

2025 International Conference on Advanced Mechatronics and Intelligent Energy Systems

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AIPCP25-CF-AMIES2025-00118 | Article

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Application of 3D Printing in Conformal Cooling Molds

Kailin Wang^{1, a)}, Bingwen Zhou^{2, b)} and Ye Zhou^{3, c)}

¹ *Beijing University of Chemical Technology, Beijing, 100029, China*

² *Nanjing Institute of Technology, Nanjing, 211167, China*

³ *Yang-En University, Quanzhou, 362014, China*

^{a)} Corresponding author: 2022090116@buct.edu.cn

^{b)} zbw8595@163.com

^{c)} zye2120@163.com

Abstract. The emergence of 3D printing technology has not only changed the manufacturing mode of some traditional industrial products but also brought tremendous changes to traditional manufacturing processes. Conformal cooling molds have a more complex structure compared to ordinary molds due to the existence of internal waterways. The article starts from the design and manufacture of conformal cooling molds and the theory of 3D printing, combining the design and manufacture of conformal cooling molds with the advantages of 3D printing. This paper discusses the application of 3D printing technology in conformal cooling molds, focusing on analyzing the influence of selective laser melting (SLM) technology on the forming accuracy of waterways. This article adopts two experimental designs, studies the influence of different process parameters on the dimensional accuracy and surface roughness of waterways, and also proposes an optimization scheme. This research has certain significance and value for improving the forming accuracy of waterways, also provides new ideas and directions for future studies at the same time.

INTRODUCTION

Mold is an important piece of equipment for the production of industrial products. It is complementary with machinery, electronics, automotive, petrochemical and construction industries. Cooling waterways need to be designed in various molds such as injection molds, die-casting molds and blow molding molds, most traditional cooling water channels are processed into straight shapes by drilling, which has defects such as uneven cooling. 3D printing can directly manufacture molds with complex internal waterways that cannot be processed by traditional techniques, which is worth studying. Molds with cooling channels are important tools in industrial production, especially in the manufacturing of plastic products. In the process of molding plastic products, the cooling stage occupies 2/3 of the whole molding process. Therefore, improving the heat exchange efficiency and reduce the cooling time has become an important part of the design of the cooling mold with the shape. Among the many solutions, the design of the conformal cooling waterways is one of the most effective ways to improve the heat exchange efficiency of the mold and to reduce the cooling time of the molded part, which can reduce the cooling cycle time by up to 70% [1] [2]. The use of SLM printing technology to manufacturing conformal cooling molds enables the design and manufacture of more efficient and complex cooling water circuits, bypassing the limitations of traditional machining processes. However, this technology still has defects such as the step effect and surface particles, which will affect the accuracy of the channels. This paper reviews the shortcomings of the existing SLM molded conformal channels and further investigates the effects of different printing angles and laser power on the particle condition and step effect on the mold surface, and provides a reference direction for improving the surface accuracy of follower channels molded by SLM technology.

THE CURRENT APPLICATION STATUS OF 3D PRINTING TECHNOLOGY IN CONFORMAL COOLING MOLDS

The Concept and Design Principle of Conformal Waterways

Concept of Conformal Waterway

The conformal waterway is a new type of mold cooling waterway based on 3D printing technology. The traditional cooling water channels (as shown in Figure 1) are mostly processed into straight shapes by drilling, which has significant defects. 3D printed conformal water channels (as shown in Figure 2) can be designed according to the shape and contour of the mold cavity or core, making the cooling water channels highly fit the shape of the cavity, increasing the cooling rate and cooling effect, and improving the quality of the plastic part.

Processing Method

SLM (Selective Laser Melting) is an additive manufacturing technology that can melt metal powder layer by layer with a high-energy laser beam and then form it layer by layer according to a preset three-dimensional model. Eventually, it can produce molds with complex internal structures and waterways that closely fit the cavity.

Comparative Analysis of Conformal Waterways Formed by SLM Technology and Traditional Waterways

Technical Advantages

Due to the problem of low powder connection strength during the SLS technology forming process, Meiners from the Fraunhofer Institute for Laser Technology in Germany proposed the concept of selective laser melting technology based on the melting and solidification of metal powders [3], and in 1999, the first SLM forming equipment based on stainless steel powder was developed, attempting to solve this problem. Compared with traditional waterways, products manufactured using SLM technology do not require subsequent high-temperature sintering and copper infiltration. The process is simple, and the relative density can reach 99.5% of that of normal metals [4]. By analysing the stress field, thermal field and according to the shape of the plastic part, the conformal waterways of the software component were used to make the waterway shape conform to the mold cavity and improve the cooling effect [3]. SLM technology is widely applied to various complex-shaped injection molds, such as molds for automotive parts, molds for electronic product casings, and molds for toys. By optimizing the design of the cooling waterway, the cooling efficiency and product yield rate can be enhanced, production costs can be reduced, and the production cycle can be shortened. And in die-casting molding, the conformal waterway of SLM technology can reduce the cycle time, lower the scrap rate of castings, labour costs and the overall production cost. The cooling result simulated by the traditional scheme requires $10.77\text{s}/^{\circ}\text{C}$, while the cooling result simulated by the conformal scheme is $4.52\text{s}/^{\circ}\text{C}$. The simulation results show that the maximum temperature of the mold cavity surface after cooling by the traditional cooling water channel is 40.45°C , while the maximum temperature of the mold cavity surface cooled by the conformal cooling water channel is 30.37°C [5].

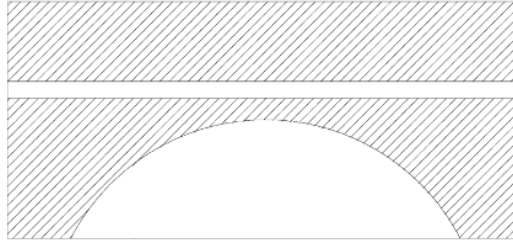


FIGURE 1. Schematic diagram of the traditional waterway

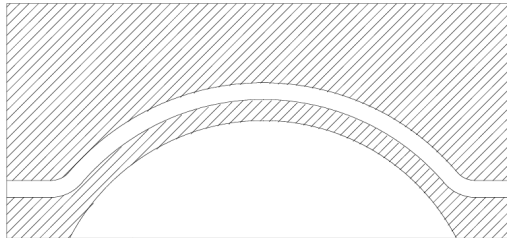


FIGURE 2. Schematic diagram of conformal waterway

Cost Advantage

The conformal waterway molds manufactured by SLM technology have higher density and mechanical properties, and can better cope with high-temperature and high-pressure environments, reducing the wear and deformation of the molds [6]. Although the initial cost of processing conformal waterways with SLM technology may be slightly higher than that of traditional methods, it can shorten the cooling time, improve production efficiency and reduce the scrap rate, and can also reduce the wear and deformation of molds, thereby enhancing the overall economic benefits.

The traditional straight-through water channels cannot meet the requirements of high-precision plastic part forming, while the conformal water channels formed by SLM often have surface particles, succession effects and other unavoidable drawbacks of SLM technology, resulting in a decrease in the surface accuracy of the water channels. Clogging and the decline in cooling performance are prone to occur in small-diameter waterways. Therefore, it is necessary to improve the surface accuracy of waterways.

OPTIMIZATION SCHEME

The waterways manufactured by the existing SLM technology suffer from insufficient manufacturing accuracy. Therefore, the existing SLM technology is difficult to manufacture waterways with small diameters. The manufacturing accuracy of waterways is mainly affected by the step effect of 3D printing, as well as surface particles. In order to investigate the factors affecting the accuracy of waterway manufacturing and how their variations affect the accuracy, two sets of experimental scenarios are proposed in this paper.

Surface Particulate Improvement

According to Guo Xu's research, the generation of particulate matter on the surface of SLM products is related to the adequacy of support [3]. When insufficiently supported, the amount of particulate matter on the inner surface of

the waterway increases and becomes pendulous, when adequately supported, the surface produces less or no particulate matter. If a section of the simplified model of the waterway as shown in the figure 4 is extracted, taking the bottom surface and the side surface as the base surface, and printed with the same parameters. Due to the force of gravity being applied downward parallel to the internal surface, there is less demand for support. Little or no particulate matter exists on the internal surfaces of the bottom-based model. For models with the side as the base surface, since the gravity is directly perpendicular to the inner upper surface and lacks support, there will be more suspended particles inside this model. The bottom-based model was rotated on the axis of one side (as shown in Fig. 4), and printed at different angles respectively.

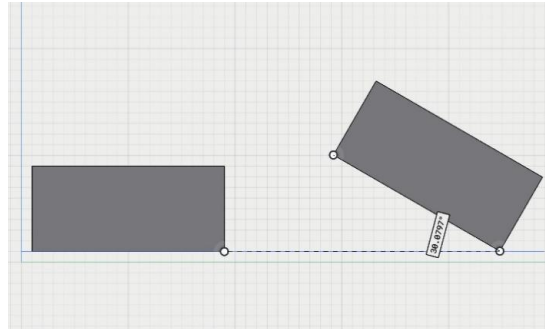


FIGURE 4. Schematic sketch of the angle change in 3.2

The amount of particulate matter and the degree of suspension was positively correlated with the angle. Therefore, to reduce the production of particulate matter inside the waterway, the waterway should be designed so that the long side of the mold coincides with the Z-axis as much as possible [7]. When printing waterways, try to place the waterway axis perpendicular to the print base (XY plane) or reduce the angle between the waterway axis and the Z-axis to minimize particle production. The reduction of particulate matter increases the volume of the waterway, which allows for a fuller injection of coolant and reduces uneven coolant distribution, resulting in a more even heat transfer and improved consistency of cooling.

Effect of SLM Printing Laser Power on Waterway Manufacturing Accuracy

According to the research of Lv Haiqing et al, the variation of laser power in SLM printing has a significant impact on the surface accuracy of hexahedra with a parallelogram cross-section [8]. A section of the non-coaxial waterway shown in Fig. 5 is intercepted, and its cross-section can be considered as an inverse model of the model used by Lv Haiqing et al.

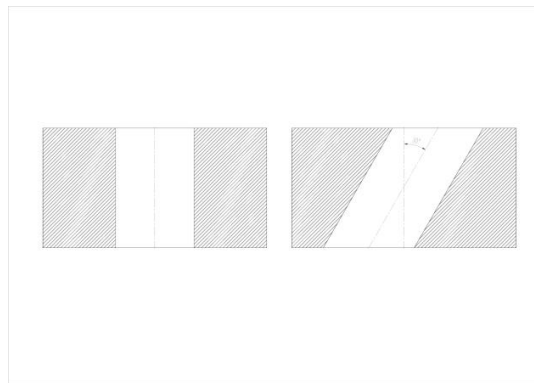


FIGURE 5. Schematic diagram of coaxial and non-coaxial waterways

By applying low power and higher power lasers respectively for SLM forming. The surface accuracy of the model formed with a higher power laser should be better than that of the model formed with a lower laser power ideally [9-11]. For non-coaxial conformal channels, an appropriately increased laser power enables the powder to melt more thoroughly, expands the molten pool, and overlaps with the molten channels formed in the previous scanning cycle, resulting in a better combination between molten channels, reduces the occurrence of step effects and their impact on surface accuracy. Secondly, the higher laser power increases the heat input, melting the particles attached to the surface, reducing the attachment of surface particles, and improving the surface accuracy of the watercourse to a certain extent. Taking all the above into consideration, when printing waterways, the laser power for scanning the tilted non-coaxial part can be appropriately increased, thereby reducing the significance of the step effect. In addition, the laser power in the unsupported sections should be increased to reduce the particles attaching to the inner surface of the waterways. In the research of Lu Haiqing et al, it was also mentioned that the main factor affecting surface accuracy are different for the upper and lower surfaces of a hexahedron, suspended particulate matter on the upper surface of the hexahedron is less frequent, due to adequate support, so the main factor affecting the accuracy of the upper surface is the step effect. The lower surface is less supported, both the step effect and the attached particulate matter have a greater impact on the surface accuracy of the lower surface. In order to optimize the scanning program, the laser power for scanning the upper and lower surfaces of the channel can also be differentiated, and the balance between energy consumption and surface accuracy[12].

CONCLUSION

In the research on the accuracy of conformal waterway molds for SLM printing and forming. The experiment found that both the printing Angle and the printing laser power are the main factors affecting the surface accuracy of waterways. This paper proposes an optimization scheme for the printing inclination Angle, in order to solve the problem of particulate matter adhesion on the surface of waterways in 3D printing technology, achieve the effect of improving the surface accuracy of waterways, and achieve the consistency of cooling effect. The wall thickness of the waterways is also a major factor affecting the cooling effect. In the future, it is extremely important to further optimize the multi-parameter synergy model and study the optimization of parameters such as scanning speed and layer thickness. Thus, the parameter optimization strategy can be extended to the SLM printing of irregular thin-walled structures, promoting its application in fields such as internal combustion engine cylinders and aerospace. In the future, an intelligent recommendation system for process parameters is also a considerable option, in combination with machine learning to achieve an integrated closed-loop optimization of "Design, Simulation, Printing".

AUTHORS CONTRIBUTION

All the authors contributed equally and their names were listed in alphabetical order.

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