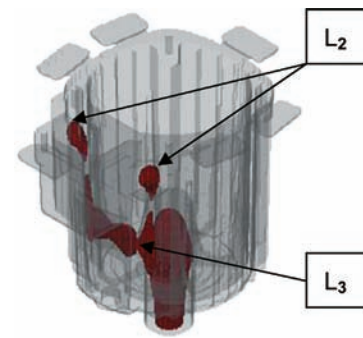


Fig. 6 Liquid phase in the casting at $t = 158.62$ s

2.3 Experiment results

The thick locations of the casting were cut off by digital electric spark cutting machine to observe the position and size of shrinkage, as shown in Fig. 7. Figure 8 is the corresponding simulation results. The solidification times are used to judge the shrinkage defects.

Brown location in the figure stands for the first solidified zone and yellow is the last solidified zone. The simulation results are in good agreement with the actual casting, and it can provide useful guideline for the actual production.

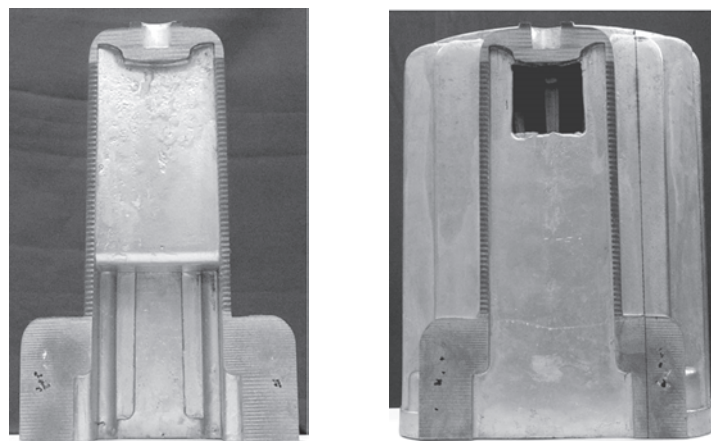


Fig. 7 Transverse sections

3 Optimization of casting methods

3.1 Simulation and optimization of cylinder body casting

Because of the feeding passage was prematurely blocked during solidification, large volume isolated liquid island was formed at the location P and it is harmful to the mechanical properties of the casting. So the casting method needs to be improved. Forced cooling system was adopted

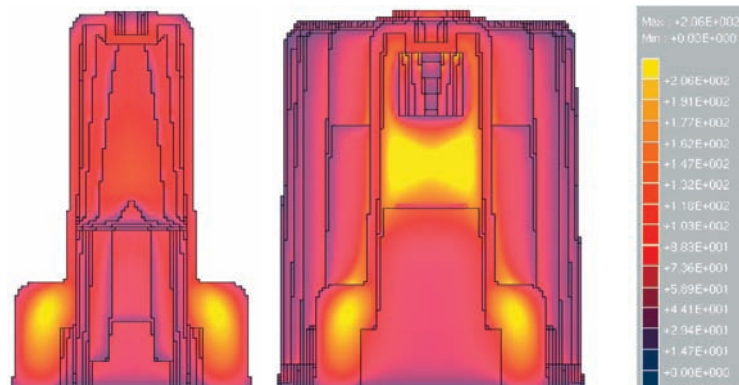


Fig. 8 Simulation results of solidification (judging by solidification time)

according to the mold structure. Cu was used as the chill near location P to speed up the cooling. There are four improved programs:

Program I : Two strengthening ribs were added at upper gate runner and location P.

Program II : Rotating the ribs at the bottom of the casting to certain angle and connecting them to the thick location.

Program III: Inserting copper billets in lower die near location P.

Program IV: Inserting copper billets in upper die near location P.

The geometrical models of all programs are shown in Fig. 9.

Table 2 lists the solidification time of the isolated liquid in the modified and the original unmodified programs. The simulation results illustrated that existing time of L₁ are all reduced in the four improved programs but they are not being eliminated completely. Hence, shrinkage in location P still exists.

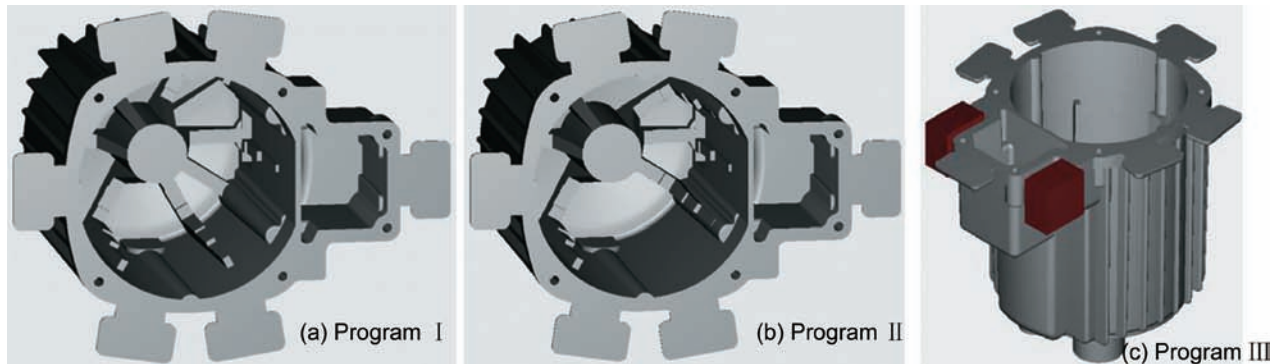


Fig. 9 The geometrical models of four programs

Table 2 Solidification time of isolated liquid islands in different programs

	L ₁ generating time s	L ₁ blocking time s	L ₂ disappearing time s
Original program	96.82	158.62	179.22
Program I	115.36	158.62	179.22
Program II	111.24	154.5	177.16
Program III	96.82	156.56	158.62
Program IV	96.82	158.62	166.86

All the programs above cannot eliminate the shrinkage defects in the location P, so program V was combined with program II and program IV in order to search for optimal program. The geometrical models are shown in Fig. 10. The simulation result indicated that the generating time of isolated liquid island L₁ in program V is 111.24 s, blocking time is 154.5 s and disappearing time is 166.86 s. It still cannot totally eliminate the defect in casting.

Program VI can widen the feeding passage in Program V.

The geometrical models are shown in Fig. 11. The simulation result indicated that it obtained a better result than that in Program V. The island volume is smaller and less shrinkage formed.

In order to eliminate the defect in the location P, copper billets were inserted in both upper die and lower die, as shown in Fig. 12 (program VII). The results showed that the isolate island did not appear in the location P and no shrinkage formed.

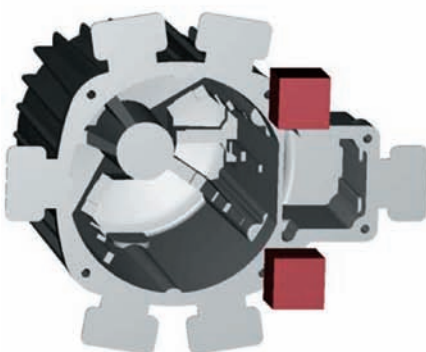


Fig. 10 Program V

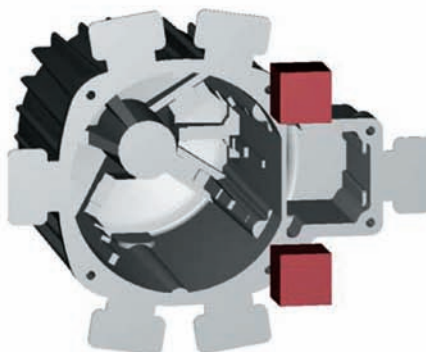


Fig. 11 Program VI

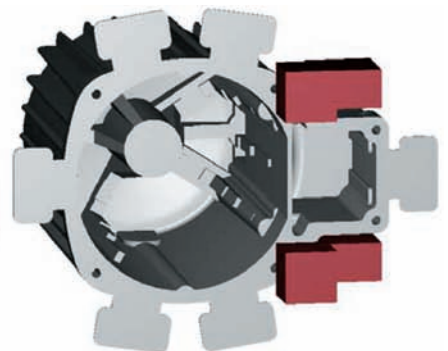


Fig. 12 Program VII

3.2 Analyses of optimization programs

Figure 13 shows the existing time of isolated liquid islands in all optimization programs. In program I to program V large isolated liquid island was generated and shrinkage defects cannot be eliminated. Program VI did not generate isolated liquid islands in the whole solidification process and no shrinkage defect was generated. But Inserting copper billet in lower die is difficult to realize. Program VII did not generate large and only small isolated liquid island generated in the last stage. Above all, the improvement can be realized easier. Therefore, program VI is the optimal casting method.

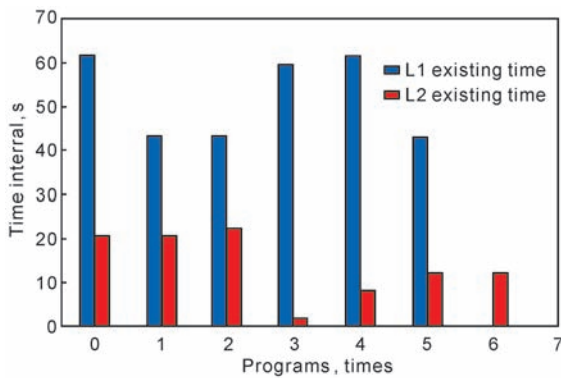


Fig. 13 Existing time of the isolated liquid islands

4 Conclusions

The mold filling and solidification process of LPDC cylinder body can be visualized through simulation. Casting method

can be improved based on the simulation results. Inserting copper billets at suitable location of the die and changing the strengthening rib position can improve the solidification sequence and is beneficial to feeding. Using the improved casting method, shrinkage defect can be eliminated completely.

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