Effect of Process Parameters on the Automobile Part in Hot Stamping Process

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Abstract. In this study, the influence of variables, including friction coefficient and initial blank temperature, on the formability in the hot stamping process of steel was analyzed. The formability indexes have maximum thickness thinning rate and springback. The friction coefficient is chosen between 0.05 and 0.4. The range of initial blank temperature varies from 825 to 995 °C. The combination of central composite design and response surface method was used to analyze the relationship between the variables and indexes. The maximum thinning rate of the hot formed part increases obviously with the increase of the friction coefficient. The maximum thinning rate increases slightly with the decrease of the initial blank temperature. The springback increases with the decrease of the friction coefficient significantly. The initial blank temperature affects the springback slightly.

Keywords: Hot stamping; Thinning rate; Springback; Friction coefficient.

1. Introduction
In recent years, the hot stamping of steel has gained a lot attention. Ganapathy et al. [1] studied the hot stamping of Boron steel using experiment and simulation methods. A novel grip was designed for improving the test data accuracy. The higher heat generation was also improved. Li et al. [2] investigated a novel hot-stamping process of steel experimentally. A hot stamped B-pillar part was investigated. The part was hot stamped in various temperature conditions, and the forming defects were analyzed. Lin et al. [3] investigated the heating period in the hot stamping process of boron steel. The model for austenite formation in the hot stamping process was established. Nan et al. [4] studied the selective heating method in the hot stamping of boron steel to get a tailored graged microstructure after press hardening in cold dies. The material models including viscoplastic-damage constitutive model and phase transformation model were founded and input into the finite element model. So the microstructure evolution can be simulated and analyzed. Li et al. [5] analyzed the properties of boron steel after tailored microstructure hot stamping. The unified damage equation for the hot stamping was developed. The crashworthiness was also studied after the component was formed. The automotive safety component was also analyzed experimentally with tailored microstructure and property after the hot stamping [6]. Yang et al. [7] employed the finite element simulation method and experimental validation to analyze the effect of selective cooling on the car body. The part with rapid cooling can reach a high tensile strength and the slow cooling can reach a low tensile strength. Xiao et al. [8] analyzed the heating method for the hot stamping process. The electrical heating furnace was replaced.
by resistance heating. The heating rate is high. The experiments and numerical simulation were used to study the forming process on the hot-formed part. Li et al. [9] analyzed the hot stamping of 22MnB5 in terms of different phase fractions. The constitutive model was also studied. In this study, the effect of process parameters on the performance of the hot-stamped part was analyzed. The process parameters include friction coefficient and initial blank temperature. The central composite design and response surface method were used for analysis.

2. Finite Element Model of Automobile Part
The hot stamping model contains four main parts, including die, punch, blank holder and blank. The blank was firstly heated to an elevated temperature and then moved to the cold dies. The part analyzed is a threshold reinforcement. The material used in this study is 22MnB5, which is a hot forming material. The mechanical thermal properties were given for different strain rates and forming temperatures in the FE code autoform. Then the stamping was conducted. The part was held between the cold dies for several seconds for quenching for the formation of the martensite phase. The finite element model for hot stamping is shown in the following Fig. 1.

![Finite Element Model for Hot Stamping](image)

**Figure 1.** The finite element model for hot stamping

3. Design of FE Tests
In this study, the two main process parameters are studied. They are friction coefficient and initial blank temperature. The test design employs the central composite design, which is effective and efficient.

| No. | Friction coefficient | Temperature/°C | Thinning rate | Springback/mm |
|-----|----------------------|----------------|--------------|---------------|
| 1   | 0.05                 | 910            | 0.136        | 3.278         |
| 2   | 0.1                  | 850            | 0.142        | 3.115         |
| 3   | 0.1                  | 970            | 0.140        | 3.67          |
| 4   | 0.22                 | 994.9          | 0.155        | 3.793         |
| 5   | 0.22                 | 825.15         | 0.175        | 4.248         |
| 6   | 0.22                 | 910            | 0.153        | 3.243         |
| 7   | 0.35                 | 850            | 0.202        | 2.266         |
| 8   | 0.35                 | 970            | 0.199        | 2.271         |
| 9   | 0.4                  | 910            | 0.262        | 2.281         |

**Table 1.** The process parameters and the levels.

**Table 2.** The results for the corresponding test design.
The following is the result for case 5 with friction coefficient of 0.22 and temperature of 825 °C. The results are the distribution of thinning rate. It can be seen from the Fig. 2 that the corner and sidewall have the obvious large thinning rate.

![Figure 2. The thinning rate distribution of the part for the case 5.](image)

The Fig. 3 is the springback distribution of the result. It can be seen from Fig. 3 that the edge of the part has the obvious springback. The springback of the formed part will accumulate from the middle to the edge.

![Figure 3. The springback distribution of the part for the case 5.](image)

4. Results and Discussion

The response surface method was used to study the relationship between process parameters and formability. The Fig. 4 shows the relationship between thinning and temperature and friction coefficient. It can be seen from the result that the thinning increases obviously with the increase of the friction coefficient. As the friction coefficient increases, the force constrains the material flow strongly, which is deleterious for the formability. At the same time, the concentrated stress increases, leading a high maximum thinning rate. The maximum thinning rate increases slightly with the decrease of the initial blank temperature. This was because the decrease of the initial blank temperature reduces the formability of the blank at the elevated temperature. So the maximum thinning rate of the formed part increases. The fitting formula for the relationship between thinning and friction coefficient and temperature is shown in the equation (1), the $R^2$ is about 0.96, where A is for friction coefficient, and B is for temperature.

$$\text{Thinning}=0.94103-0.25388A-1.6733e^{-3}B-3.3333e^{-5}AB+1.292A^2+8.85417e^{-7}B^2 \quad (1)$$
The relationship between springback and temperature and friction coefficient is shown in Fig. 5. It can be seen from Fig. 5 that the springback increases with the decrease of the friction coefficient significantly. The high friction coefficient constrains the material flow especially between the blank holder and the die. So the material surfs a sufficient plastic deformation. Then the residual stress decreases. At the same time, the initial blank temperature affects the springback slightly. Because the initial blank temperature varies between 825 and 995 °C, the blank can form sufficiently in plastic deformation. So the springback can be constrained. An obvious advantage of hot stamping is the decrease of the springback. The fitting formula for the relationship between springback and friction coefficient and temperature is shown in the equation (2), where $A$ is for friction coefficient, and $B$ is for temperature.

$$\text{Springback}=55.93146 + 23.80016A - 0.12061B - 0.01833AB - 23.944A^2 + 6.84375e^{-5}B^2 \quad (2)$$

To get a deep understanding on the relationship between springback and thinning rate and optimize the process parameters, the multi-objective genetic algorithm was applied. The friction coefficient and the blank temperature are the process variables. The springback and thinning rate are the objectives. After the optimization, the relationship between the springback and the thinning rate can be got based on the hot forming technology of steel. It is the Pareto frontier for the thinning rate and the springback, which is shown in Fig. 6. It can be seen from Fig. 6 that the increase of the thinning rate leads to the decrease of the springback. Several samples with moderate thinning rate and springback values are selected from the Pareto frontier, which are shown as follows. The simulated results and predicted results in Pareto frontier were also compared and the deviation is also shown in Table 3. Three sample results are given in Table 3. It can be seen that the simulated results and predicted results show good consistence. It indicates the availability of the fitting equations.
5. Conclusion

In this paper, the relationship between the thinning rate and springback and forming parameters was researched. The maximum thinning rate of the hot formed part increases obviously with the increase of the friction coefficient, especially, when the friction coefficient is higher than 0.29. The maximum thinning rate increases slightly with the decrease of the initial blank temperature. The thinning rate is lower than 22%. The springback increases with the decrease of the friction coefficient significantly. The initial blank temperature affects the springback slightly. When the friction coefficient is low, the springback firstly decreases and then increases with the increase of the forming temperature. The relationship between the thinning and springback was also analyzed. The thinning rate increases with the decrease of the springback. The optimized process parameters can get the proper thinning rate and springback value. When the friction coefficient is 0.28 and the temperature is 924, the thinning rate is 0.17 and the springback is 2.94, which is a proper combination. In terms of the future research direction, the tool design and cooling analysis should be studied.

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