Properties Prediction Modelling for Hot Stamping Products and its Validation in a U-cap part

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Abstract. Microstructure evolution models were introduced to describe the ultra-high strength hot stamping process, where both diffusional and non-diffusional phase transformations were contained. In addition, the mechanical properties of the final hot stamping products including hardness, strength and elongation etc. were predicted through a series of analytical and empiric models. Based on the platform of LS-DYNA, the presented models were used to simulate the hot stamping process of a U-cap part, the predicted phase fractions and mechanical properties were close to the measured results.

1. Introduction

Microstructure evolution models for hot forming technologies attract many attentions. Kirdaldy and Venugopalan [1] introduced the K-V model for the diffusional phase transformation. Li et al. [2] presented a revised model where the CCT curve was used instead of TTT curve. Åkerström et al. [3] developed the A-O model in which the effects of boron element were considered according to the character of hot stamping steel. As for non-diffusional phase transformation, the basic model was proposed by Koistinen and Marburger [4], and later the Lee model was presented where the effects of temperature were further involved [5]. Furthermore, mechanical properties can be predicated based on microstructure characteristics. Bok et al. [6] predicted the phase fractions and hardness of a B pillar. Zhu et al. [7] and Caia et al. [8] also simulated the hardness of hot stamping parts.

In this paper, the microstructure evolution and properties prediction models for the hot stamping process were studied and integrated into LS-DYNA, which was then used to simulate a U-cap part forming process, and the phase fractions and final mechanical properties were obtained and compared.

2. Properties prediction models and its validation

In this work, the Li model and K-M model were used to describe the diffusional transformation and the non-diffusional phase transformation respectively. The expressions of these models can be found in [2] and [4].

The mechanical properties including the hardness, strength and elongation were predicted by using the hardness mixed rule, empiric model and two-phase mixed formula, respectively. And the detail expressions of the above models can be found in [2, 9, 10].

The uncoated and cold-rolled steel B1500HS with a thickness of 1.4mm produced by BaoSteel was chosen to study, its chemical components was Fe-0.23C-0.24Si-1.3Mn-0.046Al-0.0026B-0.002S.
Gleeble3500 thermal-mechanical machine was used to simulate the hot stamping process, the specimen was heated up to 920°C and held for 5 minutes to get fully austenitization, then it was quenched to the room temperature at a cooling rate of 30°C/s. After that, the phase fractions and mechanical properties were analyzed. Using the above models, the predicted phase fractions such as austenite, bainite, and martensite were 1.5%, 2.1%, and 96.3%, respectively, and the fractions of ferrite and pearlite were lower than 0.05%, which were consistent with the theoretical values.

In order to obtain the strength, elongation and austenite content of the heat treated B1500HS, the tensile test and XRD analysis were carried out. It can be found that the calculated values agree well with the experimental results as shown in Table 1.

### Table 1. Comparison between the predicted and experimental values of austenite fraction and the mechanical properties.

|        | Austenite (%) | Tensile strength (MPa) | Elongation (%) |
|--------|---------------|------------------------|----------------|
| Experiment | 1.5           | 1558                   | 6.1            |
| Prediction | 1.5           | 1522                   | 6.1            |

3. **U-cap part hot stamping experiment**

A U-cap part for hot stamping process was conducted to obtain the phase fractions and final mechanical properties. The experimental tool and the final product are shown in Figure 1.

![Figure 1. U-cap part by hot stamping.](image)

The microstructure evolution is deeply depended on the temperature during the hot stamping. A theoretical model describing the heat transfer coefficient between the tool and the sheet has been presented in our early work [11]:

$$h_{c} = \frac{1}{R(1-P/E)} \left( \frac{P}{E} k_{\text{blank}} k_{\text{die}} + \left( 1 - \frac{P}{H} \right) k_{f} \right)$$

(1)

Where $P$ is the pressure, $E$ is the Young’s Modulus, $H$ is Vickers hardness, $R$ is the contact surface roughness, $k_{\text{blank}}$, $k_{\text{die}}$, $k_{f}$ represent the blank, die and air thermal conductivity, respectively.

The above models were integrated in the commercial FEA codes LS-DYNA to simulate the hot stamping process. The comparisons between the experimental and simulated temperature curves at different positions of U-cap part are described in Figure 2.
Figure 2. Temperature curves at different positions of U-cap part.

Figure 3(a) and (b) represent the temperature distributions during the hot stamping process after 10s and 25s respectively. Figure 3(a) shows that the flange temperature is quickly quenched to 300°C after 10s, while the bottom temperature is still above 300°C since only one-side contact exists in this area. Thus, the phase fractions are different due to the different cooling rates. Figure 3(c) and (d) show the contents of austenite and martensite after the forming process. The final phase fractions at different positions are shown in Table 2.

Table 2. Predicted values of austenite, bainite and martensite at different positions.

|          | Austenite (%) | Bainite (%) | Martensite (%) |
|----------|---------------|-------------|----------------|
| Flange   | 1.7           | 0.6         | 97.2           |
| Side     | 6.5           | 3.6         | 88.7           |
| Bottom   | 31.2          | 24.5        | 38.8           |
Then the mechanical properties were calculated, the comparisons with the experimental results are shown in Table 3.

Table 3. Comparisons between the experimental and predicted mechanical properties at different positions

| Position | Tensile strength (MPa) | Elongation (%) |
|----------|------------------------|----------------|
|          | Experiment | Prediction | Experiment | Prediction |
| Flange   | 1436       | 1513       | 8          | 6.2        |
| Side     | 1326       | 1393       | 9.6        | 6.8        |
| Bottom   | 1128       | 1176       | 10.1       | 10.9       |

4. Conclusion
In this paper, the phase fractions after hot stamping process were calculated by considering both diffusional and non-diffusional phase transformations. And the mechanical properties including hardness, strength and elongation of the final parts were predicted through the analytical and empiric formulas. Those models were integrated in the commercial FEA codes LS-DYNA, and a U-cup part for hot stamping process was simulated. The experimental measured results showed that the simulated values were acceptable and the developed model was reliable.

5. References
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