Design and Verification of a New Test Bar Die for LPDC Process Based on Numerical Simulation

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***Abstract*—In order to unify the standard for the manufacture of tensile test bars for LPDC process, a new die for LPDC process was designed. Based on the simulation results of the casting processes of the test bar die, the location and types of casting defects were analyzed, being helpful to select more suitable casting process parameters for the test bar. In this paper, the LPDC process was applied with suitable parameters based on the simulation results. The rationality of the mold design was verified. Finally, based on the simulation results, the melt filling process inside the test bar mold and the temperature field change at different points were analyzed, and the rationality of the mold design was verified.**

***Index Terms*—ProCAST, LPDC, test bar, fluidity**

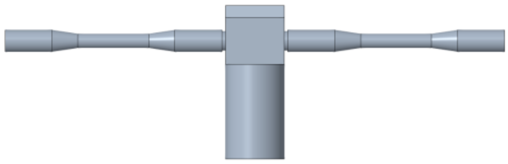
I. Introduction

The aluminum alloy castings produced by the Low-Pressure Die Casting (LPDC) process are with good comprehensive mechanical properties, high production efficiency, and high metal utilization rate, which is unmatched by the gravity casting method[1]. However, there is no uniform standard for the test bar casting method used to determine the performance of LPDC process castings, and it is usually replaced by gravity casting methods [2, 3].

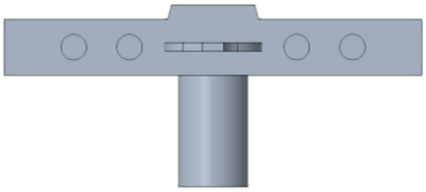
The difference between test bars processed under two different processes, LPDC and Gravity casting, was studied by Junming Cheng [4] and et al. The tensile values of the separately cast test bars are very close to that of the cast body sampling, and generally, the mechanical properties of the separately cast bars by LPDC are better than that produced by the gravity.

With the development of computer technology, Computer-Aided Engineering (CAE) is increasingly being applied to the design of the casting process, in order to reduce the impact of the actual experience of workers in the traditional casting process on product performance [4]. The self-tempering mechanism of near eutectic Al−Si casting was simulated and analyzed using CAE by Xinping Hu [6] and et al. Therefore, the production of this Al-Si alloy was guided. As a kind of special finite element software, ProCAST is less difficult to use than general finite element software and is mainly used for casting analyses [7, 8]. At present, ESI has integrated software such as ProCAST with the Visual-Environment (VE) and has become a part of VE. In the VE, the corresponding solver can be installed to perform analysis such as casting, welding, heat treatment, and automobile collision [9-11].

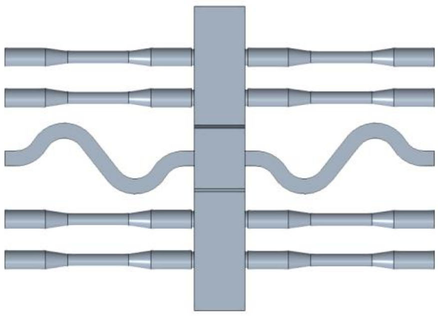
In this paper, a new test bar casting die for LPDC process was designed to simulate and verify the production of the casting, in order to verify the accuracy of the ProCAST software in guiding the actual production. As well as, it is expected that the molding method of this test bar casting could be accepted as a new detection process for the performance of LPDC castings.



(a) The front view



(b) The left view



(c) The top view

Figure 1. Shape of tensile specimen

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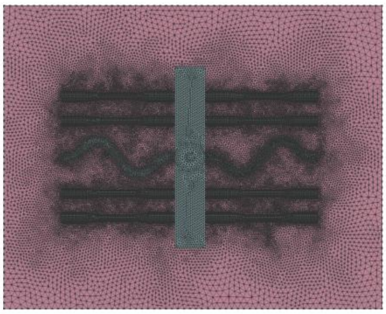
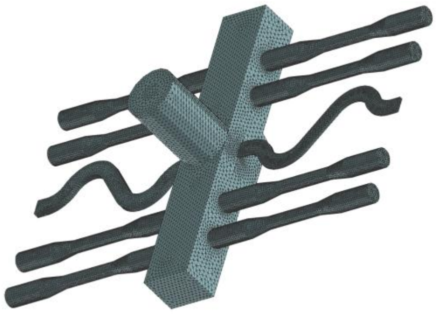


(a)



(b)

Figure 2. Finite element models

II. Model Design

The tensile test bar casting, with a new structure shape, was designed by using the Cero 4.0 software, using H13 mold steel as the die material. Fig. 1 shows the three-dimensional shape of the casting, the size as 424mm × 300mm × 130mm, and eight dumbbell-shaped tensile test bars were arranged on either side of the cross gate, respectively. Two S-shaped test bars for testing fluidity were arranged on each side of the runner. The metal die standard dumbbell type tensile test bar was manufactured following the GB 1173-86 Chinese standard, a bar with 40mm long clamped end and 60mm long testing part. Two S-shaped test bars for testing fluidity were with thicknesses of 3 mm and 6 mm, respectively. The total weight of the casting is 2.7kg.

III. Simulation Process

A. Model Pretreatment

Defining the finite element meshes before performing the simulation operation. The face file was saved in .igs format and was opened in the Visual-Mesh module and the grid was drawn. More detailed results can be obtained by setting the local finer grid values. The volume was meshed after the surface had been meshed, checked, and repaired. Fig. 2 shows the finite element model of the test bar casting under the LPDC process. Fig. 2 a) is a top view of the lower die and the casting together, Fig. 2 b) is the casting. The darker color indicates that the mesh is more finely divided here, and the simulation results will be more accurate.

B. Parameter Setting

The commercial Japanese brand aluminum alloy AC4B was tested and its composition is close to the YL112 (YLAlSi9Cu3) in the Chinese national standard GB/ T1173-1995. Calculated by VE, the liquidus was 574.8 ℃ and the solidus was 473.2 ℃.

For the LPDC process, qualities and performances of the castings are mainly affected by the pouring temperature, the die temperature and the filling time. Therefore, multiple factors were used for coupling at different levels, and orthogonal experiments were designed.

C. Analysis of Simulation Results

1) Simulation of casting filling

The optimum process parameters were obtained by orthogonal test. The temperature of the aluminum liquid was cast at 690 ℃ and the mold temperature was about 300 ℃.

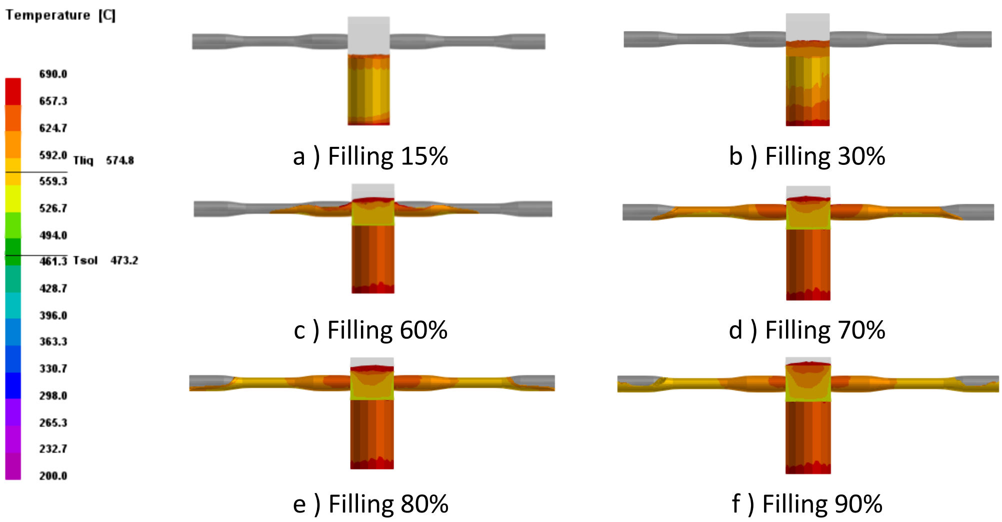


Figure 3. Aluminum liquid temperature in casting filling

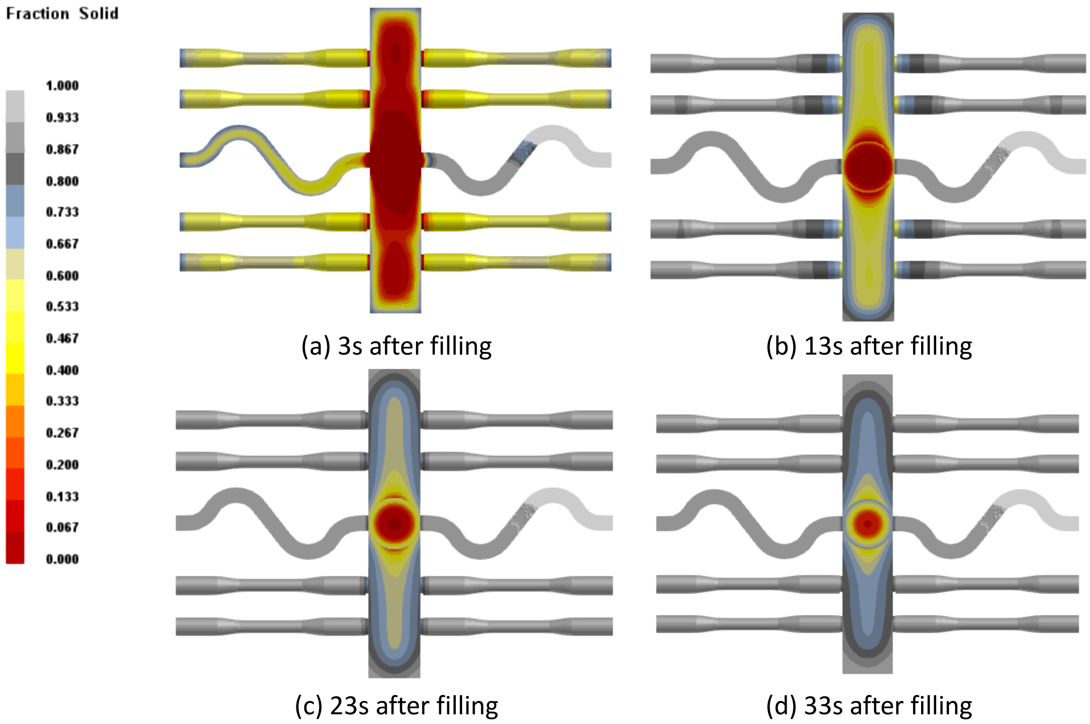
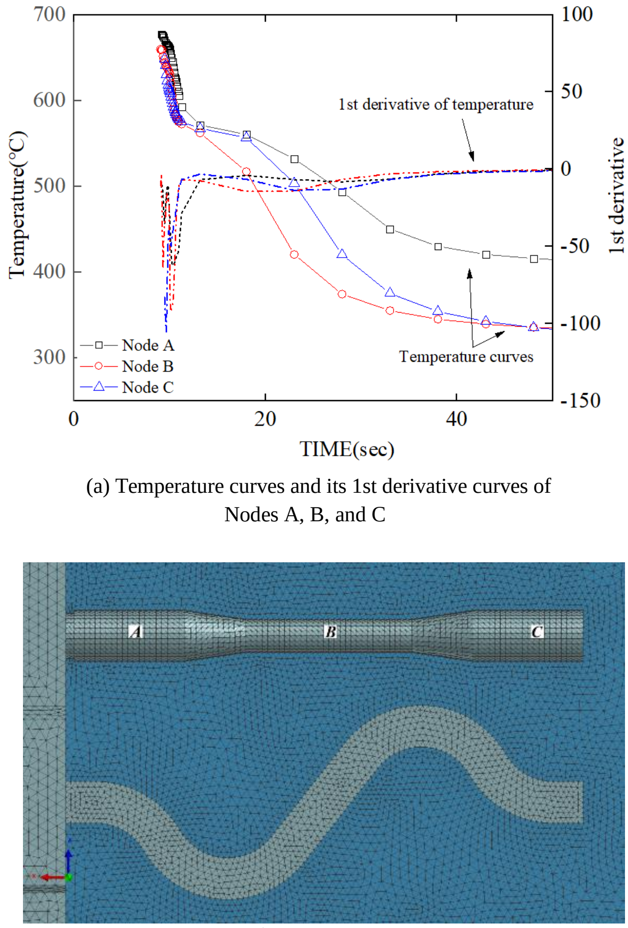


Figure 4. Solidification process of the casting



(a) Temperature curves and its 1st derivative curves of Nodes A, B, and C

(b) Positions of Nodes A, B, and C selected on the test bar

Figure 5. Temperature changes at different locations during test bar cooling

Simulation results were analyzed in the Visual-viewer module of the VE.

Fig. 3 shows that the casting was relatively stable when the casting was filled at 15%, 30%, 60%, 70%, 80%, and 90%. There was no tumbling, impacting or spattering in the aluminum filling. In Fig. 3, the left side is the different melt temperature, and the temperature is initially reduced from 700 ℃ to 200 ℃.

Fig. 4. shows the alloy solidification state at 0s, 3s, 8s, 13s, 23s and 33s after the casting was completed. In the part of the tensile test bar, there was no casting lap or short run during the solidification process. In Fig. 4, the left side is the solid fraction of the casting, which is proportionally decreasing from 1.000 to 0.000, and 1 represents complete solidification.

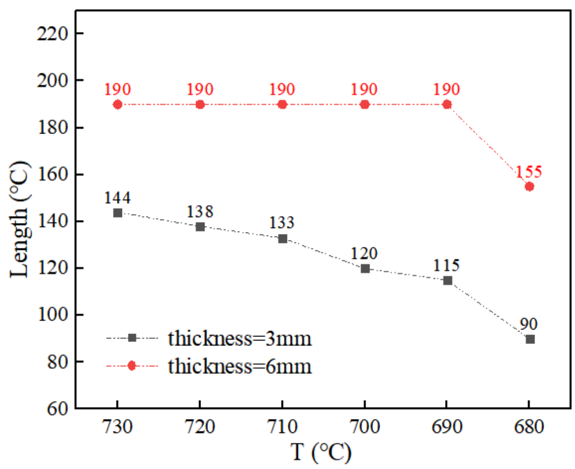
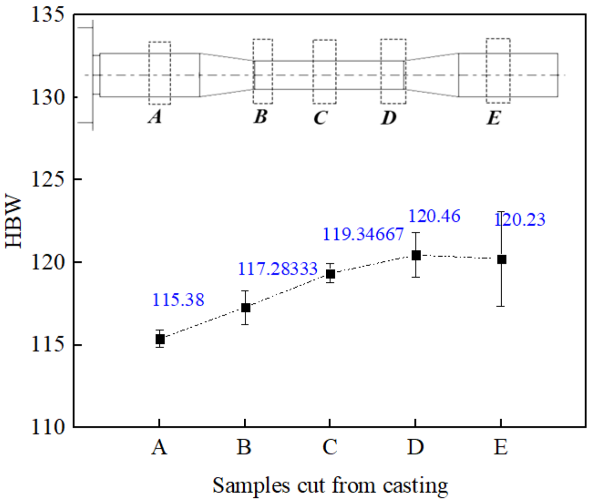
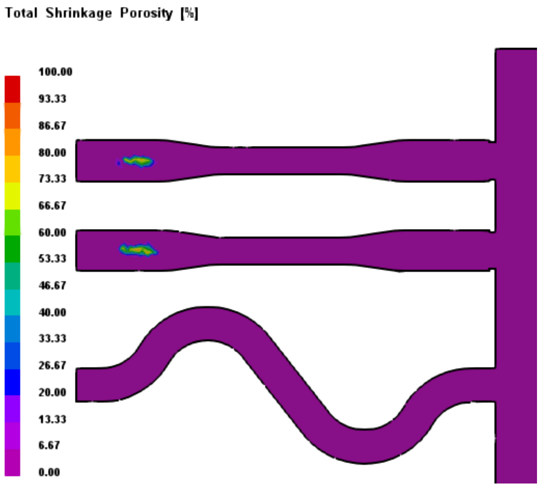


Figure 6. Length of S-shaped test bars

(a) Different grain structures



(b) Samples cut on the casting and its hardness



(c) Shrinkage distribution in tensile test bars

Figure 7. Macroscopic structures and hardness of test bar

The microstructure and mechanical properties of castings are affected by the temperature distribution and cooling rate of the casting solidification and cooling process[6]. Fig. 5 shows the temperature changes of three nodes A, B, and C at different positions on the central axis of the test bar during the simulation of the cooling process. Fig. 5 (a) shows temperature curves during the solidification and first derivative of points A, B, and C; Fig. 5. (b) shows selected positions of points A, B, and C. After the liquid aluminum was entered the mold, the liquid surface with small amplitudes of fluctuations, was reflecting small amplitudes of fluctuations on the first derivative curve image. The first derivative has always been shown as negative values, indicating that the melt at three points of A, B, and C has been decreasing. The above shows that there was no large fluctuation and impact at three points in the melt.

IV. Production Verification

The length of S-shaped test bars formed under different pouring temperatures were measured and recorded, and the results were shown in Fig. 6. The melt was blocked by the cavity wall of the S-shaped test bar during the pouring process. The melt in the 3mm test bar cavity was cooling faster than the 6mm one. In comparison, the 6 mm thick test bar was well filled at most melt filling temperature, but the 3 mm one was ordinary. The fluidity of gravity casting and LPDC under different process parameters was compared as also. The melt temperature was set to 690 ° C and the mold temperature was 300 ° C, which made the 3 mm thick fluidity test bar are acceptable. Moreover, the gravity casting was performed by using this mold, and the test bar forming was difficult, and the performance was worse than that of the test bar formed by the LPDC process.

Based on the simulation and analysis of the new test bar die, a smooth pouring of melt could be obtained combined with LPDC process. As well as, the suitable process parameters are obtained.

As shown in Fig. 7 primary crystal temperatures at the three nodes decreased by different magnitudes with respect to the liquidus. The Node A temperature was 571 ° C, the Node B was 567 °C, and the Node C was 562 °C. The maximum subcooled degree occurred at Node C. During the filling process, equiaxed crystal nuclei fell off after the aluminum liquid got in touch with the mold wall, and equiaxed crystal nuclei was free and flowing with the aluminum liquid. At the same time, as the melt subcooled degree was increased, fine equiaxed crystal enrichment occurred at point C farthest from the gate position. Due to the filling sequence, the temperature of the die at the point C was lower than that of the other test positions of the test bar, and the subcooled degree of the melt caused the heterogeneous nucleation to occur, and additional equiaxed grains were generated.

Fig. 7 (b) shows samples A, B, C, D, and E were cut from near to far on tensile test bars, and the Brinell hardness was measured after photographing. Fig. 7(a) shows that samples had been polished and were deeply etched by Keller's solution until the grains could be visible to the naked eye. The crystal grains are all equiaxed crystals, and the grain size gradually decreases with the increase of the distance from the case gate. Conversely, the overall hardness increases with the increase of the distance from the case gate.

Fig. 7 (c) shows that the total shrinkage distribution in tensile test bars. The left side is the total shrinkage porosity of the teat bar, which is proportionally decreasing from 100.00% to 0.00%. The feeding effect of the melt at sample E position was weak, slight shrinkage was caused to cause the hardness of sample E to be lower than that of sample D.

The rationality of the new tensile test bar mold was completed and simulated by using this mold, which proves that the mold is reasonable and has guided significance for determining the parameters of the actual LPDC process.

V. Conclusions

- A new LPDC test bar metal die had been designed, and the simulation process of the pouring process was carried out with the ProCAST module in Visual-Environment. The optimal process parameters of the test bar casting were obtained and the possibility of defect formation defects were estimated.
- The simulation and verification of the fluidity measurement function of the new test bar die was carried out. The mold can be used to determine the fluidity of the aluminum liquid under the LPDC process.
- The anatomical and grains observation of the test bar castings revealed that the hardness was higher than the industry standard, which verified the rationality of the die.

Acknowledgment

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References

[1] T. Liang, Y. Qu, X. Liu, F. Wang, and M. Zhang, “Simulation of filling and solidification processes of rump pan by ProCAST,” *Advanced Materials Research*, vol. 2605, no. 785, 2013.

[2] S. Lu, F. Xiao, S. Zhang, Y. Mao, and B, Liao, “Simulation study on the centrifugal casting wet-type cylinder liner based on ProCAST,” *Applied Thermal Engineering*, vol. 73, pp, 512-521. 2014.

[3] J. Wang, P. Fu, H.Liu, D. Li, and Y. Li, “Shrinkage porosity criteria and optimized design of a 100-ton 30Cr2Ni4MoV forging ingot,” *Mater. Des*, vol. 35 pp. 446-456. 2012.

[4] J. Cheng, Q. Lu, L. Li, H. Li, “A study on the mold of low-pressure casting of aluminum alloy test bar,” *Special Casting*, vol. 3, pp. 67-69, 2014.

[5] H. Lu, R. Chen, Y. Zhao, L. Wu, Z. Li, and H. Yang, “Numerical simulation and process optimization of aluminum alloy connecting rod based on ProCAST,” *Advanced Materials Research*, vol. 712, 2013.

[6] X. Hu, L. Xie, J. Zhang, “Self-tempering effect of near eutectic Al−Si casting with different wall thickness solidified and cooled in permanent die,” *Trans. Nonferrous Met. Soc. China*, vol. 21, pp. 2576-2583, 2011.

[7] S. Lu, F. Xiao, S. Zhang, Y. Mao, and B. Liao, “Simulation study on the centrifugal casting wet-type cylinderliner based on ProCAST,” *Applied Thermal Engineering*, vol. 73, pp. 512-521, 2014.

[8] H. Liu, F. Feng, C. Yan, and X. Zheng, “Computer simulation of the filling process of air intake hood based on ProCAST,” *Advanced Materials Research*, vol. 1684, no. 487, 2012.

[9] K. S. Keerthiprasan, M. E. Murali, P. G. Mukunda, S. Ajumdar, “Numerical simulation and cold modeling experiments on centrifugal casting, Metall,” *Mater.Trans*, vol. 42, pp. 144-155, 2011.

[10] N. Hua, L. Tian, Z. Cao, Z. Yu, F. Cai, “Centroid, area and volume of revolution of a plane figure,” *Stud. Coll. Math*, vol. 16, pp. 50-52, 2013.

[11] N. Song, Y. Luan, Y. Bai, Z. Xu, X. Kang, D. Li, “Numerical simulation of solidification of work roll in centrifugal casting process,” *J. Mater. Process. Technol*, vol. 28, pp. 147-154, 2014

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