Investigation of the influence of forming parameters on the springback of hot-stamped hat-shaped parts

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Abstract. The application of hot stamping parts has become a dominant approach to achieve lightweight design and increase crashworthiness performance in the automotive industry. Compared to the cold stamping parts, the main feature of the hot stamped component is its high strength and good size stability. However, recent studies have shown that the springback or size deviation of hot stamped parts caused some assembly problems. This paper aims to investigate the influence of forming parameters on the part’s springback via a hot stamping hat-shaped die. Three different forming parameters with the same blank heating temperature (930°C) were conducted in the study: (1) transfer time 8 sec/die quenching 15 sec (2) transfer time 8 sec/die quenching 8 sec and (3) transfer time 18 sec/die quenching 15 sec. The selected forming parameters are used to evaluate the effect of the before-forming blank temperature and die-opening blank temperature on the springback of the hot stamping parts. The results show that the case 3 with a prolonged transfer time causes a small portion of ferrite phase formation in the hot-stamped part, resulting in the decrease of the tensile strength and a more significant springback is observed.

1. Introduction
Hot stamping has become a dominant design approach to achieve the lightweight goal in the automotive industry [1-2]. In the hot stamping process, firstly the sheet blank is heated to 900-930 °C in the furnace and soaked for 5 minutes. Then the blank is transferred to the die. The upper die moves down to form the blank and close for a few seconds to conduct the die quenching. When the cooling rate is above 27 °C/s, the microstructure of the blank changes from the high temperature soft austenite phase to the hard martensitic phase [3-5].

The springback or size deviation phenomenon of the hot stamped parts is one of the main technical issues need to be solved for the manufacturer. The factors causing springback of hot stamped parts is complex and is a combination effect of elastic recovery, thermal shrinkage, temperature distribution and transformation induced plasticity [6-9]. It is suggested that a sufficient die holding time is required to ensure that the blank temperature is below the martensite finish temperature. It is considered that the martensite phase transformation is beneficial to decreasing the stress level of the hot stamped parts [6].

The work presented in this study aims to investigate the effect of blank temperature before die-closing and quenching time on the springback of hot stamping parts. The following three different forming parameters with the same blank heating temperature (930°C) were conducted: (1) transfer time 8 sec/die quenching 15 sec (2) transfer time 8 sec/die quenching 8 sec and (3) transfer time 18 sec/die quenching 15 sec.
2. Experimental Setup and CAE Model

The hat-shaped hot stamping tool set including cooling channels shown in Figure 1 is installed in a 200 ton hydraulic press. The force of middle pad is 4 ton. The material of the blank is China Steel’s boron steel CSC 15B22 [5]. The chemical composition of 15B22 is listed in Table 1. The blank’s size and thickness are 320 mm x 200 mm and 1.4 mm respectively.

During the experiment, firstly the blank is heated to 930 °C in the continuous furnace and soaked for 3 minutes. Then the blank is transferred to the die for forming and die quenching. As shown in Table 2, three different experimental conditions are carried out in this study. Test 1 and Test 2 compare the formed parts with different die holding time while Test 1 and Test 3 compare the formed parts with different blank transfer time.

A longer transfer time results in a larger temperature drop of the blank before die closing. Each test condition was conducted twice. During the die-tryout, infrared thermal imaging is recorded to monitor the temperature change of the blank. ATOS 3D scanner is used to measure the springback of the hot-stamped parts.

![Figure 1. Schematic of hat-shaped hot stamping tool](image)

### Table 1. Main chemical composition of CSC15B22 [5]

| Steel    | C  | Si  | Mn  | P   | S   | B   |
|----------|----|-----|-----|-----|-----|-----|
| 15B22    | 0.22 | 0.23 | 1.2 | 0.015 | 0.004 | 0.002 |
| Fe       | balance |     |     |     |     |     |

### Table 2. Test conditions of the hat-shaped hot stamping experiment

| Test   | Blank thickness | Blank size | Blank temperature | Soaking time | Blank transfer time | Die holding time |
|--------|-----------------|------------|-------------------|--------------|---------------------|------------------|
| Test 1 | 1.4mm           | 320x200 mm | 930°C             | 3 min        | 8 sec               | 15 sec           |
| Test 2 | 1.4mm           | 320x200 mm | 930°C             | 3 min        | 8 sec               | 8 sec            |
| Test 3 | 1.4mm           | 320x200 mm | 930°C             | 3 min        | 18 sec              | 15 sec           |

After the hot stamping test, the subsize specimen following ASTM E8 standard at different locations (flange, side wall and top surface) were cut from the hat-shaped parts as shown in Figure 2. Tensile test is conducted by a MTS tensile test machine to obtain the part’s strength. The microstructures were also examined by light optical microscope.

![Figure 2. Schematic of tensile test specimen and test locations](image)
The CAE model for the hot stamping process is built by Pam-Stamp software as shown in Figure 3. The 22MnB5 material properties including CCT curves in the software’s database is used for the simulation. The friction coefficient is 0.45. The normal contact pressure and gap dependent heat transfer coefficient is incorporated in the model.

![CAE model for the hot-stamping test](image)

**Figure 3.** CAE model for the hot-stamping test

### 3. Results and Discussions

#### 3.1. Springback (Size deviation)

Figure 4 shows the ATOS 3D scanning results for the three different test conditions. The top surface of the hat-shaped part is used as the reference plane for the comparison between the scanning data and CAD model.

For the parts of Test 1 and Test 2, the springback is \( \leq 0.35 \text{ mm} \), within the OEM’s geometric tolerance requirement (<0.5 mm) for the hot stamping parts. From the results of Test 1 (die holding time=15 sec) and Test 2(die holding time=8 sec), the decreased die holding time does not show any significant effect on the amount of springback. From the infrared thermal imaging results listed in Table 3, it can be observed that the average blank temperature of Test 2 when die opening is 150 °C, higher than that of 112 °C for Test 1 due to a longer die closing time. The results of Test 1 and Test 2 also suggest that the temperature change below 150 °C during cooling-on-air does not cause a noticeable size change for the hot-stamped part.

For Test 3, the scanning result shows that the maximum springback of the part increases to 0.58~0.59 mm. Due to a longer transfer time, the blank’s temperature before die closing has decreased to 576 °C, which may cause a difference in the blank’s microstructure compared to Test 1 and Test 2.

![ATOS 3D scanning results](image)

**Figure 4.** ATOS 3D scanning results
|            | Blank transfer time | Die closing time | Average blank temperature before die-closing | Average cooling rate (in air) | Average blank temperature when die-opening |
|------------|---------------------|------------------|---------------------------------------------|-----------------------------|-------------------------------------------|
| **Test 1** | 8 sec               | 15 sec           | 700 °C                                      | 28.7 °C/s                   | 112 °C                                    |
| **Test 2** | 8 sec               | 8 sec            | 700 °C                                      | 28.7 °C/s                   | 150 °C                                    |
| **Test 3** | 18 sec              | 15 sec           | 576 °C                                      | 19.6 °C/s                   | 107 °C                                    |

### 3.2. Material Strength

The tensile test results for the Test 1, Test 2 and Test 3 specimen are listed in Figure 5. Firstly, it can be seen that the YS and TS on the sidewall are slightly lower compare to the value on the flange and on the top surface. This may be caused by the lower cooling rate on the side wall due to the lower contact pressure on the blank.

Secondly, for the same position, the samples of Test 1 has the highest YS and TS. For Test 2, the die holding time decreased from 15 sec to 8 sec, resulting in a slightly decrease of TS from 1512 MPa to 1499 MPa on the flange, 1450 MPa to 1435 MPa on the sidewall, and 1498 MPa to 1492 MPa on the top surface. For Test 3, the blank transfer time increases from 8 sec to 18 sec, causing a lower average blank forming temperature of 576 °C. The CAE results shown in Figure 6 indicate that this leads to a small portion (2~2.6%) of ferrite phase transformation. The TS and YS of Test 3 are the lowest among three test conditions. Compare to Test1, TS drops from 1512 MPa to 1464 MPa (-3.4%) on the flange, 1450 MPa to 1424 MPa (-1.7%) on the sidewall, and 1498 MPa to 1463 (-2.3%) on the top surface.

**Figure 5.** Tensile test results

**Figure 6.** Simulation results for the prediction of ferrite phase fraction. The color bar represents the phase fraction of martensite (upper) and ferrite (lower).
3.3. Microstructure
Phase transformation of boron steel is influenced by the cooling rate. A sufficiently high cooling rate (>27 °C/s) results in a full martensitic microstructure while a slower cooling rate causes a bainite or ferrite/pearlite phase transformation [1-2].

Figure 7 shows the microstructure of hot-stamped parts under Test 1, Test 2 and Test 3 forming parameters. For Test 1 and Test 3, the blank is transferred to the die immediately after exiting the furnace with a transfer time of 8 sec before die closing. The microstructure on the flange, side wall and top surface all show a martensitic microstructure. For Test 3, due to the intentionally prolonged blank transfer time (18 sec), the average temperature drops to 576°C. This air cooling thermal history induces a small portion of ferrite phase transformation as observed microstructure.

The microstructure observation is in accordance with the CAE prediction shown in Figure 6. The tensile strength of ferrite is around 600 MPa, comparably lower than that of martensite of 1500 MPa [2]. This explains the tensile test results showing that the strength of Test 3 is slightly lower than that of Test 1 and Test 2. The formation of ferrite in the blank may cause unbalanced stress distribution compared to the part with a fully martensitic microstructure, resulting in a more significant springback as shown in Figure 4 after stress relaxation when the part is removed from the die.

Figure 7. Microstructures of the hot stamped parts for Test 1, Test 2 and Test 3 conditions with the blank transfer time of 8sec, 8sec and 15sec respectively. From left to right shows the microstructure on the flange, side wall and top surface respectively.
A typical continuous of cooling transformation of 22MnB5 is shown in Figure 8 [10]. The critical cooling rate to avoid bainite and ferrite transformation is 27 °C /s. For Test 1 and Test 2, the average air cooling rate of the blank is 28.7 °C /s, which is slightly above the critical cooling rate. For Test 3, the average air cooling rate is decreased to 19.6 °C /s due to a prolonged transfer time, a slower cooling rate causes the formation of ferrite observed in Figure 7.

The CAE results also show that for the Test 3 case, the formation of 1.9% ferrite phase fraction could be observed during air cooling while Test 1 and Test 3’s blank maintains a fully austenite state before die closing, which is consistent with the experimental observation.

4. Conclusion
The work presented in this paper discusses three different forming parameters and compare the amount of springback for hat-shaped hot stamping parts. The springback of the parts increases when the blank transfer time increases from 8 to 18 sec. The increase in the transfer time leads to the formation of ferrite microstructure. The ferrite/martensite mixed microstructure may cause unbalanced stress distribution during the die quenching. After stress relaxation, a more significant springback of the formed parts is observed.

For the tests of the same blank transfer time, the decrease of die quenching time from 15 sec to 8 sec is only slightly lowering the part’s strength, while the amount of springback does not show a significant difference. For the hot stamping process, ensuring a sufficient die quenching time and decreasing the blank transfer time are suggested in order to increase the part’s strength and prevent excessive springback.

References
[1] Karbasian H and Tekkaya A E 2010 J. Mater. Process. Technol. A Review on Hot Stamping 210 p 2103–2118
[2] Taylor T and Clough A 2018 Mater. Sci. Technol. Critical Review of Automotive Hot-Stamped Sheet Steel from an Industrial Perspective 34 p 809–861
[3] Hu K, Zhou S, Han R, Gao J and Yang Y 2018 J. Mater. Sci. Chem. Eng. Microstructure Evolution and Simulation in 22MnB5 Steel during Hot Stamping 6 p 9–14
[4] Nikravesh M, Naderi M, Akbari G H and Bleck W 2015 Mater. Des. Phase Transformations in a
Simulated Hot Stamping Process of the Boron Bearing Steel 84 p 18–24

[5] Wang S W and Lee P K 2013 China Steel Technical Report Investigation of Die Quench Properties of Hot Stamping Steel 15B22 26 p 22–31
http://www.csc.com.tw/csc_e/ts/ena/publ.html

[6] Nakagawa Y, Mori K I and Maeno T 2018 The Int. J. Adv. Manuf. Technol. Springback-Free Mechanism in Hot Stamping of Ultra-High-Strength Steel Parts and Deformation Behaviour and Quenchability for Thin Sheet 95 p 459–467

[7] Bao J, Liu H, Xing Z, Song B and Yang Y 2013 Eng. Rev. Springback of Hot Stamping and Die Quenching with Ultra-High-Strength Boron Steel 33 p 151–156

[8] Lee M G, Kim S J and Han H N 2009 Comput. Mater. Sci. Finite Element Investigations for the Role of Transformation Plasticity on Springback in Hot Press Forming Process 47 p 556–567

[9] Nakagawa Y, Mori K I and Maeno T 2016 Key Eng. Mater. Prevention of Local Thinning and Springback in Hot Stamping of Thin Sheets 716 p 487–493

[10] Min J, Lin J, and Li J 2011 J. Comput. Theor. Nanosci. Effect of Deformation Temperature on the Microstructure of Boron Steel 22MnB5 4 p 938–942