Research for Process on Investment Casting of Mouse Head Based on 3D Printing

Yue Zhang1, Xue-Ying Li2,3, Chang-Liang Ma1 and You Xiao1

1 School of Intelligent Manufacture, Taizhou Institute of Sci. & Tech., NJUST. No.8 East Meilan Road, Hailing District, Taizhou, Jiangsu, 225300. China
2 School of Mechanical, Aerospace and Civil Engineering, The University of Manchester. Oxford Road, Manchester, M13 9PL. UK
3 Nanjing Mint Co. Ltd. No.919 Tianyin Street, Jiangning District, Nanjing, 211100. China
Email: zhangyue2716@njust.edu.cn

Abstract. The rat head is selected as the object for the application of PLA 3D printed model in investment casting of alloy ZL104. In order to optimize the process of casting, CAE analysis software AnyCasting is performed for the design of gating system. The top gating system shows the excellent casting results with little shrinkage defects. The solutions from simulation are conformed in the reality experience, which demonstrates that AnyCasting can provide accurate predictions of casting results, as well as reliability reference for the design of the process. Meanwhile, using the 3D printed rat head model for investment casting is practicable.

1. Introduction
Investment casting is defined as a type of casting that using wax patterns to producing the mode cavity [1], which is remarked as a near moulding process due to its high precision comparing with final part, which is adaptable for manufacturing of casting with high accuracy and complex shape. Thus investment casting is suitable for precious metal and the parts with structures difficult for machining [3]. However, the traditional investment casting using wax model demands complicated processes, along with high cost and time consuming, especially the casting with complex surface [2].

Recently, with the development of rapid prototyping (RP), 3D printing expands the further developments of investment casting in model manufacture. Meanwhile, the numeral simulation applications also improve the quality of casting [5].

In this paper, the gating systems of process of rat head casting will be focused. CAE analysis software AnyCasting is used for simulating the cast quality of three different gating system include top gating system, bottom gating system and side gating systems [6] for the research of the process of alloy ZL104 rat head. As well as determining the best solutions for casting. Finally, the selected solutions will be printed and utilized in experience.

2. Methodology
Before the practice of manufacture, it is valuable for utilize simulation software AnyCasting for the decision of gating system. The parameters of simulation are set depend on reality manufacture condition of workshop. Thus the results of production will only be affected by the management of different gating system.
2.1. Modelling

The 3D model is generated in figure 1. The foundation of rat head is square with 46mm, and the totally height is 70mm. Material of the rat head is alloy ZL104. Its ears are bending so it will lead to unstable filling even shrinkage defects and cause faulty parts. Therefore, it is valuable for performing CAE simulation of filling process for its suggestions in manufacturing.

![Figure 1. 3D model of rat head.](image1)

The STL modelling and meshing of model are shown in the figure 2. Three types of gating system are created. Top gating system, bottom gating system and side gating system are added to the rate head as Figure 2. The preprocessing module AnyPRE is used for the creation of meshes. Take the top gating system as the example, the account of flexible finite elements is 41616 in Figure 3.

![Figure 2. 3D STL file of rat head.](image2)  ![Figure 3. Meshing of model with top gating system.](image3)

2.2. Simulation of gating system

The simulation are carried in the software Anycasting. Three types of gating systems are designed for research, top gating system, bottom gating system and side gating system. The elements for simulation is chosen according to the material ZL104.

| Temperature of casting(℃) | Temperature of shell preheat(℃) | Speed of casting (cm/s) | Material of heat preservation |
|---------------------------|---------------------------------|-------------------------|-----------------------------|
| 750                       | 750                             | 25                      | none                        |

The type of case is filling and solidification analysis. The results of preprocessing are saved for later treatments. Finally the results will be displayed by post-processing module in form of images.

![Table1. Simulation elements](image4)
Combined defected parameter and probabilistic defect parameter are two evidences that for determining the filling results.

2.3. Reality experiments
After the optimization of gating system, the best solution with minimum defects will be printed for fabrication in reality experiment. PLA is the material for printing while the material of finished products is ZL104. Temperature for casting is 750°C. Casting shell is made by thermo stability plaster because of its advanced liquidity, low thermo conductivity and high accuracy in re-model.

3. Results and discussion

3.1. Filling results of simulation
The results of top gating system are shown in Figure 4. The Fig explains the state of metal fluid in 3.6966 sec and the solidification time in 855.3247 sec. Shrinkage defects occur during the period of time that fluid-solid state change into solid body. As is shown in the figure 4(a)(b), the solidification along from the top to the bottom and from outside to inside. The combined defect parameter analyses the possibility of defect. Figure 4(c) means the possible defects, it is clear that there exist defects at the ears and foundation. While the probabilistic defect parameter in figure 4(d) proof that the shrinkage defects and gas porosity will not appear.
Figure 4. The solidification progress of top gating system (a)(b) is from top to the bottom and from outside to inside. The combined defects (c) is appears at ears and foundation, but there is no probabilistic defects (d).

The results of side gating system are shown in figure 5, whose metal fluid is injected from the foundation of model. Its solidification progress is form right side to counter (a)(b). The combined defects (c) will happen at the ears and foundation, which is same to top gating system. Figure 5(d) forecasts that shrinkage defects will occur in the place between the head and foundation shown as the yellow area.
Figure 5. The solidification progress of side gating system is from right side to left, and the combined defects (c) is appears at ears and foundation. Probabilistic defects (d) is in the place between the head and foundation.

Figure 6 demonstrate the filling of bottom gating system. The solidification progress of bottom system is the metal fluid solidifications from head and from outside to inside. In figure 6(c), it can be find that compare with the side gating system, the defects at ears is less but defects at foundation is more. Area of probabilistic defects is same with but smaller than side gating system.
Figure 6. The solidification progress of bottom gating system is from top to bottom and outside to inside. The combined defects (c) at ears is less but defects at foundation is more. Probabilistic defects (d) is in the place between the head and foundation.

Therefore, according to the combined defects and probabilistic defects elements, the defects will appear in the corner such as ears and the corner of foundation. Top gating system displays the most outstanding results with no shrinkage defects. So top gating system will be chose for further experience.

3.2. Experiment and confirmation

Mix the thermo stability plaster with water as proportion 100:50 until no bubble. Immersing the 3D printed mould into mixed plaster. Then put it into the casting mold when the plaster is dried like figure 7(a). Airing the whole mold for 3 hours. Then heating them in 400°C for 15min and arising the temperature to 600°C for 30min. After ensuring that the PLA mould is burned, pouring the ZL104 into the mold.

The casting is displayed as Figure 7(c). The casting is full filled without any defects, moreover, its clear appearance proof the advance of 3D printed model in investment casting. Cutting the gating system and the final impeller is in Figure 7(d).
4. Conclusions
In summary, the application of 3D printing rat head in investment casting is experienced. With the assistance of CAE analysis, the optimal process of casting rat head is explicated. The results are below.

(1) 3D printed mold can produce the casting with excellent surface qualification and high accurate of size.
(2) Top gating system shows the outstanding superiority for investment casting of rat head.
(3) The research for process on investment casting of mouse head based on 3D printing can solve the problems that come from the complex manufacture of mold, as well as improve the effectiveness of produce.

References
[1] Handayani, D., Wagner, N., Okhuysen, V., Seitz, M. and Garibaldi, K., 2020. Utilization of 3D Printed Materials in Expendable Pattern Casting Process. Light Metals 2020, pp.338-344.
[2] Kang, J. and Ma, Q., 2017. The role and impact of 3D printing technologies in casting. China Foundry, 14(3), pp.157-168.
[3] Martinez, D., Bate, C. and Manogharan, G., 2020. Towards Functionally Graded Sand Molds for Metal Casting: Engineering Thermo-mechanical Properties Using 3D Sand Printing. JOM, 72(3), pp.1340-1354.
[4] Melnyk, R., Ezzat, B., Belfast, E., Saba, P., Farooq, S., Campbell, T., McAlevey, S., Buckley, M. and Ghazi, A., 2019. Mechanical and functional validation of a perfused, robot-assisted partial nephrectomy simulation platform using a combination of 3D printing and hydrogel casting. World Journal of Urology.
[5] Sama, S., Badamo, T. and Manogharan, G., 2019. Case Studies on Integrating 3D Sand-Printing Technology into the Production Portfolio of a Sand-Casting Foundry. International Journal of Metalcasting, 14(1), pp.12-24.
[6] Shangguan, H., Kang. J., Yi, J., Deng, C., Hu, Y. and Huang, T., 2018. Controlled cooling of an aluminum alloy casting based on 3D printed rib reinforced shell mold. China Foundry, 15(3), pp.210-215.
[7] Wang, D., Dong, A., Zhu, G., Shu, D., Sun, J., Li, F. and Sun, B., 2018. Rapid casting of complex impeller based on 3D printing wax pattern and simulation optimization. The International Journal of Advanced Manufacturing Technology, 100(9-12), pp.2629-2635.
[8] Wang, J., Sama, S. and Manogharan, G., 2018. Re-Thinking Design Methodology for Castings: 3D Sand-Printing and Topology Optimization. International Journal of Metalcasting, 13(1), pp.2-17.