Research and application of direct water cooling system for hot stamping of high strength steel automobile integrated door ring

Miyin Dan†, Xiao Wang, Jian Hu and Linfeng Li
Chongqing Zhixin Industrial Co., Ltd., Chongqing 401123, China
**Email: danmiyin@zhixin.asia*

In this paper, a kind of water direct cooling processing device and method for high-strength automobile integrated door rings are proposed. By directly contacting water with high-temperature parts, the device can instantly vaporize water and generate air flow, so as to accelerate cooling and reduce the pressure holding time of hot stamping die. This device can effectively improve the cooling effect of complex parts, save the loading process and improve the body strength. In the specific implementation process, the combination of direct water-cooling structure and circulating water structure is adopted, and the water spraying time and amount are controlled through the air control structure, so as to realize the accurate cooling of parts. The device has the advantages of simple structure, safe operation, good cooling effect, etc., and is suitable for the production of high-strength automobile integrated door rings.

Keywords: High strength steel hot stamping; Integrated door ring; Direct water cooling; Hot stamping forming die.

1. Introduction

With the rapid development of the automotive industry, the requirements for the strength and safety of the automotive body structure are getting higher and higher. As an advanced manufacturing process, hot stamping technology can improve the strength and formability of parts, so it is widely used in the manufacture of automotive body safety components. However, the cooling effect in hot stamping process has an important impact on the strength of parts. With the progress of hot stamping technology of ultra-high strength steel, hot stamping technology is gradually developing from simple part forming to complex structure forming [1]. Based on the impact energy distribution load path of lightweight body structure parts, the plates with different thickness and strength levels were selected for laser welding. After integrated hot stamping forming, the multi-component integrated hot stamping lightweight body parts with reasonable distribution of high-strength plastic region were obtained.

Aiming at the problems such as poor cooling effect of the existing circulating water cooling method in the processing of complex parts, difficult to guarantee the performance of parts and high production cost, this paper aims to put forward a high-strength water direct cooling processing device and method for automotive integrated door rings, so as to achieve accurate cooling of complex parts and improve the hot stamping effect.

Y. Zhang and M. Ma (eds.), *Proceedings of the 7th International Conference on Advanced High Strength Steel and Press Hardening (ICHSU 2024)*, Atlantis Highlights in Materials Science and Technology 3,
https://doi.org/10.2991/978-94-6463-581-2_6

2. Analysis of cooling technology for hot stamping

Hot stamping is the process of forming high-strength steel plate after heating to high temperature. Through the phase transformation during heating and cooling, the strength and hardness of parts are improved, so as to meet the requirements of automobile body structure.

At present, the common cooling method is to open a water channel in the mold module and cool it through the circulating water system. However, there are difficulties in design and processing when dealing with the mold water channel of complex parts, such as limited cooling speed, poor part size, unstable cooling effect, etc. [2]. These problems lead to the instability of part performance and the increase of production cost. To solve these problems, some scholars have proposed a precision cooling temperature control method of blowing cooling, which is to pre cool local blanks before hot stamping. This method can greatly reduce the cooling effect due to thinning, and control the thinning can increase the forming height by 80% [3]. In order to reduce the heat preservation time at the bottom dead point of hot stamping, there are also methods to directly invade the hot stamping parts into the water tank during forming and clamping to accelerate cooling [4]. Due to the large part size and complex structure of the door ring, according to the principle of direct water cooling, a set of direct water spray cooling device and control system are designed to improve the cooling efficiency and shorten the production cycle.

3. Design of direct water-cooling system for high strength automobile integrated door rings

3.1. *Design of water direct cooling processing device*

The apparatus comprises a hot stamping forming die, accompanied by a circulating water system and a water jet direct cooling mechanism, depicted in Figure 1. Refer to Figure 2 for a comprehensive view of the die insert, internal water channel, and nozzle design. The circulating water system efficiently directs cooling water through a looped system consisting of a circulating water pipe and pump. Simultaneously, the direct water cooling structure interfaces directly with high-temperature components via a direct cooling water pipe and air control structure, achieving effective cooling.

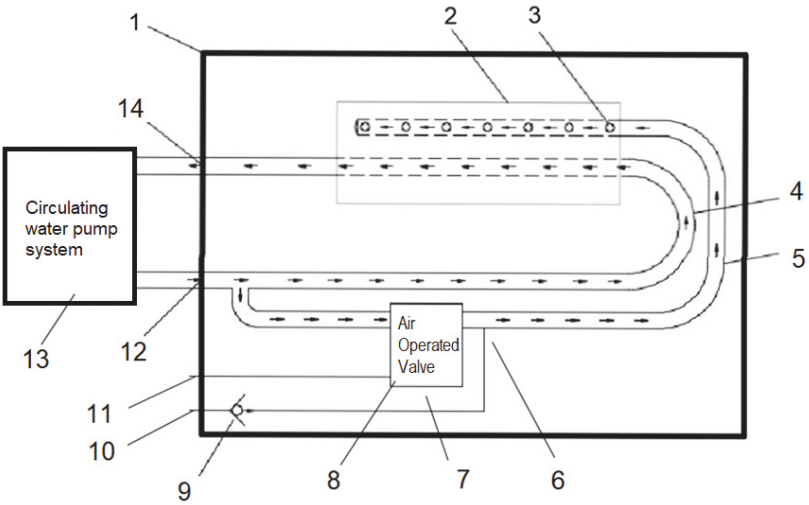

Fig. 1 Schematic diagram of direct water spray cooling device
(1-mold, 2-mold insert, 3-spray nozzle, 4-circulating water pipe, 5-direct cooling water pipe, 6-water direct cooling structure, 7-gas control structure, 8-gas controller, 9 one-way valve, 10 drainage pipe, 11 water control pipe, 12 water inlet end, 13 circulating water pump, 14 water outlet end.)

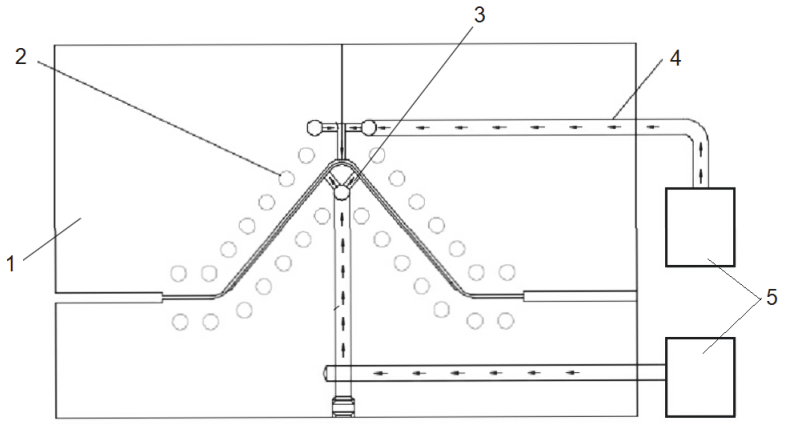

Fig. 2 Schematic diagram of sectional structure of die insert
(1-die insert, 2-circulating water pipe, 3-spray nozzle, 4-direct cooling water pipe, 5-gas controller)

A set of circulating water structure and water direct cooling structure are installed on the hot stamping forming die. The water direct cooling structure is connected with the circulating water structure. The circulating water structure includes a circulating water pipe with an overall annular structure, which is formulated according to the surface structure of the mold. One end of the circulating water pipe is the water inlet end and the other end is the water outlet end. The inlet and outlet ends are connected to the circulating water pump at the end. The circulating water pipe can be a high-pressure water pipe with a diameter of 8-40mm. To ensure the cooling water flow speed and cooling efficiency, and improve the

heat transfer performance. The circulating water pump drives the cooling water to circulate in the circulating water pipe, so as to form the circulating cooling water, so that its surface can contact with most of the parts' surfaces, reducing the heat of parts and achieving the cooling effect, see Figure 3.

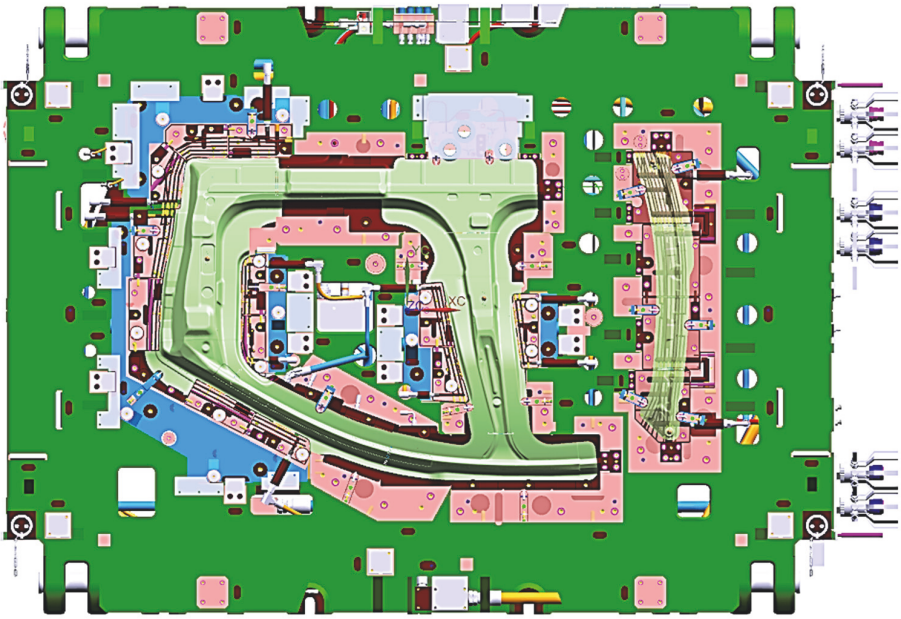

Fig. 3 Door Ring Lower Mold and Water Spray Cooling System Diagram

A water pipe branch is connected at the inlet end of the circulating water pipe to form a water direct cooling structure. By directly connecting with the circulating water structure, the direct water cooling structure can be reduced to simplify the equipment structure, and the direct water cooling structure can achieve the water spraying effect through the force of the circulating water structure without adding a separate pump.

Specifically, the water direct cooling structure includes a direct cooling water pipe integrally arranged in the hot stamping forming die. In the application example, the direct cooling water pipe can be a high-pressure water pipe with a diameter of 8-40mm. According to the specific structure of the parts, the structure and position of the direct cooling water pipe can be adjusted adaptively to meet the cooling requirements of different positions of the parts with complex structure, improve flexibility and cooling efficiency.

A pneumatic control structure is installed at the connecting end of the direct spray cooling pipe and the circulating return water pipe, which is used to send the cooling water in the circulating water pipe into the direct cooling water pipe through pneumatic control to form direct cooling water. At the same time, the spraying time and quantity of direct cooling water in the water direct cooling structure can be accurately controlled by means of air control.

The pneumatic control structure device includes the pneumatic control equipment installed on the direct cooling water pipe, and the water control air pipe and drainage air pipe respectively connected with the pneumatic control equipment. The pneumatic control equipment controls the start and stop of the water control pipe and the drainage pipe respectively. Among them, the water control pipe is used to let the direct cooling water enter the direct cooling water pipe by blowing air; The exhaust pipe is used to discharge the residual water in the direct cooling water pipe by blowing. A check valve is also set on the exhaust pipe to prevent the water in the direct cooling water pipe from flowing into the exhaust pipe in reverse and causing damage.

3.2. *Operation of direct water cooling processing method*

The method includes three steps: spraying water, draining water and closing drainage. The contact time and cooling effect between cooling water and parts are ensured by accurately controlling the water spraying time and amount. Through the direct contact of water with high-temperature parts, instant gasification, air flow is generated, cooling is accelerated, and the pressure holding time of hot stamping forming die is reduced. Avoid the problem that the heat cannot be transferred effectively due to the mold processing gap. It can effectively control the timing of direct water cooling, cooling in stages, avoid the problem of cooling cracking before forming, and make the size and mechanical properties of parts better and stable. The working steps are as follows.

First, the parts are sent into the hot stamping forming die, and the water control pipe is started when the die is closed, that is, the water control pipe is opened at the point, so that the water in the circulating water pipe is blown into the direct cooling water pipe through the air control method according to the set spraying time, and is sprayed out from the spray port to contact the parts before gasification, so that the cooling water can directly contact the surface of high-temperature parts through the insert.

Then, the water spraying time is set according to the material thickness of the part. In this embodiment, the water spraying time is ≥ material thickness 1.5s. By accurately controlling the water spraying time, the water spraying amount can be accurately controlled, so that the water spraying amount can be vaporized at the moment of contacting the surface of high-temperature parts, forming air flow and accelerating cooling effect. At the same time, it also avoids the residual caused by too much water, which will lead to the rust of the mold or the cracking caused by contacting the parts, which will affect the performance of the parts.

Finally, after the set spraying time is over, the water and air pipe is closed, and the drainage pipe is opened at the same time, so that the drainage pipe will empty all the water in the direct cooling water pipe.

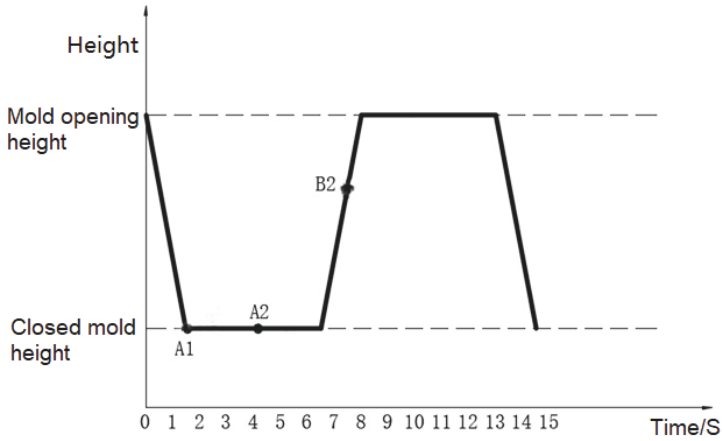

Fig. 4 Schematic diagram of operation control time flow

After closing the mold and ensuring the completion of hot stamping, 1-2 seconds before opening the mold, that is, A2 time point shown in Figure 4, is the dynamic time point set according to the material thickness in this example. Control the water control pipe to close. At this time, cooling water will no longer be blown into the direct cooling water pipe. At the same time, open the drainage pipe. All the cooling water remaining in the direct cooling water pipe can be blown out through the drainage pipe, and then the cooling water in the direct cooling water pipe can be emptied. Avoid residual cooling water overflowing from the water pipe to contact the parts, resulting in parts cracking, etc.

In this application case, the cooling water is directly contacted with the high-temperature parts by using the die insert combined with the water spray port, and then vaporized instantaneously, so as to generate air flow and accelerate the cooling. While effectively improving the cooling effect, it can also prevent the parts from cracking caused by the cooling water during the hot stamping process, which will affect the performance of the parts. In order to solve the problem of poor cooling effect due to the complex structure of parts, effectively improve the cooling effect of parts with different structures, simplify the design structure of cooling channel, and reduce the difficulty of operation.

4. Experiment and result analysis

A series of experiments were carried out to verify the cooling effect of the water direct cooling processing device and method for high-strength automobile integrated door rings. The experimental results are shown in Table 1. The experimental results show that the device and method can effectively improve the cooling effect of complex parts, and improve the quality and efficiency of hot stamping.

Table 1 Comparison of water spraying time and cooling effect of different plate thicknesses

Parameter	Material thickness (mm)	Spraying time (s)	Part Temp. (℃)	Water residue
Expt. 1	3.8	8	67	Too much to evaporate
Expt. 2	3.8	7	83	Too much to evaporate
Expt. 3	3.8	6	98	Less and capable of evaporation
Expt. 4	3.8	5	114	nothing
Expt. 5	3.8	4	139	nothing

From the above experimental examples, it can be seen that for parts with the same material thickness, the longer the water spraying time, the better the cooling effect. However, if the water spraying time is too long, such as experimental example 1 and experimental example 2, there will be residual water, and there will be more residual water. The temperature of the mold and parts will not make it evaporate, which will affect the performance of the parts, and also cause rust. However, the water spraying time is too short, such as experiment 4 and Experiment 5. Although there is no residual water, the cooling effect is not enough.

Compared with experimental example 3, according to the material thickness of the part, set the cooling time as 6S according to the material thickness ≥ 3.8*1.5s=5.7s, and the cooling effect is better than that of experimental example 4 and experimental example 5. Although there is a little water residue, the residual amount can evaporate during mold opening without affecting the performance of the part. The cooling effect is the best within the range of water spraying time ≥ material thickness *1.5s, which effectively improves the cooling effect, It can accelerate the cooling speed, avoid the residue of cooling water, realize the whole gasification process, avoid rust, cracking and other conditions, and improve the mechanical properties of hot stamping parts.

It can be seen from the data in Table 2 that closing the cooling system before or after mold opening has different effects and product quality. From the above comparison, it can be intuitively found that it takes less time to close the drain pipe 303 before the mold is opened, reducing the pressure holding time, and there is no cooling water left around the spray port 33 before the next part is put into the mold, which can effectively prevent the overflow of cooling water from contacting the part and causing the part to crack. However, if the drain pipe 303 is closed after opening, there will be a small amount of water. Although its cooling effect is better, it will lead to the incomplete evaporation of water before the parts are put into the mold, resulting in residue, which will affect the hot stamping formability in contact with the parts.

Table 2 timing and cooling effect of cooling system shutdown

Cooling system shutdown sequence	Part temp. (℃)	Time taken (s)	Water residue
Close after mold opening	95	2	less
Close before mold opening	118	1	nothing

5. Conclusion and Prospect

In this paper, a high-strength direct water cooling device and method for the processing of automotive integrated door rings are proposed. Through the direct contact between water and high-temperature parts, the precise cooling of complex parts is realized. Dynamic time point set according to blank thickness. Control the water control pipe to close. At this time, cooling water will no longer be blown into the direct cooling water pipe. At the same time, open the drainage pipe. All the cooling water remaining in the direct cooling water pipe can be blown out through the drainage pipe, and then the cooling water in the direct cooling water pipe can be emptied. Avoid residual cooling water overflowing from the water pipe to contact the parts, resulting in parts cracking, etc.

For parts with a blank thickness of 3.8mm, after 4-8 seconds of water spray cooling, the hot blank can be cooled to below 67-139 ℃, and the average holding time can be shortened by about 40%. Experiments show that the device and method can effectively improve the quality and efficiency of hot stamping. Future research can further optimize the device and method, improve the cooling effect and production efficiency.

References

1. Yisheng Zhang, Yilin Wang, bin Zhu, et al. research progress of hot stamping technology based on multi part integration Journal of plastics engineering, 2023, 30 (8): 1-7
2. Dihui Liu, Xue Tang, Sansi yang Method of cooling water flow distribution for considering sheet thickness. Journal of Hunan University (Natural Sciences) 2022,49 (8): 93-100
3. E. OTA, Y. Yogo, T. Iwata, N. Iwata, K. Ishida, K. Takeda, formability improvement technology for heated sheet metal forming by partial cooling, in metal forming 2014, Vol. 622 of key engineering materials (trans tech publications, 2014), pp. 279 – 283
4. Tomoyoshi Maeno, Ken Ichiro mori, Masaki Fujimoto Improvements in productivity and formability by water and die queuing in hot stamping of ultra-high strength steel parts, CIRP annals - manufacturing technology 64 (2015) 281 – 284