Parameter Optimization of Hot Stamping for an Extension Part Based on DYNAFORM under the Background of New Engineering

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Abstract. Based on the finite element analysis software eta/DYNAFORM, the hotstamping model of the front longitudinal beam on an extension part was established. The finite element numerical simulation of the beam was carried out by the method of thermal coupling. The effects of different stamping speed, holding time, and temperature field and friction factor on forming quality were analyzed. The results show when the stamping speed of 200 mm/s, the holding time of 6s and the friction factor of 0.4, the martensite content is relatively higher and the springback is smaller. It provides an important basis for reasonable technological parameters of ultra-high strength parts, and also provides technical support for the new engineering construction.

1. Introduction
At present, hot stamping technology is widely used in military, aerospace, automotive and other industries. This technology has many advantages, such as high forming precision, small rebound, and low degree of work hardening, which is especially suitable for forming complex stamping parts. However, it is not easy to determine the correct sheet temperature, stamping speed, and cooling rate, holding time, friction factor, cooling rate and other process parameters during the forming process. Therefore, only a few companies in China have introduced hot stamping forming lines from abroad. This article used DYNAFORM finite element simulation analysis software, which had powerful sheet forming analysis ability and streamlined pre-processing and post-processing functions. In this paper, an extension part was taken as the research object, and its three-dimensional parts was shown in Figure 1. The effects of different stamping speed, holding time, friction factor and initial mold temperature on the forming quality were studied, and reasonable process parameters were determined which could provide technical guidance for actual production.

Figure 1. Three-part drawing of extension part Figure 2. Hot stamping process
2. Forming Principle of Hot Stamping
The principle of hot stamping is shown in Figure 2. First of all, the high-strength boron alloy steel sheet having ferrite and pearlite structure at room temperature is heated to an austenite state, and then sent it to a mold with a cooling device to be stamped. The steel sheet is held in the mold for a period of time after forming and is quenched by the mold. A high-strength part having a uniform martensite structure at room temperature can be obtained finally.

Experience has shown that the minimum cooling rate (i.e. the critical cooling rate) of austenite to martensite transformation is 27 K/s. To prevent the organizational transformation from austenite to bainite and ferrite, the mold cooling rate of steel plate must be greater than the critical cooling rate.

3. Model Establishment
Hot stamping includes two mutual influence processes of sheet deformation and heat transfer. Therefore, the deformation and heat transfer must be solved by coupling.

3.1. Heat Transfer Model
The main heat transfer methods in the hot stamping forming process include:(1) thermal convection and heat radiation between the furnace and the air during the transfer from the furnace; (2) thermal convection and heat radiation between the convex, concave die, binder ring and the air at initial stage of stamping;(3) heat transfer between the convex, concave molds, the binder ring and the sheet during the stamping process. It can be seen that the temperature of the hot stamping process is constantly changing, that is to say, the heat transfer process of the hot stamping process is an unsteady process, which conforms to the non-steady-state thermal differential equation.

\[
\rho \frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x} (\lambda \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y} \left( \lambda \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( \lambda \frac{\partial T}{\partial z} \right) + \Phi
\]  

(1)

Where: \( \rho \) is the density of the micro-element; \( c \) is the specific heat capacity; \( T \) is the temperature; \( \Phi \) is the heat generated by the heat source per unit volume per unit time.

Here are the heat transfer equation for hot stamping process. The heat conduction equation is

\[
Q_{ci} = -\lambda_{ij,j}A \frac{\partial T}{\partial X_i}
\]  

(2)

The thermal convection equation is

\[
Q = hA(T_i - T_f)
\]  

(3)

The thermal radiation equation is

\[
Q = \varepsilon A \sigma \left( T_1^4 - T_2^4 \right)
\]  

(4)

Where: \( Q \) is the heat transferred; \( \lambda_{ij} \) is the thermal conductivity; \( h \) is the convective heat transfer coefficient; \( A \) is the area; \( \varepsilon \) is the surface temperature of the continuum; \( \sigma_0 = 5.67 \times 10^{-8} \text{ W \cdot m}^{-2}\text{K}^{-4} \) is the Stefan-Boltzmann constant.

3.2. Finite Element Model
The forming process and heat transfer process of the front longitudinal beam are coupled by the hot forming analysis module provided by the sheet forming finite element analysis software Dynaform 5.7. The material used for the simulation was 22MnB5 with a thickness of 1.8 mm. Figure 3 is the hot stamping finite element model and Table 1 is the modeling parameters. For thermo-mechanical coupling simulation analysis, the temperature changes with time, so it is necessary to define the stress and strain of the material at various temperatures. Figure 4 shows the stress-plastic strain relationship of 22MnB5 at different temperatures.
4. Simulation Results and Analysis

Based on the model above and simulation conditions, a deformation-heat transfer coupling simulation analysis was performed on the forming process of an extension part. In order to simplify the model and save computer resources, a certain cross-section of the plate was selected for research. As shown in Figure 5 below, seven points at the top, side and bottom regions were selected as the research objects.

**Figure 3.** Finite element model of hot stamping

**Figure 4.** Stress-plastic strain relationship of 22MnB5 at different temperatures

**Table 1.** Setting parameters of finite element model

| Thermal boundary conditions | Initial temperature of sheet metal | 800°C |
|-----------------------------|-----------------------------------|-------|
| Preheating Temperature of Die | 50°C | |
| Radiation coefficient | 0.8 SBC | |
| heat transfer coefficient | 5W/(m²K) | |
| Thermal Contact Conditions | Thermal conductivity | 0.08W/(mK) |
| | Radiation coefficient | 7.6 SBC |

**Figure 5.** The points of cross-section
4.1. Effect of Different Stamping Speed on Forming Quality

The speed of hot stamping determines whether the stamping process can be completed before the phase change of the sheet, which plays a vital role for the subsequent pressure holding and cooling. Figure 6 is the highest and lowest temperatures of the sheet at the end of hot stamping at a blanking force of 80 MPa and speeds of 100 mm/s, 150 mm/s, 200 mm/s, 250 mm/s, and 300 mm/s. It is not difficult to see that the higher the speed, the slower the temperature of the sheet is, and the smaller the temperature difference is. The shorter contact time between the sheet and the mold, the drop of the lowest temperature is more obvious, and the maximum temperature drop is not obvious, mainly because some of the mechanical energy in the stamping process is converted into the internal energy. At a large stamping speed, although the temperature difference before and after deformation is small, it is easy to crack in the rounded transition region. At a small punching speed, the temperature difference before and after deformation is large and the phase change occurs earlier so that the martensite is generated prematurely leading to pull cracked on the side wall. For comprehensive consideration, the speed of hot stamping is preferably about 200mm/s.

![Figure 6. Temperature curve of sheet metal formed at different stamping speed](image)

4.2. Effect of Different Dwell Time on Forming Quality

Since the hot forming process needed to be completed before the phase change occurs, the holding time of the stamping mold cannot be too long. The forming time was set to 1.5 s. The phase transition start temperature of the martensite is 425 °C and the end temperature of phase transition is 280 °C. In order to explore the effect of the length of the dwell time on the phase transformation of martensite, the dwell time was set to 3s, 4s, 5s, 6s, 7s, and 8s. The simulation results are shown in Figure 7. As the dwell time increases, the martensite content of each part increases. The growth trend is obvious in 3-6s, and the increase decline after that. This is mainly because the quenching cooling rate is greater than 27 °C / s at the first 6s. The quenching effect is good, which is beneficial to the formation of martensite. After that, the temperature difference becomes smaller, the cooling rate decreases below 27 °C / s. Some part of the austenite is no longer converted to martensite, but becomes pearlite or bainite so that the content of martensite tends to be stable. It can be concluded that not the longer the holding time is, the better the effect is. The reasonable holding time is the prerequisite for ideal martensite structure.
Influence of Temperature Field of Different Parts on Forming Quality

Since the sheet preferentially contacts with the bead ring, the temperature drops faster. When the blanking ring and the mold close, the temperature at the crimping ring drops rapidly, as shown in point 1 and point 2 in Figure 8. After that, the sheet moves and contacts with the punch, the heat is absorbed by the mold leading to temperature drop of the sheet as shown by point 7 in Figure 8. Since point 5 and point 6 are at the rounded corners, the deformation is large and the temperature drops slowly. Points 3 and 4 are in a region where plastic deformation is large. As the forming progresses, the sheet temperature keep substantially stable because of the heat of plastic deformation and the heat generated by the friction. In areas with severe plastic deformation, the heat of plastic deformation and the heat generated by friction may cause the temperature of the sheet to be higher than the initial temperature of the sheet.

Conclusion

(1) In this paper, the finite element model of hot stamping of front longitudinal beam extension part was established by DYNAFORM. The forming process and heat transfer process were coupled to study the influence of different process parameters on forming quality in hot stamping process, such as stamping speed, holding time, temperature field, friction factor.

(2) The simulation analysis results show that the reinforcement has higher martensite content and less rebound with the stamping speed of 200mm/s, the dwell time of 6s, and the friction factor of 0.4.

(3) It can be found that numerical simulation technology will greatly reduce the development cost of hot stamping dies and shorten the development cycle. This technology can provide theoretical guidance for design and mode trial, and also provide technical support for the new engineering construction.
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7. References
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