Optimization of Cooling System for Hot Forming Based on Orthogonal Experiment

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Abstract. Taking the U-shaped part of 22MnB5 ultra-high-strength steel as an example, a finite element model of hot stamping is established. The temperature field distribution characteristics of the sheet during the hot forming process are analyzed by DEFORMV11.0 software combined with the orthogonal experimental design method. The diameter of the pipe, the distance from the pipe to the mold surface, and the distance between the pipe and the pipe will affect the temperature field of hot stamping. Then, the cooling system parameters is designed and optimized.

1. Introduction
In the automotive industry, the parts prepared by hot stamping can significantly improve the collision safety of the vehicle body, reduce the weight of the vehicle, and meet the requirements of the automotive industry for safety, energy conservation, environmental protection, comfort [1-3]. At present, the major automotive manufacturers in Europe, America, and Japan have adopted the hot stamping technology to produce the ultra-high-strength steel structural parts, such as the door crash bars, the bumper reinforcement beams, the A, B, C pillars, the door frame reinforcement beams, etc. The application proportion is increasing year by year [4-5]. When the cooling rate of the sheet is enough high, the austenite will be transferred into the martensite structure. If the cooling effect is not good, the bainite will be generated and the mechanical properties of the stamping part is finally affected. Therefore, the control of the cooling rate during the hot forming process is vital [6]. The hot stamping technology has been researched in Europe and other developed countries for many years. The hot stamping molds in China are mainly imported from these countries. The few relevant data and research results have been published. The numerical simulation combined with the orthogonal experimental design method in this paper is applied to analyze the influence of the mold cooling system on the temperature field of the sheet during the forming process. This can provide the data support for the optimization of the mold cooling system structure.

2. Establishment of Finite Element Model During Hot Stamping

2.1. Establishment and Meshing of Geometric Models
Among automobile parts, B-pillar parts are safety structural parts of automobile bodies. It plays a decisive role in the side collision prevention performance of automobiles. Figure 1a is a B-pillar part of an automobile. It is a U-shaped part in terms of the forming process. In this study, a partial U-shaped feature of a B-pillar part is used as the geometric model. The material is 22MnB5. The initial thickness is 1.8 mm. The U-shaped stamping parts are shown in figure 1b. In order to improve
the calculation efficiency, the geometric model is treated symmetrically according to the characteristics of the U-shaped part. The minimum size is set to 1mm and the size ratio is 5. The minimum size of the concave and convex grids is 0.8 mm and the size ratio is 5. The meshed finite element model is shown in figure 2.

![Figure 1. FE geometry model of U-shaped blank.](image)

![Figure 2. FE mesh used for the simulation of hot stamping](image)

### 2.2. Selection and Establishment of Material Models
During the hot stamping process, the thermodynamics of the mold material will directly affect the geometric accuracy and mechanical properties of the part. The concave and convex simulations in this study used the hot work die steel H-13 commonly in the Deform-3D material library. The material model was defined as a rigid body. The sheet material was 22MnB5 defined as a plastic body.

### 3. Orthogonal Experiments and Analysis Based on Numerical Simulation

#### 3.1. Orthogonal Experimental Results
In this paper, the orthogonal parameter design and simulation method are used to carry out the parameter design of the cooling pipe for the hot stamping process. After analysis, the maximum temperature difference of the U-shaped part is used as the experimental index. The diameter of the pipe, the distance from the pipe surface to the mold surface and the distance between the pipe and the pipe are experimental parameters. In this paper, the initial hot stamping temperature of the sheet is 750 °C. The process parameters and levels are shown in table 1. The results of orthogonal experiments are shown in table 2.

#### 3.2. Results Analysis
The analysis results of the maximum temperature difference of the U-shaped part is showed in table 3. It can be seen from table 3 that the extreme difference of the cooling pipe diameter is the largest. The extreme difference of the distance between the pipes is the smallest. The distance to the mold is the second factor, and the distance between the pipes is the smallest. This results in the optimal combination A2C2B1.

| Level factor A: Cooling pipe diameter | Level factor B: Spacing between pipes | Level factor C: Distance from pipe to die surface |
|--------------------------------------|--------------------------------------|-----------------------------------------------|
| 1                                    | 7.5                                  | 27.0                                          |
| 2                                    | 8.0                                  | 28.0                                          |
| 3                                    | 8.5                                  | 29.0                                          |
| 4                                    | 9.0                                  | 30.0                                          |
| 5                                    | 9.5                                  | 31.0                                          |
Table 2. 25 set of training samples and corresponding orthogonal experiment results.

| Test number | Pipe diameter (mm) | Pipe spacing to mold (mm) | Distance from pipe to mold surface (mm) | Highest temperature (°C) | Lowest temperature (°C) | Maximum temperature difference of U-shaped part after holding pressure (°C) |
|-------------|--------------------|--------------------------|----------------------------------------|--------------------------|--------------------------|--------------------------------------------------------------------------|
| 1           | 7.5                | 27.0                     | 9.0                                    | 155                      | 57.7                     | 97.3                                                                      |
| 2           | 7.5                | 28.0                     | 10.0                                   | 208                      | 23.7                     | 184.3                                                                     |
| 3           | 7.5                | 29.0                     | 11.0                                   | 184                      | 23.4                     | 160.6                                                                     |
| 4           | 7.5                | 30.0                     | 12.0                                   | 134                      | 47.8                     | 86.2                                                                      |
| 5           | 7.5                | 31.0                     | 13.0                                   | 96.5                     | 44.6                     | 51.9                                                                      |
| 6           | 8.0                | 27.0                     | 10.0                                   | 392                      | 65.1                     | 326.9                                                                     |
| 7           | 8.0                | 28.0                     | 11.0                                   | 139                      | 45.7                     | 93.3                                                                      |
| 8           | 8.0                | 29.0                     | 12.0                                   | 208                      | 47.5                     | 160.5                                                                     |
| 9           | 8.0                | 30.0                     | 13.0                                   | 136                      | 43.9                     | 92.1                                                                      |
| 10          | 8.0                | 31.0                     | 9.0                                    | 112                      | 64.4                     | 47.6                                                                      |
| 11          | 8.5                | 27.0                     | 11.0                                   | 139                      | 73.7                     | 65.3                                                                      |
| 12          | 8.5                | 28.0                     | 12.0                                   | 114                      | 58.6                     | 55.4                                                                      |
| 13          | 8.5                | 29.0                     | 13.0                                   | 120                      | 48.5                     | 71.5                                                                      |
| 14          | 8.5                | 30.0                     | 9.0                                    | 106                      | 42.6                     | 63.4                                                                      |
| 15          | 8.5                | 31.0                     | 10.0                                   | 84.2                     | 40.6                     | 43.6                                                                      |
| 16          | 9.0                | 27.0                     | 12.0                                   | 138                      | 68.8                     | 69.2                                                                      |
| 17          | 9.0                | 28.0                     | 13.0                                   | 242                      | 23.1                     | 218.9                                                                     |
| 18          | 9.0                | 29.0                     | 9.0                                    | 76.6                     | 56.6                     | 20                                                                        |
| 19          | 9.0                | 30.0                     | 10.0                                   | 71.7                     | 46.9                     | 24.8                                                                      |
| 20          | 9.0                | 31.0                     | 11.0                                   | 279                      | 56.7                     | 222.3                                                                     |
| 21          | 9.5                | 27.0                     | 13.0                                   | 129                      | 50.1                     | 78.9                                                                      |
| 22          | 9.5                | 28.0                     | 9.0                                    | 160                      | 80.4                     | 79.6                                                                      |
| 23          | 9.5                | 29.0                     | 10.0                                   | 160                      | 46.2                     | 113.8                                                                     |
| 24          | 9.5                | 30.0                     | 11.0                                   | 127                      | 51.4                     | 75.6                                                                      |
| 25          | 9.5                | 31.0                     | 12.0                                   | 175                      | 78                       | 97                                                                        |

Table 3. Analysis results of orthogonal experiment.

| Experimental index | Factor, level | Cooling pipe diameter (mm) | Watercourse spacing (mm) | Waterway die surface spacing (mm) |
|--------------------|---------------|----------------------------|--------------------------|----------------------------------|
| 1                  |               | 116.060                    | 127.520                  | 61.580                           |
| 2                  |               | 144.080                    | 126.300                  | 138.680                          |
| 3                  |               | 59.840                     | 105.280                  | 123.420                          |
| 4                  |               | 111.040                    | 68.420                   | 93.660                           |
| 5                  |               | 88.980                     | 92.480                   | 102.660                          |
| Extreme            |               |                            |                          |                                  |
| Primary and secondary factors | A₂>C₂>B₁ |               |                          |                                  |
| Excellent level combination | A₂C₂B₁ |               |                          |                                  |
| Excellent level |               | A₂                          | C₂                       | B₁                                |
4. Conclusion

25 groups of orthogonal experiment design methods with three factors and five levels combined with finite element method were applied to optimize the structure of the mold cooling system during the hot forming process. The diameter of the pipe, the distance from the pipe to the mold surface, and the distance between the pipes were obtained. The values are 8.0 mm, 10.0 mm, and 27 mm respectively. The most important factor affecting the quality of hot stamping products is the diameter of the cooling pipe. The distance between the pipes has the smallest effect. This can provide the valuable references to design the cooling system in the hot stamping process.

References

[1] Taylor T, Clough A 2018 Critical review of automotive hot stamped sheet steel from an industrial perspective Mater. Sci. Tech. Lond. 34 (7) 809-861
[2] Mori K, Bariani P F, Behrens B A 2017 Hot stamping of ultra-high strength steel parts CIRP Annal. 66 (2) 755-777
[3] Kim D K, Woo Y Y, Park K S 2018 Advanced induction heating system for hot stamping Int. J. Adv. Manuf. Tech. 99 (1-4) 583-593
[4] Zhou J, Wang B, Huang M 2014 Effect of hot stamping parameters on the mechanical properties and microstructure of cold-rolled 22MnB5 steel strips Int. J. Min. Met. Mater. 21 (6) 544-555
[5] Bouaziz O, Zurob H, Huang M 2013 Driving force and logic of development of advanced high strength steels for automotive applications Steel Res. Int. 84 (10) 937-947
[6] Zhao J, Jiang Z 2018 Thermomechanical processing of advanced high strength steels Prog. Mater. Sci. 94 174-242