Research on rapid design method and software for cooling system of hot stamping mold with high strength steel

Yilin Wang†, Bin Zhu, Liang Wang and Yisheng Zhang

State Key Laboratory of Materials Processing and Die & Mould Technology, Huazhong University of Science and Technology, Wuhan 430074, China

**E-mail: wangyilin@hust.edu.cn*

Combined with the characteristics of cooling system design for hot stamping dies, this paper divides the design process of cooling water channel into three main functional parts: the design of cooling water channel holes, the design of cooling water channel centerline and the design of cooling water channel structure. Identify the shape characteristics of the segmented end face through the curvature change of the end face side curve, and then realize the automatic arrangement of the cooling waterway holes according to the triangular arrangement method of the cooling waterway holes. The cooling water channel line is divided into straight-through and T-type, and the discrete fetch point is used to judge the distance change to identify the mold cavity surface characteristics, in order to realize the cooling water channel line with the shape arrangement. The automated design of cooling channels is realized through parametric design technology. Combining the advantages of penetrating cooling waterway and block independent cooling waterway, a hybrid cooling waterway is proposed to meet the cooling waterway design of various types of hot stamping molds.

Keywords: High-strength steel; Hot stamping die; Cooling system; Mold water channel; Automatic design.

1. Introduction

In recent years, the development of automobiles has gone into the development path of lightweight and electrification, and energy-saving and emission reduction, comfort and safety have been given unprecedented attention. High-strength steel hot stamping technology solves the molding problem of high-strength steel and is rapidly gaining applications [1]. The most important difference between the hot stamping die for high-tensile steel and the ordinary stamping die is that there is a set of cooling system inside, and the design quality of the cooling system directly affects the design quality of the whole set of hot stamping die[2]. However, the structure of the cooling system inside the hot stamping die is complicated, with different standards, various design methods, and the design quality mainly depends on the design level and experience of the designers, which have seriously affected the design efficiency and design quality of the whole set of hot stamping die.

At present, enterprises design the cooling system of hot stamping die mainly by engineers according to the specific structure and shape of the die, with their own design level and experience to complete manually. The core of the hot stamping die is the design of the cooling system, its design efficiency directly affects the design efficiency of the whole set of hot stamping die, and its design quality plays a decisive role in the quality of

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molded parts. Factors affecting the cooling effect of the cooling system is more, only the cooling system structure of the factors include the cooling waterway diameter, cooling waterway distance from the mold cavity surface, cooling waterway spacing, the number of cooling waterway, etc. Therefore, as soon as possible to design a hot stamping die cooling design CAD system, will be designed from the design of the complex, cumbersome design process to be liberated from the design process, it is obviously of great significance.

2. Cooling system for hot stamping dies made of high-strength steels

Micro-alloyed martensitic high-strength steel, after hot stamping, the strength of high-strength steel of about 600MPa can be increased to 1500-2000MPa, and the shape and dimensions are highly accurate with almost no rebound. The design of the cooling system is the core of the hot stamping die, without a good cooling system, in a large number of continuous productions, the die temperature rises gradually, resulting in the cooling rate does not reach the rate of austenite to martensite transformation rate requirements, the strength of the decline in the organization of poor uniformity. Therefore, a good cooling system should be able to make the mold cooled quickly and uniformly. In order to design a highly efficient cooling system, we should focus on the size parameters of the cooling channels, the structure and arrangement of the cooling channels and other design knowledge [3].

2.1. *Calculation of cooling water channel parameters*

Based on the principle of heat balance, it is assumed that the heat transferred from the high-temperature sheet to the mold is equal to the heat transferred from the mold to the cooling water. The diameter d of the cooling channel should be chosen to ensure the efficiency of heat transfer and sufficient turbulence of the cooling water in the channel. The larger the channel diameter *D*, the more water flow is required to maintain turbulence. However, the smaller the channel diameter, the more cooling channels can be set up, thus facilitating the overall cooling uniformity. Once the heat is transferred from the blank to the mold, heat conduction dominates in tool steel (as shown in Figure 1). The conductible heat flux (heat energy per unit area and per unit time, W/m2) is a function of the thermal conductivity of the tool steel (k in W/m) and the distance between the cooling channels and the mold surface, Ly. The distance between the mold surface and the cooling channels (Ly in Figure 1) depends on how the mold has been designed and manufactured. The number of cooling channels, the distance between the channels Lx and the diameter of the cooling channels *D* all affect the heat transfer from the tool to the cooling medium. For optimum performance, all three parameters must be minimized [4]. However, the principle of selecting these parameters, after considering engineering feasibility and cost factors, should take into account that 1) an increase in the number of cooling channels will increase the cost of the tool, 2) as the diameter d decreases, the maximum drilling depth will be limited and more die segments may be required, and 3) a shorter distance, Ly, between the tool surface and the cooling channels will increase the stress concentration around the channels.

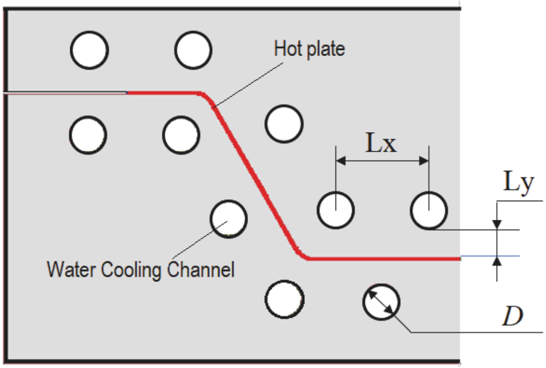

Fig.1 Definition of cooling channel parameters

Normally, the diameter of the cooling channel *D* depends on the thickness of the sheet t. Table 1 shows the recommended values for the diameter of the channel.

Table 1 Empirical selection parameters for water channel size and hot stamping plate thickness

Sheet thickness, *t(mm)*	Cooling water channel diameter, *D(mm)*
$t \le 2$	$8 \le D \le 10$
$2 < t \le 4$	$10 < D \le 12$
$4 < t \le 6$	$12 < D \le 14$

The cooling water flow rate *v* can be derived from equation (1):

$$v = \frac{Re \cdot \upsilon}{D} \quad (1)$$

To achieve turbulent flow in the cooling water, the Reynolds number (Re) needs to be greater than 4000. However, when the Reynolds number (Re) exceeds 10000, the thermal conductivity increases slowly while the pressure drops sharply, resulting in an overall decrease in heat transfer efficiency. Research has found that the value of the Reynolds number (Re) should fall between 4000 and 10000 for optimal overall efficiency.

υ represents the kinematic viscosity coefficient, which is derived from equation (2).

$$\upsilon = \frac{-0.003554Tw^2 - 0.0677Tw + 1000}{35304 \times (0.02Tw^2 + 5.92Tw + 153.23)} \quad (2)$$

where *Tw* represents the temperature of the cooling water. In order to achieve the required cooling rate, it is generally required that the overall surface area of the cooling channels, *Ac* is greater than the surface area of the molded part, *Ap*, as shown in equation (3).

$$A_c = n\pi Dl \ge A_p \quad (3)$$

The number of cooling channels, *n*, is derived from this, as shown in Equation (4):

$$n \geq \frac{A_p}{\pi D l} \tag{4}$$

Where, l indicates the length of the cooling channel. The distance H between the center of the cooling channel and the surface of the cavity is:

$$H = \lambda_T \cdot \left[\frac{A_c(T_m - T_w)}{W \cdot C_p \cdot (T_i - T_e)} - \frac{1}{\alpha_c} \right] \tag{5}$$

Where, λ_T is the thermal conductivity of the mold, Cp is the specific heat capacity of the mold, Ti is the initial temperature of the high-temperature sheet, Te is the mold exit temperature of the molded part after stamping, Tm is the average temperature of the surface of the mold, α_c is the heat transfer coefficient between the mold and the cooling water, and W represents the weight of the sheet that has been stamped in one hour, which is given by Equation (6):

$$W = \frac{w \times 3600}{t_c} \tag{6}$$

where w is the weight of the sheet and t_c is the cooling time of each molded part.

2.2. *Cooling Waterway Patterns*

In actual production, the penetrating cooling waterway is often used in the hot stamping molds of parts with small size, simple shape and little change, such as the hot stamping mold of the front bumper of an automobile, etc., see Fig. 2. Since the segmented cooling waterway has obvious advantages for the molds with large size and complex shape, it is often used for the parts with complex shape in the actual production, such as the mold of the B-pillar of an automobile, as shown in Fig. 3.

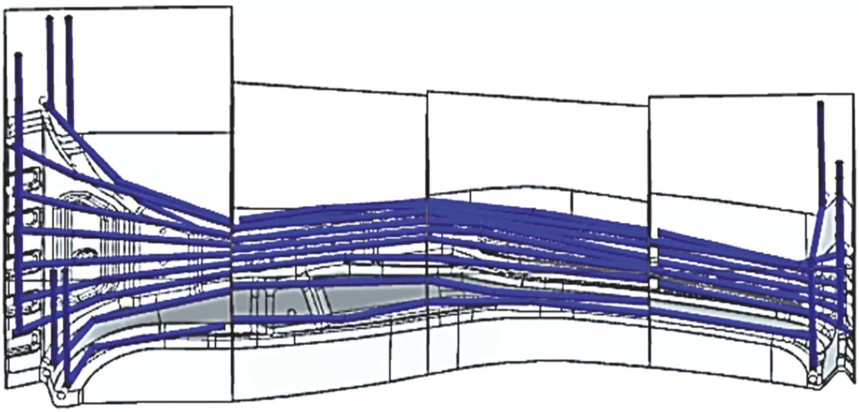

Fig. 2 Schematic diagram of the structure of a through watercourse

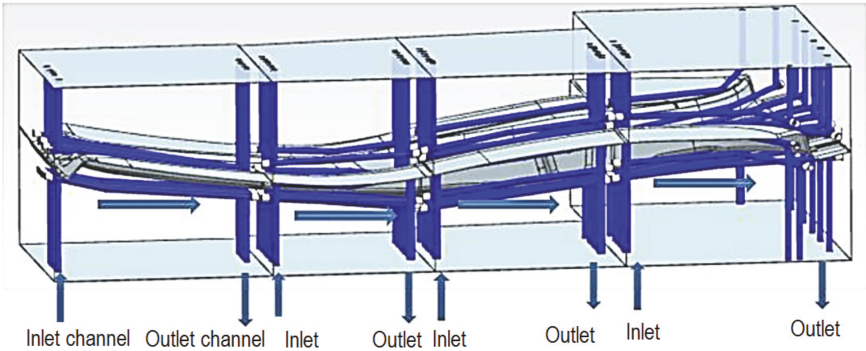

Fig. 3 Schematic diagram of segmented watercourse structure

3. Automated design method of cooling waterway

3.1. *Auxiliary system for waterway design*

The main purpose of studying the cooling design system is to improve the design efficiency and accuracy of the cooling system of the hot stamping die for high-strength steel, leaving a large number of complex numerical calculations and general feature recognition to be completed by the computer, and the designers only need to make certain adjustments and modifications to the results of the automated design of the computer, in order to reduce the complexity of the design of the cooling system of the hot stamping die and to avoid the manual calculations of the designers and reduce the variability of design quality due to the designers' Design level of different design quality variability, so as to improve the overall design efficiency and design quality.

3.2. *Basic functions and framework of cooling design system*

The cooling system of hot stamping die mainly includes two major parts: standard parts and cooling waterway. Among them, the standard parts is to play a connection waterway, water collection, water, water in and out of the function, to prevent cooling water leakage, to ensure that each cooling waterway have enough cooling water flow, generally in the completion of the cooling waterway design according to the specific structure of the waterway and then add the corresponding standard parts, such as Figure 4. while the design of the cooling waterway is the core of the entire cooling system, which mainly includes the transverse cooling waterway, longitudinal in and out of the waterway and waterway plug holes. It mainly includes transverse cooling channels, longitudinal inlet and outlet channels and waterway plug holes, etc. The shape and structure of the cooling waterway largely determines the cooling effect of the mold, therefore, the design quality of the cooling waterway is the key to the quality of the cooling system [5].

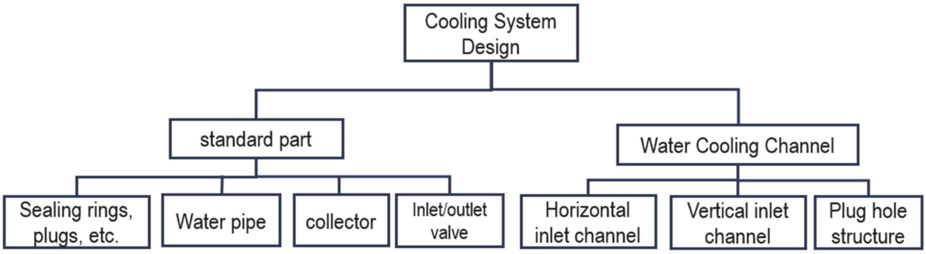

Fig. 4 Hot stamping mold cooling system design framework

According to the characteristics of the top-down design process of cooling waterway, the whole design system is divided into three main modules: the design of cooling waterway line, the detection and fine-tuning of cooling waterway line, and the generation of cooling waterway. When entering the latter two modules, the design results of the previous module are automatically recognized. For example, when entering the detection module of waterway line, it automatically recognizes the waterway line, waterway hole and other information designed by the waterway line design module, on the basis of which it then carries out the detection and fine-tuning design. The flow of the whole cooling design system is shown in Figure 5.

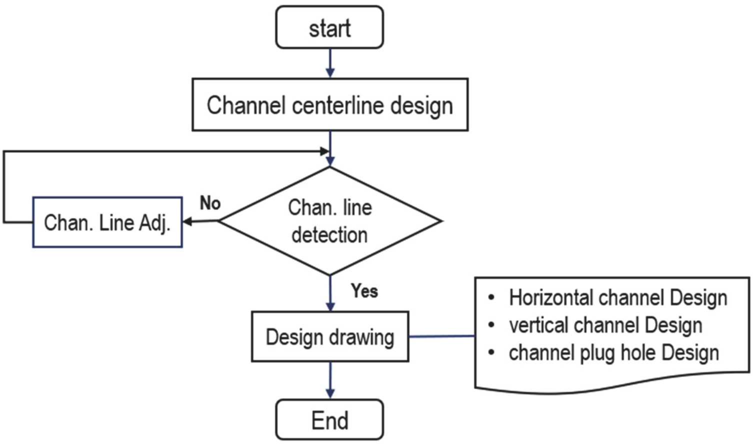

Fig. 5 Cooling system design flow

4. Automated design and software for hot stamping mold cooling system

4.1. *Straight-through cooling waterway line design method*

After selecting the waterway circles on the two faces respectively, if the positions of the two faces are relative, i.e., the distance between the two faces is greater than zero, a straight-through type waterway line is created. The selected waterway circles on the first end face are sequentially sorted according to the positive direction of the arrangement, as shown in Fig. 6 and Fig. 7.

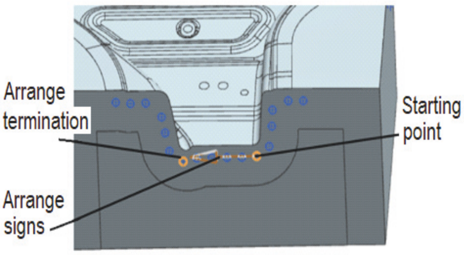

Fig. 6 Straight-through type cooling waterway

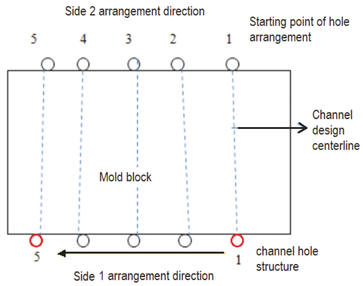

Fig. 7 Design of straight-through type waterway line

4.2. *Design method of T-type cooling waterway centerline*

The key point to create a T-shaped waterway line between two points is to find a suitable location of the turning point as shown in Figure 8. Due to the complexity of the T-type waterway line, it is not easy to follow the shape of the cavity according to the characteristics of the design; at the same time, due to the waterway line can be artificially adjusted to make the design of the waterway line as much as possible in line with the distribution of the temperature field, you can simply use the two-point ray to take the nearest point as a turning point to create the T-type waterway line.

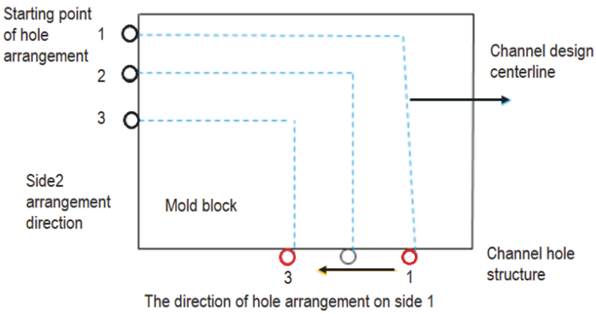

Fig. 8 Schematic design of T-shaped waterway line

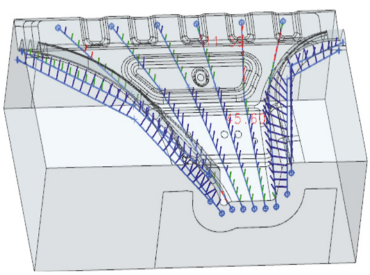

Fig. 9 Results of inspection of automatically generated watercourse lines

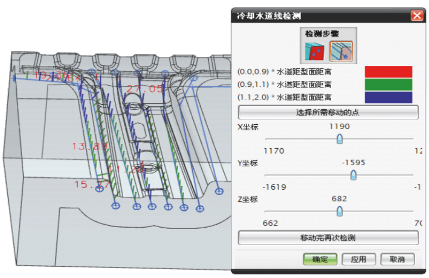

Fig. 10 Manual adjustment of the automatically generated waterway line

The difficulty and core of the design still lies in the design method of the cooling waterway holes, and the design of the hybrid cooling waterway and the arrangement of the waterway lines are shown in Figure 9. According to the triangular arrangement method of the waterway holes, the hybrid cooling waterway is proposed, and finally the waterway line is divided into straight and T-type, and the design methods of the two cooling waterway lines are analyzed.

4.3. *Design of Cooling Water Line Pipe Shape*

The author applies the developed software to enter the cooling water pipe line design dialog box, as shown in Fig. 10, the ways to generate the end face circle are "copying the circle of the adjacent face", "selecting the face to generate directly" and "generating between two points of the edge curve", because it is the first sub-module, the end face circle of the adjacent block has not been designed. "Since this is the first sub-module, the end face circle of the neighboring sub-module has not been designed yet. At the same time, the location of the required water holes is mainly concentrated in the vicinity of the notch on the end face, so the method of "generation between two points of the edge curve" is selected. Then select the end face and then select the start and end points of the generated end face circle on the side curves to generate the waterway circle on the end face, as shown in Figures 11 and 12. Using the "selection of the surface directly generated" approach can be another end of the block to create a waterway circle, the same can be designed in the two sides of the hole structure elements of the waterway circle.

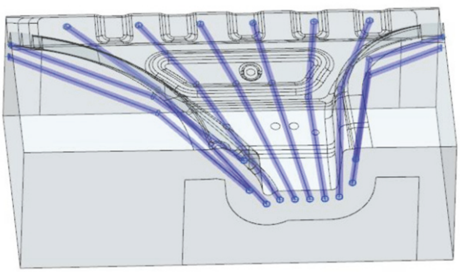

Fig. 11 Automatically generated cooling water channels.

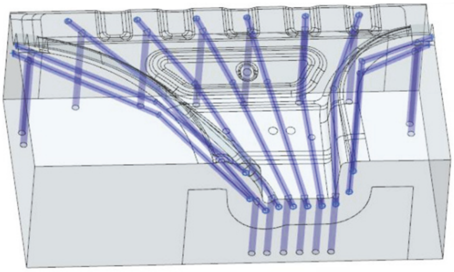

Fig. 12 Longitudinal inlet and outlet waterways generated by supplementary design.

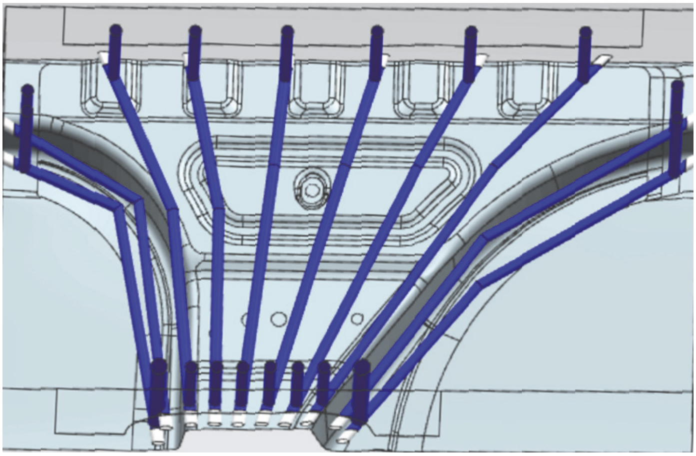

Fig. 13 Computer-aided completion of cooling waterway design.

5. Summary

This paper studies the rapid design method of cooling system and the development of software to realize the rapid deployment of cooling waterways. Combined with the characteristics of hot stamping die cooling system design, the design process of cooling waterway is divided into three main functional parts: the design of cooling waterway holes, the design of cooling waterway lines and the design of cooling waterways. Identify the shape characteristics of the end face of the block through the curvature change of the end face side curve, and then realize the automatic arrangement of the cooling waterway holes according to the triangular arrangement method of the cooling waterway holes. The cooling water channel line is divided into straight-through type and T-type, and the change of distance is judged by using discrete picking points to identify the characteristics of the mold cavity surface, so as to realize the cooling water channel line arranged according to the shape. Preliminary automated design of cooling channels is realized by parametric design technology. Combining the advantages of through-type cooling waterway and block-independent cooling waterway, a hybrid cooling waterway is proposed to meet the cooling waterway design of various types of hot stamping molds.

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