Numerical and Experimental Investigation on Hot Stamping of TWB B-Pillar

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Abstract. In order to achieve the targeted crashworthiness performance, the application of Tailor-Welded-Blank (TWB) on the crash-relevant components has become a trend in the automotive industry. This paper aims to investigate the mechanical property and structural performance of the hot stamped TWB B-pillars. After hot stamping, the strength grade for the hard zone is 1500 MPa while the soft zone’s strength grade is 590 MPa. The CAE model shows that the intrusion distance is decreased for the TWB design compared to the monolithic material B-pillar. The three point bending performance could be adjusted by changing the range of the soft zone. It is observed that the weld line has a low crack sensitivity during hot stamping. The transition zone between the hard zone and soft zone is less than 1mm. The ATOS scanning results show that no significant effect on the part’s size deviation for the TWB design compared to the monolithic material B-pillar.

1. Introduction
In recent years, hot stamping has become the most efficient way for automakers to reach the goal for body structure lightweight and safety performance improvement. During the traditional hot stamping process, a blank is first heated and soaked in the furnace at the temperature range 900-930 °C, then the blank is quickly transferred to the die for forming and in-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 with an ultimate tensile stress above 1450 MPa [1].

In order to enhance the crashworthiness and better protect the passenger’s safety, the application of hot stamping parts has changed from the monolithic material to tailored property design [2]. The combination of tailor-welded blank (TWB) and hot stamping process can produce a body structural part which includes both the hard zone and soft zone. During the crash, the hard zone can prevent intrusion while the soft zone can absorb more kinetic energy [3]. Peister et al. investigated the mechanical property of TWB Usibor1500-AS/Ductibor500-AS via a hat shaped hot stamping die, and the results showed that the width of transition zone between hard/soft zones is smaller than 2 mm [4]. Peister et al. also discussed the axial crush energy absorption behavior of Usibor1500-AS/Ductibor500-AS TWB rails, and the weld seam failure was not observed during the crush test [5]. Choi et al. investigate the weld line’s displacement of HPF1470/340Y TWB after hot-stamping via a lab-scale B-pillar, and the results show that the weld line’s movement during forming is related to the range of soft zone [6]. The load–displacement curve under the three point bending test and part’s size deviation for the monolithic material and TWB hot stamped parts are rarely discussed.
In this study, the numerical and experimental investigations on the CSC15B22/440W TWB hot stamped B-pillar were conducted. The width of transition zone between the hard zone and soft zone after hot stamping was measured. A simplified CAE model was used to predict the energy absorption performance for the three point bending tests. The effect of soft zone’s range on the intrusion distance and energy absorption was discussed. Finally, the size deviation for the monolithic material and TWB hot stamped parts were compared.

2. Experimental method

2.1 TWBs sample preparation, die try-out and three point bending test

As shown in Figure 1, three different types of blanks (Monolithic material/TWB with the soft zone d=110 mm/TWB with the soft zone d=260 mm) are prepared for the B-pillar hot stamping die tryout. The material used for the hard zone is CSC15B22, and the material used for the soft zone is 440W. The thickness of 15B22 and 440W are both 1.8 mm. The main chemical composition of 15B22/440W are listed in Table 1.

![Figure 1. Preparation for the monolithic material blank and TWBs](image1)

(a) Monolithic  
(b) TWB \_d=110 \text{mm}  
(c) TWB \_d=260 \text{mm}

The B-pillar hot stamping die and three point bending test jig are shown in Figure 2. The monolithic material blank and TWBs are heated to 930 ℃ and soaked for 4 minutes in the furnace. Then the blank is manually transferred to the die. The transfer time is 8–10 seconds. Die quenching time is 15 seconds, and the die holding pressure is 550 ton. The die tryout parameters are listed in Table 2.

![Figure 2. Hot stamping die tryout and three-point-bending test](image2)

(a) TWB before die closing  
(b) After die quenching  
(c) Three-point-bending test jig

| Material | C  | Si  | Mn   | P    | S    | B   |
|----------|----|-----|------|------|------|-----|
| 15B22    | 0.2-0.25 | 0.2-0.3 | 1.0-1.5 | 0.015 | 0.004 | 0.002 |
| 440W     | 0.05-0.1 | 0.04-0.08 | 1.0-1.5 | 0.015 | 0.0018 | 0.0002 |

Fe : balance (wt%)
Table 2. Die tryout parameters of monolithic and TWB B-pillars

| Blank Temperature (°C) | Furnace Atmosphere | Soaking Time (sec) | Transfer Time (sec) | Die Holding Time (sec) | Die Holding Pressure (ton) |
|------------------------|--------------------|--------------------|--------------------|------------------------|--------------------------|
| 930                    | N₂                 | 240                | 8~10               | 15                     | 550                      |

2.2 CAE model setup

In order to compare the energy absorption characteristic for the monolithic and TWB B-pillars, a three point bending CAE model is built by PAM-STAMP. Figure 3 shows the three point bending test jig model and the mesh of TWB B-pillar. Our test results show that the HAZ of the laser weld seam is very narrow (<1 mm), so the mechanical property of the weld line is not incorporated in the model, only material data for 15B22 and 440W are input. The weld line is built before meshing to insure the mesh has good connectivity between the hard zone and soft zone.

As shown in Figure 4, three different B-pillar designs are discussed in this study: Monolithic, TWB_soft zone 110 mm, and TWB_soft zone 260 mm. For the TWB_soft zone 110 mm design, the weld line is close to the B-pillar’s bottom end and located outside the punch projection area. For the TWB_soft zone 260 mm design, the weld line is close to the projection of punch’s center line.

Figure 3. Schematic of three point bending CAE model

![Figure 3](image)

(a)Monolithic (b)TWB_soft zone 110 mm (c)TWB_soft zone 260 mm

Figure 4. Schematic of monolithic and soft zone’s range for the TWB B-pillars

To further compare the intrusion distance for the monolithic and TWB B-pillar designs, a simplified fixed-end CAE model is used as shown in Figure 5. During the side impact, the intrusion displacement of the B-pillar is critical to the passenger’s safety. Point A, which is close to the passenger’s chest height, is selected as the observation point during the simulation. The intrusion displacements and section profiles for different B-pillar designs are compared under the same intrusion distance of the punch.
2.3 Mechanical property test and ATOS scanning
After die tryout, the tensile test specimen following ASTM E8 standard at different locations of 15B22 and 440W were cut from the hot-stamped B-pillars. The microstructure of the weld line is also examined by light optical microscope. Finally, ATOS 3D scanner (Compact Scan 8M) is used to measure the size deviation of hot-stamped B-pillars.

3. Results and Discussions
3.1 Hot stamping parts
Figure 6 shows the hot stamped TWB pillars with the soft zone 110 mm and 260 mm. A clear color difference is observed between the hard zone 15B22 and the soft zone 440W. During hot stamping, the blank holder first clamps the sheet’s flange then the punch moves down to close the die. The weld line is under tangential and normal tension force during the drawing process. No crack is observed for the weld lines even on the corner and stepwise part profiles, indicating that the weld line has a low crack sensitivity during hot stamping. This is rational because when the blank is heated to 930 °C, the material of 15B22, 440W and weld line are all become austenite and have good formability at high temperature.
3.2 Material Strength

The tensile test specimen is cut from the hot stamped B-pillar as shown in Figure 7. Sample #1–#3 are located at the 440W soft zone. Sample #4–#5 are located at the flange area of hard zone 15B22, and sample #6–#7 are located on the side wall of hard zone 15B22. Two different types, laser cutting and CNC milling, of tensile test specimen are prepared. The tensile test results are listed in Table 3. For the laser cutting samples, the average tensile strength is 594 MPa for 440W, and 1511 MPa for 15B22. For the CNC milling samples, the average tensile strength is 590 MPa for 440W, and 1514 MPa for 15B22. No significant difference in strength is observed between the specimen prepared by laser cutting and CNC milling.

![Figure 7. Tensile test results](image)

Table 3. The average tensile strength of hot stamped 440W/15B22

| Sample preparing method | Average Tensile Strength (MPa) |
|-------------------------|-------------------------------|
| 440W                    | 594                           |
| 15B22                   | 1511                          |
| Laser Cutting Material  |                               |
| CNC Milling             |                               |

3.3 Three point bending CAE results

The experimental and simulation results for the three point bending test are shown in Figure 8. It can be observed that the punch’s load-displacement curve is affected by the adoption of soft zone design. The monolithic, all hard zone 15B22 design, has the highest punch reaction force. For the TWB_soft zone 110 mm design, only a slightly drop in the reaction force observed because the punch is still in contact with the hard zone of the B-pillar under the punch movement. For the TWB_soft zone 260 mm design, a significant drop in the punch load is noticed because when the punch is pressing the B-pillar, the 440W soft zone will deform first due to its comparatively lower strength.

The discrepancy between the experimental and simulation results is noticed when the punch displacement exceeds 60 mm. A reasonable guess is that the B-pillar is not rigidly fixed in the jig during the test. Sliding between the B-pillar and test jig during the punch movement will affect the prediction of the B-pillar’s deformation and thus affect the punch’s load curve. Figure 9 shows the comparison of energy absorption capability between the simulation and experimental results under the punch movement range 0-60 mm. The CAE simulation shows a good agreement with the experimental results for all three types of B-pillar design.
Figure 8. Experimental and CAE simulation results for the three point bending test

Figure 9. Comparisons for the energy absorption for the three point bending at the range of punch displacement 0-60mm

Figure 10 shows the intrusion distance at the observation point A for three different types of B-pillar design. It can be seen that the monolithic design has the maximum intrusion distance while the TWB_soft zone 260 mm design has the lowest intrusion value. As listed in Table 4, the intrusion distances for the monolithic, TWB_soft zone 110mm and TWB_soft zone 260 mm designs are 81.3, 79 and 71.9 mm respectively. A lower intrusion distance represents more safety room kept for the passenger during crash.

Figure 10. Simulation results for the intrusion distance and section profile at the observation point A.
### Table 4. Intrusion distance of observation point A

|          | Monolithic All hard zone (mm) | TWB Soft zone 110mm (mm) | TWB Soft zone 260mm (mm) |
|----------|-------------------------------|--------------------------|--------------------------|
|          | 81.3                          | 79                       | 71.9                     |

3.4 Microstructure and hardness distribution of the weld line

Figure 11 shows the microstructure of 440W and 15B22 specimen cut from the hot-stamped parts. The main microstructure of 440W is ferrite with a small portion of pearlite. The microstructure of 15B22 has become fully martensite due to its high hardenability after the die quenching process.

The micrograph and hardness distribution of the weld line is shown in Figure 12. The average hardness of 440W is 194 HV0.3, while the average hardness of 15B22 is 487 HV0.3. The width of transition zone between 440W and 15B22 is within 1 mm. Since the transition zone is very narrow, the neglecting of weld line’s material property in the CAE model is acceptable. It can be noticed that the transition zone’s hardness is roughly the average value of 440W and 15B22, and showing a continuous change in hardness between the base material and weld line.

![Figure 11. Microstructures of hot-stamped 440W and 15B22](image1)

![Figure 12. Micrograph of the laser weld line’s cross section and hardness indent pattern. Hardness distribution profile of the weld line’s cross section](image2)
3.5 ATOS 3D scanning results

Figure 13 shows the ATOS 3D scanning results for the monolithic, TWB_110 mm soft zone and TWB_260 mm soft zone’s hot stamped B-pillars. The color shown in dark grey represents the area with the size deviation greater than +0.5 mm, while the color shown in light grey represents the area with the size deviation smaller than −0.5 mm.

For the monolithic B-pillar, the material is fully 15B22 so there is no boundary between the hard zone and soft zone. It can be noticed that only the upper left portion’s geometry exceeds ±0.5 mm size deviation. For the TWB_soft zone 110 mm design, the trend is quite similar. There is an insignificantly increase on the upper left area’s size deviation (+1.08 mm). The size deviation of the top flange’s middle area has a slightly increase, but still within the ±0.5 mm tolerance requirement. The 110 mm soft zone is marked by the red dashed line. It is observed that no significant deterioration in the size deviation for the soft zone including the weld line’s adjacent area.

For the TWB_soft zone 260 mm design, the size deviation of the soft zone is also within the ±0.5 mm tolerance requirement. No significant increase in the size deviation is observed. This is beneficial to the TWB’s application, indicating that the adoption of TWB design does not noticeably deteriorate the part’s dimension accuracy.

![Figure 13](image)

**Figure 13.** ATOS 3D scanning results for the (a) Monolithic (b) TWB_soft zone 110 mm and (c) TWB_soft zone 260 mm B-pillars
4. Conclusion
Numerical and experimental investigations on the monolithic and TWB B-pillars are conducted in this study. The energy absorption behavior is strongly influenced by the adoption and the range of the soft zone. The TWB CAE model without incorporating the weld line’s material property could effectively predict the punch’s load-displacement curve for the three-point-bending test. The CAE results show that the adoption of TWB design decreases the intrusion distance at the passenger’s chest height. The transition zone of the TWB is less than 1mm, and the die tryout shows that the weld line has a low crack sensitivity during hot stamping. The size deviation of TWB B-pillars show the same trend as the monolithic B-pillar design, and there is no significant increase in the size deviation observed in the soft zone. The adoption of TWB design does not noticeably deteriorate the part’s dimension accuracy.

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