Design and simulation of conformal cooling for a die-casting mold insert

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Abstract. Traditional cooling channels make the mold have defects of poor cooling and low efficiency. Selective laser melting (SLM) can be used to produce the mold with conformal cooling channels. In this paper, the design and simulation of conformal cooling channels for a die-casting mold insert are carried out. Compared with traditional cooling channels, the distribution of conformal cooling channels is closer to the die surface to be cooled and the cooling is more effective. After 5 s of simulation analysis, the effective cooling efficiency is 54.83\%, and the temperature distribution on the die surface is more uniform. The die-casting mold insert with conformal cooling channels is fabricated by XDM 250.

1. Introduction
Due to the limitation of traditional manufacturing methods and conditions, the cooling channels of the traditional mold are usually fabricated by drilling. Due to the limitation of the size of the drill and the clamping device, most of the complex molds have many difficult cooling positions, which makes the traditional molds have poor cooling, low efficiency, easy to crack and other defects\cite{1}. SLM is a popular manufacturing technology\cite{2}, which has unique advantages in fabricating parts with complex internal cavity structures\cite{3,4}. The cooling efficiency can be greatly improved by using SLM to manufacture the mold with conformal cooling channels\cite{5}. Many scholars have carried out research on the design and simulation of molds with conformal cooling channels. Kuo et al. \cite{6} confirmed that the cooling time of the wax mold with conformal cooling channels could be reduced by 81\% through experiments. Shen et al. \cite{7} compared and analyzed the cooling effect between the injection mold with conformal cooling channels and the traditional injection mold. The results showed that the cooling time could be reduced by 57.1\% and the surface temperature distribution of injection products was more uniform. Muvunzi et al. \cite{8} used a combination of milling and SLM to create a hot forming punch with conformal cooling channels. The simulation results revealed that the cooling time could be shortened by 28.6\% with the conformal cooling method. At present, the research of mold with conformal cooling channels mainly focuses on injection molds. The temperature of molten liquid metal in the die-casting mold can reach 650 °C, and the product temperature out of mold is about 200 °C. If the die-casting mold with conformal cooling channels is fabricated by SLM, the cooling time can be greatly shortened and the production efficiency can be improved.

Therefore, this paper will design conformal cooling channels for a die-casting mold insert. Fluent is
used to simulate the cooling effect of traditional cooling channels and conformal cooling channels. It will analyze the advantages of conformal cooling channels from the aspects of cooling effectiveness, efficiency and uniformity, and the die-casting mold insert is manufactured by the SLM equipment.

2. Model and simulation conditions

2.1. Model
The conformal cooling channels is designed for the die-casting mold insert. The initial model of the mold insert is showed in Fig. 1(a). The mold surface in the insert that needs to be cooled is showed in Fig. 1(a). In order to facilitate the design of the conformal cooling channels and reduce the calculation amount of the heat flow simulation, the simulation mold is simplified as shown is Fig. 1(b). The traditional cooling channels of the die-casting mold insert is formed by drilling, shown in Fig. 1(c) and Fig. 1(e). The conformal cooling channels model is shown in Fig. 1(d) and Fig. 1(f).

2.2. Simulation conditions
Fluent is used to simulate the cooling process of the mold insert. Fluent is a commercial CFD software, which is widely used in the aerospace, automotive, medical and electronics industries. Fluent’s calculations are based on the finite volume method. It targets the control volume rather than the mesh modes and discretizes the integrals of conservation equations in physical space. Finite volume method can be adapted to structured and unstructured grids, and its general approximation accuracy is second order. In this paper, the standard k-ε turbulence model is used in the simulation.

The die-casting cycle includes the process of filling, holding pressure, cooling and demoulding. In order to simplify the initial conditions of the simulation, this article assumes that the mold insert has reached a certain temperature, and then compares the cooling effects of different channels. The simulation conditions are set as follows: the initial temperature of the mold inset is 650 ℃, and the coolant is water. The water temperature is set to 25 ℃, and the water flow speed is 3 m/s. The mold material is H13 steel formed by SLM, and the material density is 7.8 g/cm³. The simulated cooling time is 5 s. Since the temperature gradient between the mold insert and the coolant is large at the beginning, a time step of 0.01 s is selected. In order to improve the calculation efficiency, a time step of 0.1 s is then selected. The discrete method of simulation time is: 5 s = 0.01 s × 20 + 0.1 s × 48. After checking the independence of the grid and the time step, the simulated calculation results are obtained.

3. Simulation result and discussion
After 5s of cooling, the overall temperature of the conformal cooling mold insert and the traditional
cooling mold insert is shown in the Fig. 2. In order to compare the cooling effects of the two cooling methods, a total of 18 points A1-A9 and B1-B9 are selected at the same position on the mold surface, as shown in the Fig. 2 (a) and (b). The temperature of the mold surface point of the two cooling methods is shown in Table 1. The following is a comparative analysis of the cooling effect of the two methods from the aspects of cooling effectiveness, efficiency and uniformity.

![Figure 2](image_url)

**Figure 2.** (a) The temperature diagram of traditional cooling mold insert, (b) the temperature diagram of conformal cooling mold insert, (c) the cross-section temperature diagram of traditional cooling mold insert, (d) the cross-section temperature diagram of conformal cooling mold insert

### 3.1. Cooling effectiveness

The conformal cooling channels are directly distributed inside the mold surface to be cooled, which is more effective in cooling the mold surface. According to the data in Figure 2 and Table 1, it can be seen that the mold surface temperature of the conformal cooling is much lower than that of traditional cooling. The average temperature of the conformal cooling mold is 423.88 K, while the average temperature of the traditional cooling mold is 919 K. Because the distribution of traditional cooling channels is limited by manufacturing methods, the distribution of channels is far away from the mold surface that needs to be cooled. It can’t cool down the mold surface in a targeted manner.

| Point | Conformal cooling mold (K) | Traditional cooling mold (K) | Temperature difference (K) |
|-------|-----------------------------|-----------------------------|-----------------------------|
| A1    | 433.61                      | 923.15                      | 489.54                      |
| A2    | 425.14                      | 922.87                      | 497.73                      |
| A3    | 423.97                      | 909.12                      | 485.15                      |
| A4    | 421.68                      | 923.15                      | 501.47                      |
| A5    | 384.86                      | 922.8                       | 537.94                      |
| A6    | 401.72                      | 910.34                      | 508.62                      |
| A7    | 434.34                      | 923.15                      | 488.81                      |
| A8    | 434.8                       | 922.85                      | 488.05                      |
| A9    | 434.55                      | 912.61                      | 478.06                      |
| B1    | 432.49                      | 923.15                      | 490.66                      |
3.2. Cooling efficiency

In order to compare the cooling efficiency of the conformal cooling channels and the traditional cooling channels on the mold surface, the cooling efficiency formula is defined as:

$$\eta = \frac{T_0 - T}{T_0} \times 100\%$$

(1)

$$\eta$$ means cooling efficiency, $$T_0$$ represents the initial temperature, and $$T$$ means the temperature after cooling. The initial temperature is 923.15 K. The effective cooling efficiency of the conformal cooling channels for the mold surface to be cooled can be obtained from formula (1) to be 54.08%. The effective cooling efficiency of the traditional method is only 0.45%. Since the distribution of the conformal cooling channels is closer to the surface to be cooled, the effective cooling efficiency of the conformal cooling far exceeds the traditional cooling method.

3.3. Cooling uniformity

It can be seen from Fig. 2 (a) that the surface cooling of the mold with traditional cooling channels is extremely uneven. The part close to the cooling water channels has been cooled to about 600 K, while the part far away from the cooling water channels still maintains a higher temperature. Compared with the mold temperature diagram with conformal cooling channel shown in Fig. 2 (b), the cooling effect of the mold surface that needs to be cooled is better, all reaching below 600 K. The temperature gradient diagram of the central section of the water channel is shown in the Fig. 2 (c) and (d). The temperature of the conformal cooling section is mostly distributed in the range of 500-700 K, and the temperature of some areas exceeds 700 K. The temperature of the traditional cooling section is divided into two parts: the high temperature area and the cooling area. The temperature in the area to be cooled reaches 900 K. The traditional cooling mold have large temperature gradients and poor cooling uniformity.

4. Mold insert forming

Based on the design analysis of the above-mentioned conformal cooling channels, the mold insert was manufactured by XDM 250 from Suzhou XDM 3D Printing Technology Co., Ltd. The process parameters are: the laser power is 275 W, the scanning speed is 900 mm/s, and the hatch space is 0.08 mm. After 14 hours of processing, the mold insert is formed, shown in Fig. 3. The surface quality of the mold insert is good and can be used in industrial production.
5. Conclusions
In this paper, the design and analysis of conformal cooling channels are carried out on a die-casting mold insert. It uses the Fluent software to simulate and analyze the advantages of the conformal cooling method in terms of cooling effectiveness, cooling efficiency and cooling uniformity. The mold insert is manufactured by XDM 250. The main conclusions obtained are as follows:

The distribution of the conformal cooling channels is closer to the part to be cooled, and the cooling is more direct and effective. After cooling for 5 s, the effective cooling efficiency of conformal cooling reaches 54.83%. Compared with traditional cooling channels, the overall temperature gradient of the mold insert with conformal cooling channels is small. Conformal cooling method has better cooling uniformity.

After 14 hours of processing with XDM 250, the mold insert is formed and can be used in industrial production.

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