# Multi-cavity Hot Stamping Die Cooling Water Flow Distribution Method Based on Equivalent Water Resistance

D. H. Liu(✉), X. Tang, and Z. C. Xiang

College of Mechanical and Vehicle Engineering, Hunan University, Changsha 410082, Hunan, China
dihuiliu@163.com

**Abstract.** The flow distribution of the cooling channel in the hot stamping mold will directly affect the quality of the formed parts in a mold multi-cavity mold. In the actual hot stamping production, the production workers need to monitor the flow of each inlet in real time, but it is often difficult to determine how the cooling water flow after the water valve regulation is redistributed to the various chambers. In this paper, the equivalent water resistance concept based on the principle of equivalent circuit is proposed, which aims to solve the problem of flow distribution of each cavity in one mode and multiple cavities, and to ensure the uniformity of the mold temperature of the parts after the cavity is formed. Firstly, a database of the relationship between the inlet pressure and the flow characteristics of the simple equivalent pipeline is established; After that, a set of multi-cavity complex molds is selected for analysis to obtain the characteristic relationship between the inlet pressure and the flow rate of the cooling channel; Finally, the characteristic curve of the equivalent pipeline is compared with the pressure flow characteristic curve of the complex waterway to obtain the simple equivalent pipeline corresponding to the multi-cavity mold. Using the hot stamping simulation analysis method, the flow distribution of simple equivalent pipelines is based on the characteristics of tandem waterways.

**Keywords:** Hot forming technology · Multi-cavity mold · The cooling system · Equivalent water resistance · Flow distribution

## 1 Introduction

The lightweight of automobiles can effectively alleviate the problems of excessive energy consumption and automobile exhaust pollution brought about by the industry's vigorous development of China's economy, and the development and application of high-strength steel hot forming parts on automotive body-in-white is one of the main ways to achieve its lightweight at this stage [1]. In particular, the molding method of one mold and multiple cavities has gradually replaced the traditional one-die and one cavity forming method, and there has been a leap forward in the improvement of generation efficiency and the reduction of low manufacturing costs, but the problems have ensued, and the


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mold temperature of the parts in each cavity varies greatly [2]. At the time of the total flow rate, how to reasonably match the flow rate of each cavity with the flow rate required for the forming and quenching of the cavity parts is a big problem.

In recent years, a number of researchers have extensively studied the influence of parallel pipeline system on flow distribution law and pressure distribution by numerical analysis method and discretization mathematical model, and the results show that the layout type of parallel pipeline has no significant effect on the static pressure distribution of the overall header. When the pressure difference between the inlet and outlet is consistent, the change in pipe diameter has a greater impact on the flow distribution [3–6]. Lim et al. proposed multiple methods to design the cooling channel of hot stamping molding dies, and used the finite element method to verify their cooling performance and cooling uniformity [7–10]; Yang and others have studied the cooling system of the hot forming mold, and show that the cooling performance of the hot form mold is mainly determined by the design form of the conformal cooling channel and the size of the water channel inlet flow [11–13]. Li et al. explored the factors that mainly affect the cooling performance of the hot forming mold in the cooling system, and analyzed in detail the effect of the diameter, spacing and gap between the mold surface on the cooling effect [14, 15].

In the hot forming process, the cooling system plays a decisive role, and a good cooling system can ensure that in the production operation with a certain workload and continuousity, the cooling rate of the hot forming mold can completely convert the high-strength steel sheet from austenite to martensitic within a controllable range to ensure the mold temperature, so as to ensure the strength and micro-structure uniformity requirements of the sheet [16]; On the basis of considering the strength of the mold, Lv et al. created a selection criterion for the cooling channel parameters of the hot stamping die, and simulated the cooling channel performance of the established model, and obtained that the cooling channel with smaller diameter had better uniformity [17].

In the cooling channel structure of the multi-cavity hot stamping die, a water valve regulating the flow is installed on each outer pipe, and the cooling water flow into each cavity can be coordinated through flow monitoring to ensure that the parts with different thicknesses, sizes and shapes in each cavity can meet the forming standards in the same quenching time. In actual production, there are commissioning personnel who cannot determine the required flow rate that enters each cavity after distribution through the inlet, and cannot clarify the water valve and the amount of regulation of the valve, which forms the phenomenon that the water valve cannot play a role in the cooling channel of the hot stamping die. In order to ensure that each chamber cooling channel has the cooling rate required for forming parts, in the same holding time, this article will combine the working characteristics of the pump and distribute the cooling water flow according to the water resistance characteristics of each cavity cooling channel.

## 2 Equivalent Water Resistance

Based on the principle of equivalent resistance: without affecting the change of voltage and loop current strength at both ends of the original circuit loop, a single resistor is used instead of multiple resistors working together in the same circuit system. By establishing a database, the role of the cooling channel in the hot stamping in the insert is equivalent to a simple pipeline under the sole action, and the connection between the insert and the insert is equivalent to the series and parallel mode in the form of a circuit, so that the flow rate between the various inserts can be obtained more quickly and accurately.

The pressure and flow in the hot stamping die waterway are compared to the voltage and current in the circuit. The resistance present in the circuit is analogous to the pressure loss in the cooling channel; There is a voltage difference in the current flowing through the resistor, which is analogous to the voltage drop that exists when the cooling water flows through the variable cross-section; When the circuit is not smooth, for example, the local resistance increase caused by poor contact is analogous to the local resistance increased when the cooling pipe is blocked and the pressure difference increases. Therefore, the preliminary qualitative analysis of the thermoforming cooling channel can be compared to the traditional circuit analysis.

### 2.1 Concept of Equivalent Water Resistance

Based on the equivalent resistance theory, it can be seen that in the series state, the equivalent resistance value is equal to the sum of each series resistance, and the more series resistance, the greater the equivalent resistance. The water flow in the hot forming cooling channel is the same as the current here, and ideally the loss of resistance along the way is not considered, the flow through the first water pipe is equal to the flow rate into the second water pipe, and the flow rate into the water pipe is equal to the flow rate of the outflow pipe (Fig. 1).

In contrast, in parallel, the reciprocal of the equivalent resistance is equal to the sum of the reciprocal values of each parallel resistance, and the more parallel resistance, the smaller the equivalent resistance. The water flow in the hot forming cooling channel is the same as the current situation here, after increasing the parallel waterway, the total flow of the inlet is divided into multiple channels, so the water resistance of the branch road can be appropriately selected, so that each branch can obtain the required flow size. By analogizing the characteristics of a shunt circuit, the cooling water flow of a multi-cavity mold can be distributed (Fig. 2).

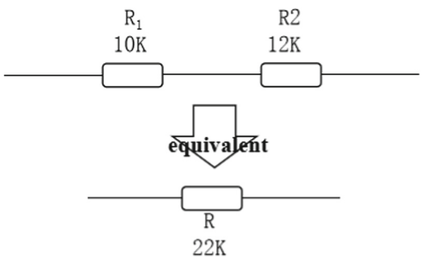



**Fig. 1.** Series circuit equivalent diagram.

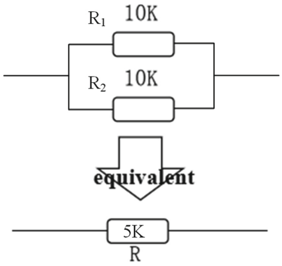


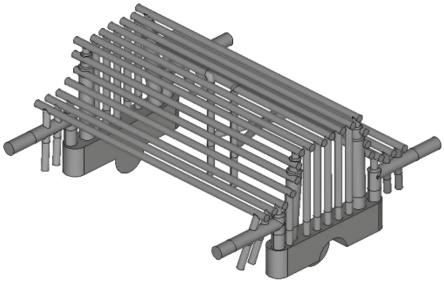

**Fig. 2.** Parallel circuit equivalent diagram.

## 2.2 Equivalent Water Resistance Method

Based on the theoretical basis of the series parallel resistance in the equivalent circuit, the cooling channel flow rate of the multi-cavity hot stamping die is adjusted. For multiple inserts of a single-cavity mold, the number of cooling channels between the inserts and the inserts is usually the same, the difference is that the complexity of the arrangement of the cooling channels in each block will change according to the complexity of the mold surface; And the flow rate into the single-chamber mold inlet is the same as the flow rate through the whole cavity cooling channel, and is equal to the flow rate that finally flows out of the mold outlet. In terms of the cooling water flow characteristics of the single cavity of the hot stamping die, it is in line with the current characteristics of the voltage across the constant circuit between the series circuits in the circuit.

The method of equivalent water resistance proposed in this paper is essentially to equate the cooling circuit formed by connecting multiple pipes with high complexity and difficult to deal with in the hot forming mold as a single pipe with the same cooling effect and simple and easy to handle. In the hot stamping cooling system, the pressure loss of the cooling channel is mainly reflected in the resistance along the distance generated between the inner wall of the pipeline and the fluid, and the local pressure loss caused by the sudden change of flow direction caused by the different connection structures between adjacent pipes. The method of equivalent water resistance is to use the relationship between the inlet pressure of the cooling pipe in the mold and the flow rate in the cooling pipe, and the complex waterway Fig. 3(a) is equivalent to the simple pipeline of Fig. 3(b).

In the actual hot forming production, one or two pumps usually provide the pressure and flow required for the cooling channel in the mold, and in order to ensure the flow requirements of each cooling water circuit on the multi-cavity mold, it is necessary to adjust the valve. Otherwise, the flow rate of each cooling circuit in the mold cannot be guaranteed, resulting in inconsistent cooling rates of the mold up and down the single cavity. Using the equivalent water resistance method, multiple simple pipes of different diameters can be connected in series to cooling water pipes in hot stamping dies with different degrees of equivalent complexity.



(a) Complex waterway pipelines

(b) Equivalent pipelines

**Fig. 3.** Equivalent water resistance method.

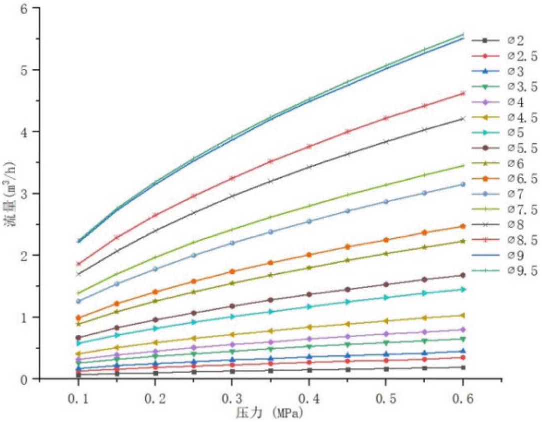
## 3 Establishment of an Equivalent Water Pipe Model

Based on the parameters provided by a company's actual press hardening, there are two pumps in production that provide pressure and flow, providing a rated flow rate of 45 $m^3$/h and a pressure of 0.5 MPa. According to the size of the actual cooling channel in the mold, the diameter of the inlet and outlet of the equivalent water pipe is determined to be 33.3 mm, the length is 47 mm, and the length of the intermediate pipe is the general length of the inner surface pipe of the single block of the hot forming mold, that is 200 mm. Establish a test model of 53 simple pipes covering the diameter of the middle section pipe 2 mm–28 mm, and the diameter is increased by a gradient of Ø0.5 mm, and the equivalent water pipe model is shown in Fig. 3(b).

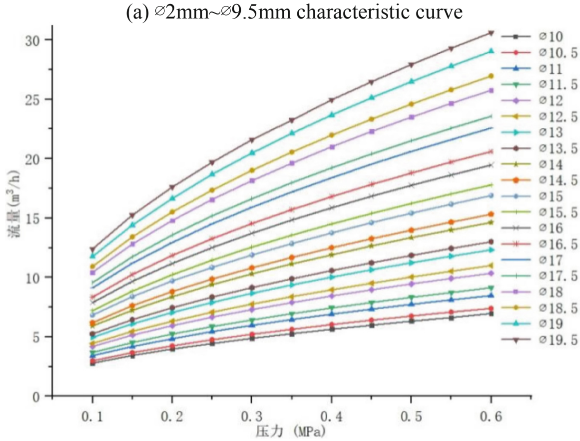
## 4 The Inlet Pressure of the Equivalent Water Pipe Related to the Flow Characteristics

The equivalent water pipe model is based on the relationship between the inlet pressure of the cooling pipe and the flow rate of the cooling pipe. Using ANSYS Fluent fluid simulation software, 11 values are taken as the inlet pressure of the equivalent water pipe inlet in increments of 0.1 MPa to 0.6 MPa in increments of 0.05 MPa, and the cooling water flow can be obtained by the equivalent water pipe under different inlet pressures. The relationship characteristics of the inlet pressure and cooling water flow of 53 equivalent water pipes are obtained as shown in Fig. 4.

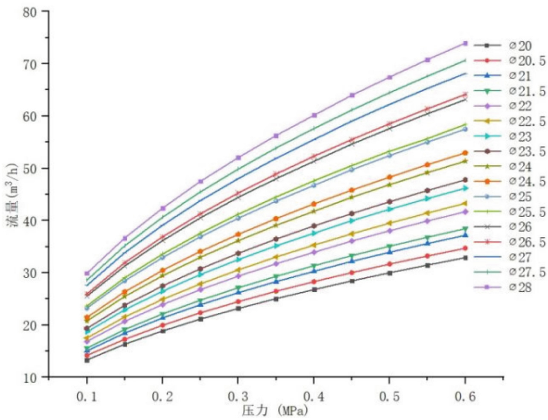
From the characteristic curves of the inlet pressure of the equivalent water pipe and the cooling water flow, it can be seen that there is a linear relationship between the inlet pressure of the equivalent water pipe and the cooling water flow, and the cooling water flow gradually increases with the increase of the equivalent water pipe inlet pressure. At the same inlet pressure, the cooling water flow increases with the increase in diameter of the intermediate pipe of the equivalent water pipe. At the same time, it can be intuitively




(a) ⌀2mm~⌀9.5mm characteristic curve




(b) ⌀10mm~⌀19.5mm characteristic curve




(c) ⌀20mm~⌀28mm characteristic curve

**Fig. 4.** Equivalent water pipe inlet pressure and cooling water flow characteristics curve.

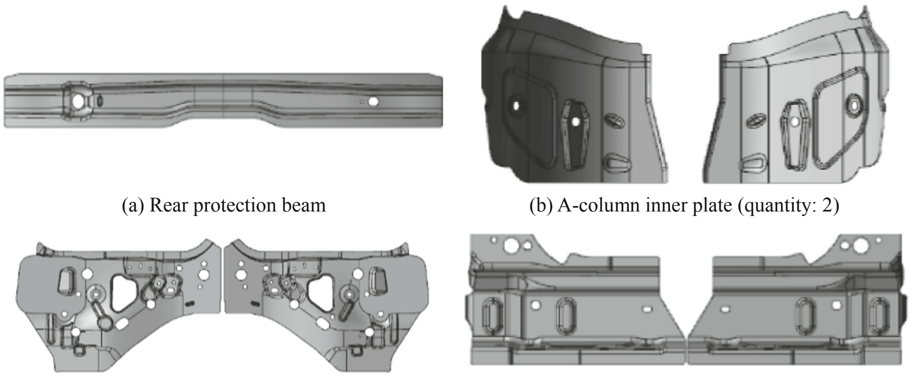
obtained that the same cooling water flow does not exist under the same inlet pressure value under different equivalent channel intermediate pipe diameters.

Therefore, when analyzing the cooling channel of any complex structure in the actual hot stamping production, the corresponding flow value can be obtained by the given inlet pressure value, and the equivalent pipe size of the complex waterway can be obtained according to the equivalent pipeline pressure and flow characteristic curve of Fig. 4.

# 5 Cooling Channel Flow Distribution Based on Equivalent Water Pipes

## 5.1 Multi-cavity Hot Stamping Die Model

This paper takes four hot stamping parts of automobile body as the research object, which are bumper rear beam, A-pillar inner plate, longitudinal beam reinforcement plate and connecting plate respectively. The parts with small area are symmetrical parts, and the thickness and area of the parts in the four cavities are relatively uniform, which can ensure the same quenching time and meet the cooling requirements of all parts. The appearance dimensions and placement of the four parts are shown in Fig. 5; The specific dimensions are shown in Table 1.



(a) Rear protection beam

(b) A-column inner plate (quantity: 2)

(c) Stringer reinforcement plate (quantity: 2)

(d) Connection plates (quantity: 2)

**Fig. 5.** The appearance and placement of the four-chamber part.

**Table 1.** Specific dimensional parameters of the part.

| Parts (quantity) | Rear protection beam | A-pillar inner plate (2) | Longitudinal Beam Reinforcement Plate (2) | Connection Plates (2) |
|---|---|---|---|---|
| Thickness (mm) | 1.6 | 1.5 | 1.5 | 1.6 |
| Area ($mm^2$) | 248679 | 154847 | 160889 | 155389 |

### 5.2 The Upper Mold Cooling Channel is Equivalent

The four-cavity upper mold cooling waterway model is simplified, considering that the forming of the three parts of the post-security beam, the A-column inner plate and the connecting plate is prone to plate deviation, so it designed the press block structure in the mold, and divided the water channel of the press block part into waterways 2, 6 and 10. The longitudinal beam reinforcement plate ensures its accurate position through the positioning hole and positioning pin of the sheet. Finally, the simplified waterway of each cavity cooling channel is shown in Fig. 6. Below, and waterways 1, 2 and 3 are the mold cooling pipes on the rear protection beam, waterways 4 and 5 are mold cooling pipes on the inner plate of column A, waterways 7 and 8 are mold cooling pipes on the longitudinal beam reinforcement board, and waterways 9, 10 and 11 are the mold cooling pipes on the connecting plate.

By using the same pressure flow analysis method as the equivalent pipeline, the simplified waterway can be analyzed to obtain the relationship between the inlet pressure and flow characteristics of the upper mold cooling channel, as shown in Table 2.

By comparing the inlet pressure and flow characteristic curve of the four-cavity waterway in the upper mold with that of the equivalent pipeline, the waterway which is closest to each waterway characteristic curve can be found in the equivalent pipeline characteristic database curve, which can be equivalent to the equivalent pipeline. The specific dimensions of the pipe equivalent to each waterway of the upper mold are finally obtained: waterway 1 can be equivalent to the pipeline Ø13 mm, waterway 2 can be equivalent pipe Ø4.5 mm, waterway 3 can be equivalent pipe Ø13 mm, waterway 4 can be equivalent pipe Ø13 mm, waterway 5 can be equivalent pipe Ø12 mm, waterway 6 can be equivalent pipe Ø14 mm, waterway 7 can be equivalent pipe Ø16 mm, waterway 8 can be equivalent pipe Ø14 mm, waterway 9 can be equivalent pipe Ø14.5 mm, waterway 10 can be equivalent pipe Ø11.5 mm, waterway 11 can be equivalent pipe Ø15.5 mm.

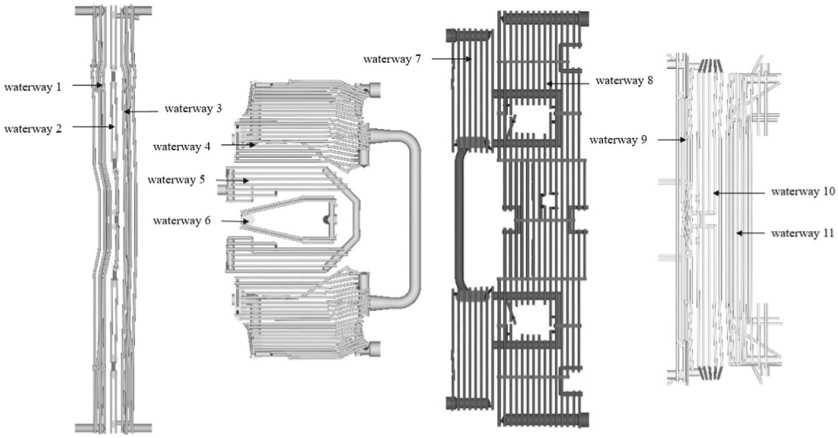



**Fig. 6.** Four-cavity mold on the mold waterway.

**Table 2.** Upper mold waterway inlet pressure and flow characteristics.

| Inlet pressure (MPa) | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Waterway 1 ($m^3/h$) | 4.84 | 6.06 | 6.91 | 7.75 | 8.51 | 9.21 | 9.87 | 10.48 | 11.06 | 11.62 | 12.15 |
| Waterway 2 ($m^3/h$) | 0.42 | 0.52 | 0.61 | 0.68 | 0.75 | 0.81 | 0.87 | 0.92 | 0.97 | 1.02 | 1.07 |
| Waterway 3 ($m^3/h$) | 4.93 | 5.93 | 6.86 | 7.88 | 8.42 | 9.12 | 9.74 | 10.35 | 10.92 | 11.46 | 11.98 |
| Waterway 4 ($m^3/h$) | 4.91 | 6.07 | 7.01 | 7.85 | 8.63 | 9.34 | 10.00 | 10.62 | 11.21 | 11.73 | 12.25 |
| Waterway 5 ($m^3/h$) | 4.22 | 5.18 | 5.98 | 6.71 | 7.36 | 7.97 | 8.53 | 9.05 | 9.54 | 10.01 | 10.46 |
| Waterway 6 ($m^3/h$) | 5.70 | 6.99 | 8.09 | 9.08 | 9.98 | 10.73 | 11.54 | 12.22 | 12.87 | 13.53 | 14.18 |
| Waterway 7 ($m^3/h$) | 5.76 | 7.10 | 8.25 | 9.27 | 10.21 | 11.04 | 11.80 | 12.59 | 13.28 | 13.91 | 14.54 |
| Waterway 8 ($m^3/h$) | 7.78 | 9.58 | 11.09 | 12.43 | 13.65 | 14.76 | 15.81 | 16.78 | 17.71 | 18.59 | 19.42 |
| Waterway 9 ($m^3/h$) | 6.24 | 7.69 | 8.92 | 10.01 | 10.99 | 11.90 | 12.74 | 13.53 | 14.29 | 15.00 | 15.69 |
| Waterway 10 ($m^3/h$) | 3.48 | 4.29 | 4.97 | 5.58 | 6.13 | 6.65 | 7.71 | 7.56 | 7.98 | 8.38 | 8.76 |
| Waterway 11 ($m^3/h$) | 7.38 | 9.10 | 10.55 | 11.84 | 13.00 | 14.07 | 15.08 | 16.02 | 16.92 | 17.74 | 18.54 |

### 5.3 The Lower Mold Cooling Channel is Equivalent

The model of the four-cavity lower die cooling channel is simplified. The lower die belongs to the fixed die, so there is no need to consider the division rules too much. It can be simplified directly according to the circulation logic of the cooling channel, as shown in Fig. 7.

Also according to the analysis method of the upper mold simplified waterway, Table 3 of the inlet pressure and flow characteristics of the lower mold waterway is obtained.

By comparing the inlet pressure and flow characteristic curve of the four-cavity waterway of the lower mold with the inlet pressure and flow characteristic curve of the equivalent pipeline, it can be obtained: waterway 12 can be equivalent to the pipeline Ø16mm, waterway 13 can be equivalent to the pipeline Ø13.5mm, waterway 14 can be equivalent to the pipeline Ø12mm, waterway 15 can be equivalent to the pipeline Ø15.5mm, waterway 16 can be equivalent to the pipeline Ø13.5mm, waterway 17 can be equivalent to the pipeline Ø20mm.

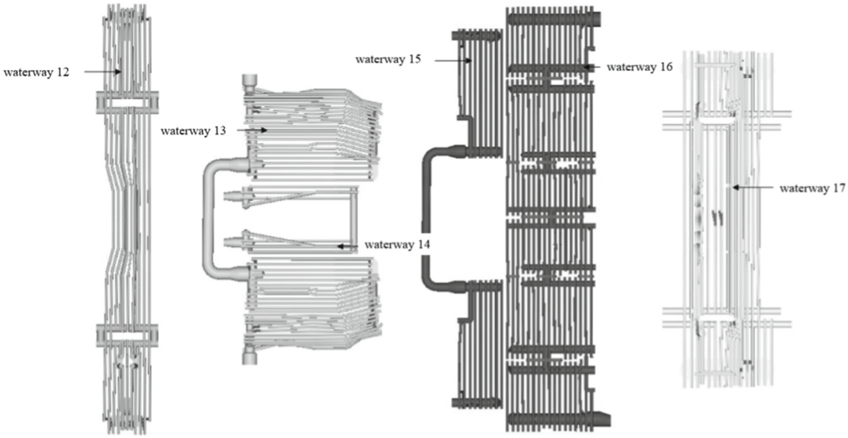



**Fig. 7.** Four-cavity mold under the mold waterway.

**Table 3.** Lower mold waterway inlet pressure and flow characteristics.

| Inlet pressure (MPa) | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Waterway 12 ($m^3$/h) | 7.81 | 9.62 | 11.15 | 12.51 | 13.73 | 14.86 | 15.92 | 16.90 | 17.89 | 18.72 | 19.63 |
| Waterway 13 ($m^3$/h) | 5.26 | 6.41 | 7.41 | 8.30 | 9.11 | 9.86 | 10.52 | 11.18 | 11.83 | 12.41 | 13.16 |
| Waterway 14 ($m^3$/h) | 3.92 | 4.81 | 5.58 | 6.26 | 6.87 | 7.43 | 7.94 | 8.44 | 8.91 | 9.35 | 9.77 |
| Waterway 15 ($m^3$/h) | 7.27 | 8.94 | 10.34 | 11.58 | 12.71 | 13.74 | 14.70 | 15.62 | 16.48 | 17.27 | 18.04 |
| Waterway 16 ($m^3$/h) | 5.46 | 6.52 | 7.76 | 8.69 | 9.52 | 10.30 | 11.02 | 11.72 | 12.39 | 12.97 | 13.56 |
| Waterway 17 ($m^3$/h) | 13.23 | 16.32 | 18.91 | 21.23 | 23.28 | 25.18 | 26.99 | 28.62 | 30.24 | 31.74 | 33.20 |

### 5.4 Multi-cavity Mold Cooling Channel Equivalent

Through the above method, the cooling channel of the complex multi-cavity hot stamping die can be simplified and analyzed, and is equivalent to a simple channel. After the upper and lower 17 channels of the mold are equivalent, the overall channel structure is shown as the Figs. 8 and 9:

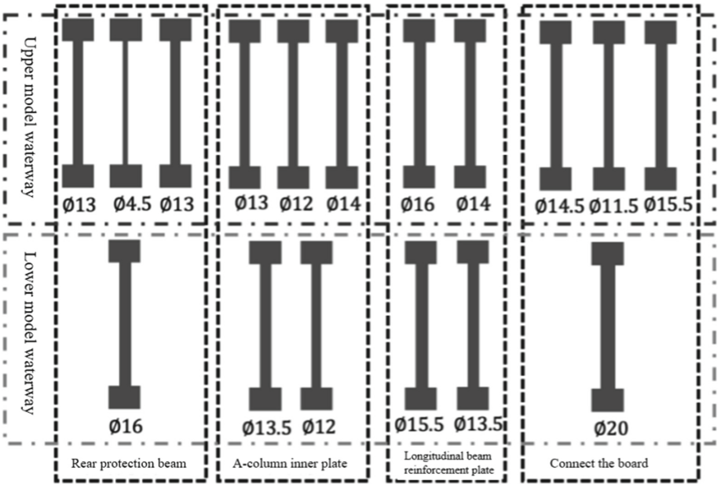
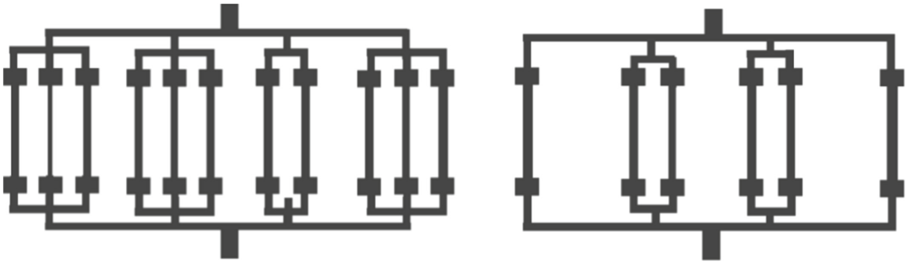



**Fig. 8.** Four-cavity mold overall waterway equivalent diagram.



(a) Upper mold waterway (b) Lower mold waterway

**Fig. 9.** Overall connection diagram

### 5.5 Multi-cavity Mold Flow Distribution Method

According to the above analysis results, the total flow rate required for each cavity of the four-cavity upper and lower mold can be calculated, and the curve of the inlet pressure can be fitted, and the mathematical model of the flow distribution can be obtained as $Q(p_i) = k_0 + k_1 p_i + k_2 p_i^2$, of which, $k_0$, $k_1$, $k_2$ is the fitting constant. According to the characteristics of the pump in actual production, the total flow rate of the cooling channel inlet $Q_p$ is 85 $m^3/h$, and its working pressure is 0.06 MPa. After the determined working pressure is substituted into the mathematical model of the flow distribution of the four-cavity upper and lower molds, the total cooling water flow required for each cavity can be obtained. For the multi-cavity hot stamping die, the analysis method proposed in this paper can obtain the cooling water flow distribution as shown in Table 4.

**Table 4.** Four-chamber cooling water flow distribution table.

| Part type | Rear protection beam | A-pillar inner plate | Longitudinal Beam Reinforcement Plate | Connection Plates |
|---|---|---|---|---|
| Upper mold cooling water flow ($m^3$/h) | 8.75 | 12.66 | 11.52 | 14.45 |
| Lower mold cooling water flow ($m^3$/h) | 6.85 | 7.89 | 10.84 | 11.30 |

Function of inlet pressure and cooling water flow of the upper and lower mold cooling pipes of the rear protection beam:

$$Q_{up} = 6.102 + 45.560p - 23.219p^2 \tag{5.1}$$

$$Q_{low} = 4.582 + 38.863p - 18.326p^2 \tag{5.2}$$

A-column inner plate, lower mold cooling pipe inlet pressure and cooling water flow function:

$$Q_{up} = 8.723 + 67.758p - 35.329p^2 \tag{5.3}$$

$$Q_{low} = 5.539 + 40.436p - 19.646p^2 \tag{5.4}$$

Longitudinal beam reinforcement plate, under the mold cooling pipe inlet pressure and cooling water flow function:

$$Q_{up} = 7.869 + 62.869p - 32.821p^2 \tag{5.5}$$

$$Q_{low} = 7.456 + 58.292p - 30.597p^2 \tag{5.6}$$

Connection plate, lower mold cooling pipe inlet pressure and cooling water flow function:

$$Q_{up} = 9.747 + 80.975p - 43.319p^2 \tag{5.7}$$

$$Q_{low} = 7.754 + 60.994p - 31.548p^2 \tag{5.8}$$

# 6 Simulation Analysis Results

## 6.1 The Influence of Flow Distribution Before and After on the Flow Rate of the Part

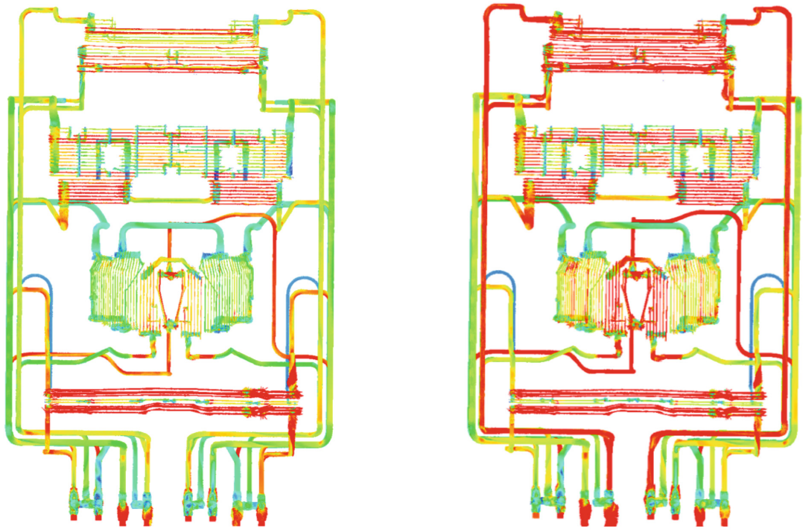
For the one-die four-cavity hot stamping model, Hypermesh is used for geometric preprocessing of its cooling channels and grid division, and ANSYS Fluent was used to perform fluid simulation analysis of its cooling channels. According to the maximum flow rate of 85m$^3$/h that can be provided by the actual production, the maximum flow rate assigned to each inlet of the mold is 10.625 m$^3$/h, that is, the boundary condition of the inlet in fluent is set before the flow distribution; after the flow distribution, the boundary condition is set according to the flow rate obtained by the 5.5. Equivalent water resistance method. After simulation analysis, the comparison diagram of the mold cooling channel flow field before and after the flow distribution is shown in Fig. 10.

According to the actual production situation, the cooling water flow rate of the hot stamped parts with a thickness of less than 2 mm is 3 m/s as the criterion. From the above figure, it can be seen that the total flow rate of the upper die increased as a whole after the flow distribution, and the uneven distribution of the pipeline flow rate was improved, and the flow rate for the rear braid beam was reduced by 1.875 m$^3$/h compared with before the distribution. The total flow of the lower mold pipe after the flow distribution is reduced as a whole, the inlet flow of the single-cavity longitudinal beam reinforcement plate and the connection plate has increased, the pipeline flow rate has been improved, and the inlet flow rate of the A-column inner plate and the rear-security beam lower die pipeline has decreased relative to before the distribution, but the overall flow rate of the A-column inner plate can still be maintained at 2.5 m/s–3 m/s. Compared with the heat transfer coefficient of the upper and lower dies before the flow distribution, the heat transfer coefficient is more uniform.

## 6.2 The Influence of Flow Distribution on Part Temperature Before and After Distribution

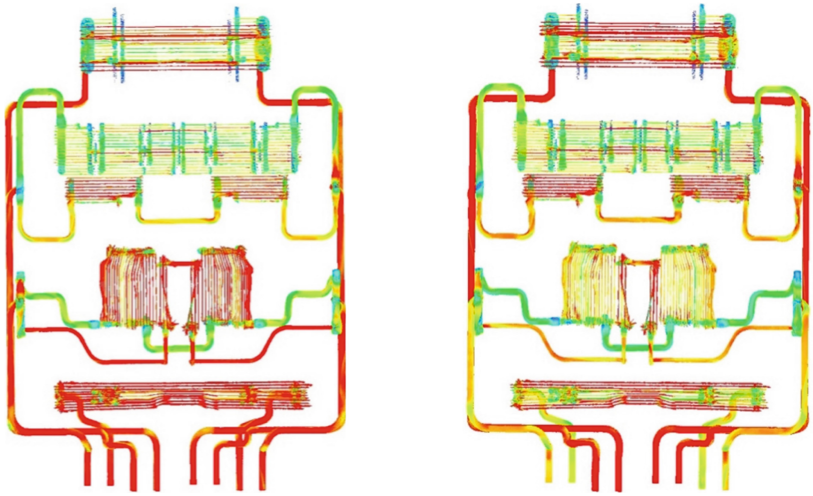
The convective heat transfer coefficient corresponding to the pipe wall was obtained through the analysis of the pipe flow rate. The fluid-structure coupling analysis method and the LS-DYNA software were used to numerically analyze the forming and quenching process of the four-cavity parts, and the temperature distribution of the mold and sheet before and after the flow distribution is obtained as shown in the following Fig. 11:

As can be seen from the above figure, changing the cooling water inlet flow of the four-cavity mold can effectively reduce the mold temperature of the formed parts and improve the temperature uniformity of the overall parts. Under the premise of ensuring that the cooling rate and mold outlet temperature of the rear security beam are qualified, the maximum temperature of the rear security beam has increased by 6.5 °C; the overall temperature of the A-column inner plate, the longitudinal beam reinforcement plate and the connection plate has been reduced, and the temperature distribution has been more uniform; Among them, the maximum temperature of the inner plate of the A column drops by 7.2 °C, the maximum temperature of the stringer reinforcement plate drops by 13 °C, and the maximum temperature of the connecting plate drops by 15.6 °C.



(a) Flow velocity distribution of the upper die pipe before flow distribution

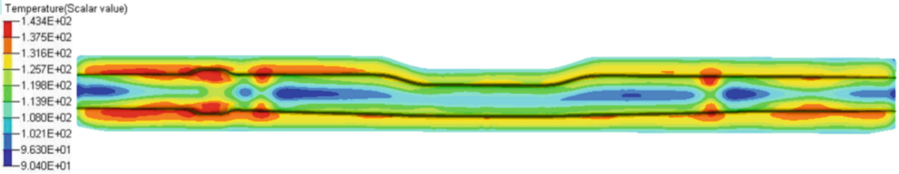
(b) Flow velocity distribution of the upper die pipe after flow distribution



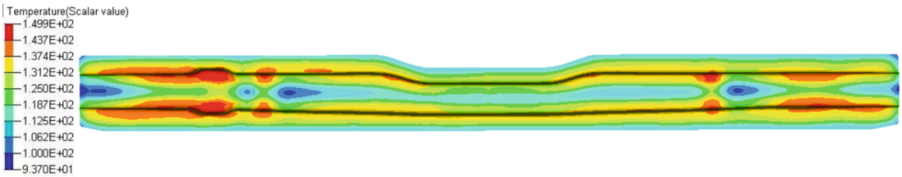
(c) Flow velocity distribution diagram of the lower mold pipe before flow distribution

(d) Flow velocity distribution diagram of the lower mold pipe after flow distribution

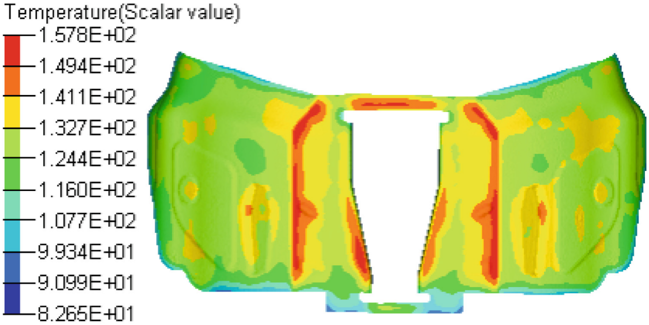
**Fig. 10.** Flow velocity distribution diagram before and after four-cavity mold flow distribution.



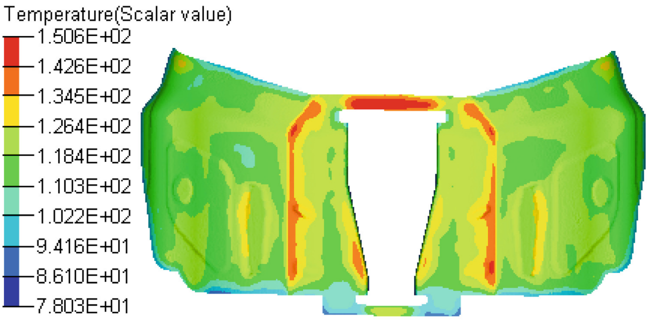

(a) Cloud map of the temperature of the beam before and after the flow distribution



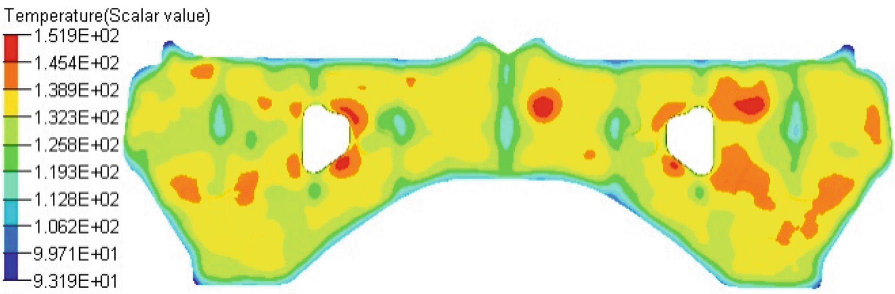

(b) Cloud map of the temperature of the beam after and after the flow distribution




(c) Cloud map of the temperature of the inner plate of the A column before the flow distribution

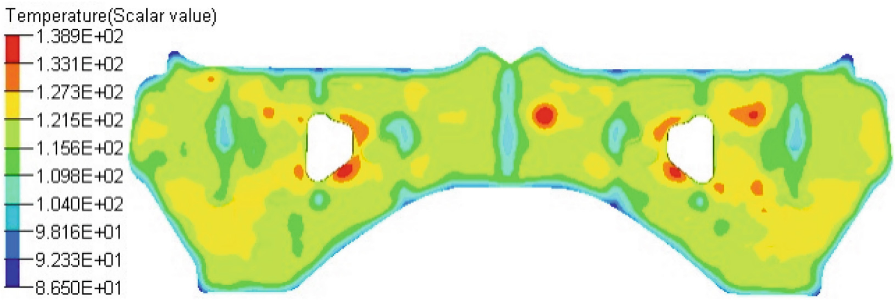



(d) Cloud map of the temperature of the inner plate of the A column after the flow distribution

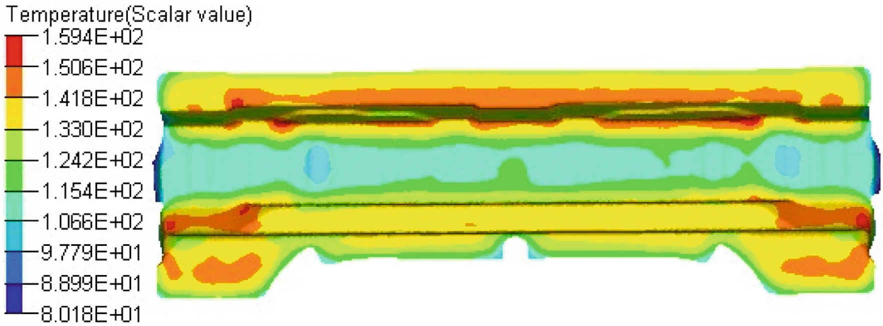



(e) Temperature cloud map of the reinforcement plate of the stringer before the flow distribution

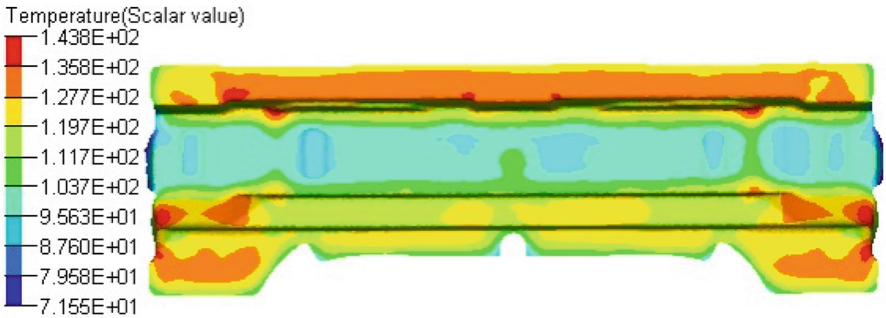
**Fig. 11.** Temperature cloud diagram of each cavity part before and after flow distribution.




(f) Temperature cloud map of the reinforcement plate of the stringer after the flow distribution




(g) Connect the plate temperature cloud graph before traffic distribution




(h) Connect the plate temperature cloud graph after traffic distribution

**Fig. 11.** (*continued*)

## 7 Conclusion

The In this paper, based on the theory of series parallel connection in equivalent circuits, this paper proposes an equivalent water resistance method for the flow distribution regulation of the cooling channel of the hot forming mold.

(1) The concept of equivalent water resistance is proposed, and the complex pipe in a single block is equivalent to a simple pipe with the same pressure drop effect according to the pressure drop characteristics inside the mold cooling channel.
(2) Based on the resistance characteristics in the hot stamping die cooling pipe, an equivalent waterway database was established by using ANSYS Fluent to analyze the

relationship between the inlet pressure and flow characteristics of simple pipelines. For the arbitrary complex multi-cavity mold cooling channel, simplify its waterway and match the equivalent waterway in the database, simplify the simulation calculation, and obtain a reasonable cooling water flow distribution.

(3) Through the joint simulation of ANSYS Fluent and LS-DYNA, a more complex set of one-mode four-cavity body parts were selected for analysis, and the mold temperature of the four-cavity parts simulated according to the flow redistribution method was finally improved. Among them, the maximum temperature of the rear-retaining beam increased by 6.5 °C to meet the requirements of the cooling rate and mold outlet temperature of the parts, and the maximum temperature of the A-column inner plate, the longitudinal beam reinforcement plate and the connecting plate decreased by 7.2 °C, 13 °C and 15.6 °C, respectively. The overall temperature distribution is more uniform while reducing the surface temperature of the part, thus verifying the feasibility of the multi-cavity hot stamping die cooling water flow distribution method based on equivalent water resistance.

## References


1. F. F, Guo, Analysis of research status of research on cooling system of hot stamping tools, *Henan Science and Technology* **29**, 60 (2019) (in Chinese).
2. D. H. Liu, A method for calculating the working flow rate of each cavity of thermoforming mold, *CN111159873A*, 2020–05–15 (Zhejiang Province).
3. J. He, Numerical Analysis of the fliow distribution in multiple branches parallel-tube configuration, Master thesis, Lanzhou Jiaotong University (2014).
4. M. Liu, D. A. Deng and Y. Q. Liu, Multiple Branch Pipe Flow Distribution System Research and Application, *China Academic Journal Electronic House Chinese Aeronautical Society*, 2017.
5. Y. Bie, M. F. Hu, W. Y. Mao and J. H. Chang, Machematical Model for Uniform Flow Distribution in Manifolds, *Journal of Power Engineering* **31**, 279 (2011).
6. Z. H. Chen and Z. S. Zhao, Theory and calculation of the flow distribution and thermal deviation of single-phase fluids in parallel pipe sets, *Boiler Technology* **10**, 2 (1974).
7. W. Lim, H. Choi, S. Ahn and B. Kim, Cooling channel design of hot stamping tools for uniform high-strength components in hot stamping process, *The International Journal of Advanced Manufacturing Technology* **70**, 1189 (2014).
8. Z. Taha, A. R. Yusoff, M. F. M. Sharif, M. A. H. Saharudin and M. F. Zamri, Comparison of Cooling Performance between High Thermal Conductivity Steel (HTCS 150) and Hot Work Tool Steel (SKD 61) Insert for Experimental Tool Using Finite Element Analysis, *Advanced Materials Research* **3011**, 163 (2014).
9. M. F. Zamri and A. R, Yusoff, Heuristic design of U-shaped die cooling channel for producing ultra-high strength steel using hot press forming, *The International Journal of Advanced Manufacturing Technology* **97**, 4101 (2018).
10. S. Yun, J. Kwon, W. Cho, D. Lee and Y. Kim, Performance improvement of hot stamping die for patchwork blank using mixed cooling channel designs with straight and conformal channels, *Applied Thermal Engineering* **165**, 1 (2020).
11. X. C. Yang, Research Cooling System of Hot Forming Tools, Master thesis, Jilin University (2015).

12. B. He, Research on Improvement of Hot Stamping Process and Optimization Design of Conformal Cooling Channels in Hot Stamping Die, Phd thesis, Dalian University of Technology (2017).
13. X. D. Xian, Fast Design Method of Cooling System of Hot Stamping Die for High Strength Steel, Master thesis, Huazhong University of Science and Technology (2015).
14. Y. Li, The Optimization Design of Cooling System in Hot Stamping Dies, Master thesis, Dalian University of Technology (2013).
15. X. Shang and L. J. Pang, Optimization Design of Insert Hot Stamping Die's Cooling System and Research on the Microstructural Uniformity Control of Martensitic Phase Transitions in Synchronous Quenching Process, Advances in Materials Science and Engineering, 7621764 (2020).
16. A. Turetta, S. Bruschi and A. Ghiotti, Investigation of 22MnB5 formability in hot stamping operations, *Journal of Materials Processing Technology* **177**, 1 (2006).
17. M. M. Lv, Z. W. Gu, X. Li and H. Xu, Optimal Design for Cooling System of Hot Stamping Dies, *The Iron and Steel Institute of Japan* **56**, 2250 (2016).