

The Investigation on the Energy Absorption Performance of Hot Stamping Tailor-Welded Blanks (TWBs) via the Hat-Shaped Three Point Bending Test

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Hot stamping technology has become an unavoidable approach to achieve the automotive body structure lightweight design. The application of tailor welded blanks (TWBs) on the hot stamped parts has become more common for some safety concerned parts such as B-pillar in order to meet the required energy absorption characteristic. This study investigates the energy absorption performance of hot stamping single property and TWB hat-shaped samples via the three-point bending test. The results show that the material grade and welding line's orientation play an important role in the energy absorption performance. For the TWBs the peak reaction force is dominated by the hard zone's material strength. The simplified CAE model developed in this study is sufficient to predict the energy absorption characteristic for the TWB hot stamping parts design.

Keywords: Hot stamping, Tailor welded blanks (TWBs), Energy absorption, Three-point bending test

1. INTRODUCTION

The application of hot stamping parts on the body structure has become an unavoidable approach for the lightweight design in the automotive industry⁽¹⁾. For the hot stamping or so called press hardening manufacturing process, the blank is heated up to 930 degree Celsius in a furnace, and subsequently transferred to a die. The die then closes and usually holds for 8-15 seconds to quench the blank. During die quenching, the microstructure of the blank changes from the high temperature soft austenite phase to the hard martensite phase if the cooling rate exceeds 27 degrees per second, raising the part's tensile strength up to 1500 MPa. In recent years, tailored property components have been applied in some specific safety concerned parts such as the B-pillar in order to meet the required energy absorption characteristic⁽²⁾. As shown in Fig.1, during the side impact the upper hard zone can resist the part deformation while the bottom soft zone can absorb the impact energy. This leads to the adaption of tailor welded blanks (TWBs) as the initial sheet in the hot stamping process. Merklein et al. discusses the manufacturing process for the tailored property B-pillars made by controlling the die quenching speed and by using laser welded blanks⁽³⁾. Li et al. investigate the mechanical property and energy absorption performance for hot stamped door impact beam⁽⁴⁾. Nevertheless, the effect of the adoption of TWBs on the hot

stamped part's energy absorption capability is rarely discussed. The aim of this study is to investigate the energy absorption performance of different material grades TWBs, and compare the results with traditional single property hat-shaped hot stamped parts. The results of this study can provide insight into TWBs hot stamping part design.

(Consider expanding Figures 4 through 7 definition between a,b,c and d labels in relation to text reference.)

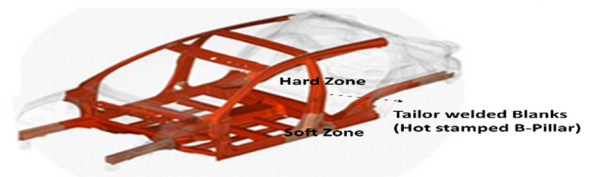


Fig.1. Schematic illustration for the application of TWBs on hot stamping parts.⁽²⁾

2. EXPERIMENTAL METHOD

2.1 Hot stamping samples preparation

The hat-shaped samples for the three-point bending test are prepared via the 200 tons hot stamping line in China Steel Corporation (CSC). Both the single property blanks and TWBs are prepared for the experiment. For the single property samples, the material of CSC's coated 15B22/590Y/340LA/440W are selected. For the

TWBs, the hard zone's material is 15B22 while the soft zone's material is 440W or 590Y as shown in Fig.2. (Are all the blanks the same size? If so consider the following correction.) The size of the blanks are 320mm x 200mm with a thickness of 1.4mm. Figure 3(a) shows the hat-shaped hot stamping die, the blank is first heated up to 930 degree Celsius in the furnace for 3 to 5 minutes. Then the blank is transferred to the die for forming and die quenching. The die holding time is 15 seconds. The temperature of cooling water for the hot stamping die is 27 degree Celsius. Figure 3(b) and 3(c) show the hot stamped single property and TWB's hat shaped samples, respectively.

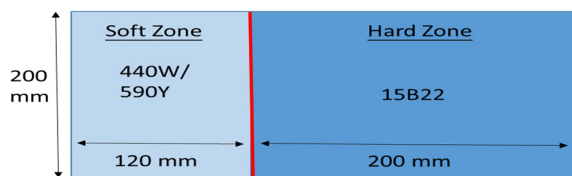


Fig.2. The size of the tailor welded blank ($t=1.4\text{mm}$).

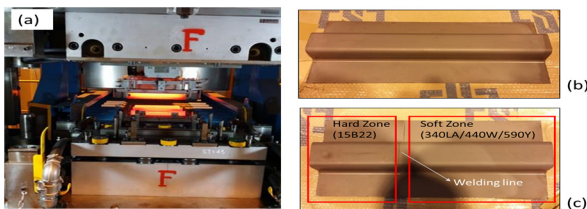


Fig.3. The hat-shaped hot stamping die and formed samples.

2.2 Three-point bending test

In the automotive industry, the three-point bending test is a widely used approach to evaluate the energy absorption capability for the hot stamped parts⁽⁵⁻⁶⁾. The experimental apparatus is shown in Fig.4. The roller diameter is 30.8mm. The span of the lower two supporting rollers is 220mm. The upper roller's moving velocity is 50mm/min towards the sample. Figure 4(a) shows the sample setup before the test, and Fig.4(b) shows the deformed sample after the test. The punch force and punch displacement was recorded during the experiment. The projection of the punch centerline is located

in the hard zone with a distance of 40mm from the welding line. In order to avoid the side wall opening of the hat-shaped samples during the punch loading, a 980Y/1.2t plate is spot welded on the bottom side of the sample as shown in Fig.4(c).

2.3 CAE simulation model setup

In this study, the CAE (Computer Aided Engineering) software of PAM-STAMP is used as the tool to simulate the three-point bending test. The simulation results will be compared with the experimental data later. The models for the single property sample, transverse welding line's TWB sample, and longitudinal welding line's TWB sample are established as shown in Fig.5(a), Fig.5(b) and Fig.5(c), respectively. The tensile test specimens are cut from the hot stamping parts in order to obtain the stress-strain curves. The true stress-strain curves for 15B22/590Y/340LA/440W are plotted in Fig.5(d).

3. RESULTS AND DISCUSSION

3.1 Three-point bending test results

The three-point bending test results for the single property samples are shown in Fig.6(a). It can be observed that the punch reaction force increases with the material's strength. The ranking of the punch force is : $15B22 > 590Y > 340LA > 440W$. The sequence is in accordance with the stress strain curves listed in Fig.5(d). The area under the punch force-displacement curve represents the energy absorption capability. The test results for the transverse welding line's TWB samples are shown in Fig.6(b). The curve of transverse TWB 15B22 + 590Y is very similar to the curve of single property 15B22 because during the three-point bending test the punch is in contact with the hard zone's material 15B22. Thus, the hard zone's material grade dominates the three-point bending performance. It can be observed that the punch force of 15B22+440W starts to decrease after a punch displacement of 30 mm, indicating that the material grade in the soft zone can still cause a different energy absorption characteristic.

Table 1 lists the maximum punch force and energy absorption for the single property and transverse welding line's TWB samples. Compared to the 15B22 sample, the maximum punch force of 590Y, 340LA, and



Fig.4. The apparatus and samples for the three-point bending test.

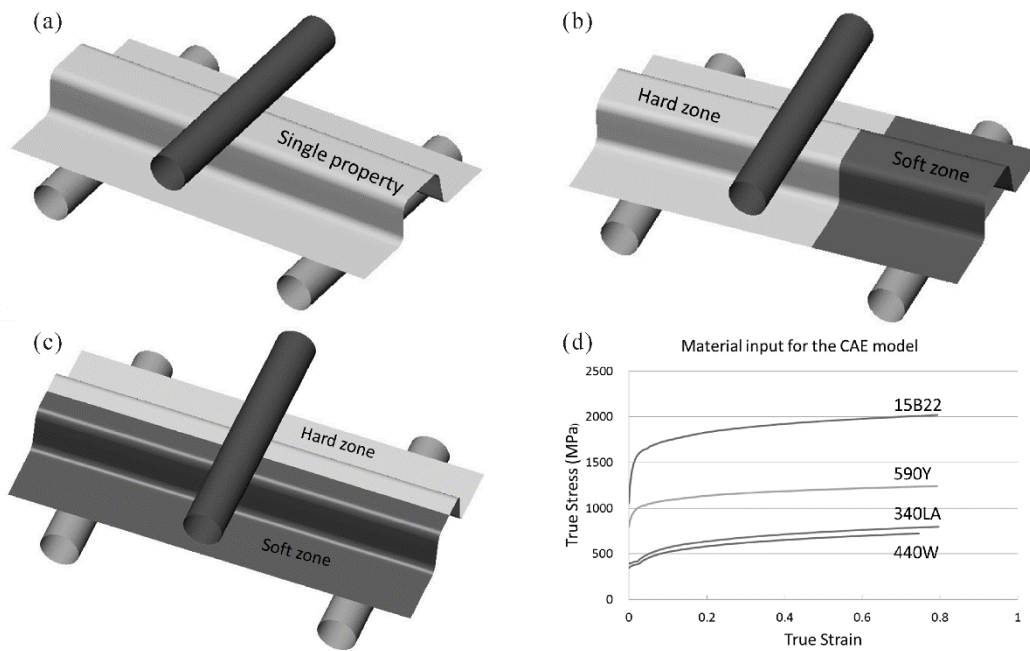


Fig.5. CAE model setup and stress-strain curves for the material input.

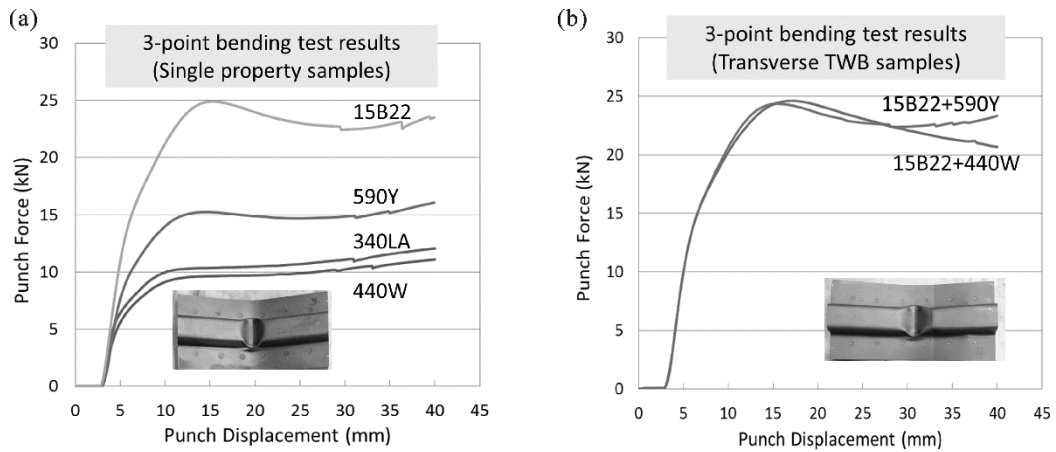


Fig.6. Experimental results for the three-point bending test.

Table 1 Three-point bending test results for the single property and transverse TWB samples

Blank	15B22	590Y	340LA	440W	15B22+590Y Transverse TWB	15B22+440W Transverse TWB
Max. Force (kN)	25 (100%)	15.2 (60.8%)	10.5 (42%)	9.7 (38.8%)	24.4 (97.6%)	24.6 (98.4%)
Energy Absorption (J)	783 (100%)	506 (64.6%)	369 (47.1%)	340 (43.4%)	780 (99.6%)	769 (98.2%)

440W drops to 60.8%, 42% and 38.8%, respectively. The energy absorption decreases to 64.6%, 47.1% and 43.4% accordingly. For the transverse TWB samples, the maximum force and energy absorption capability only decreases within 3% compared to the single property 15B22 sample.

3.2 Comparisons for the transverse and longitudinal TWBs

In order to investigate the effect of the welding line's orientation on the energy absorption performance, the hot stamped hat-shaped samples for the longitudinal

welding line was also prepared for conducting the three-point bending test. The samples with the transverse and longitudinal welding line are shown in Fig.7(a) and Fig.7(b), respectively. The experimental results are shown in Fig.7(c), it can be observed that the energy absorption capability for the longitudinal TWB samples are lower than that of transverse TWB samples. It can be explained that when the longitudinal TWB sample deforms, the punch is in contact with both the soft zone and hard zone. The punch force is affected by the soft zone's material strength. Thus, the punch force of longitudinal TWB 15B22+590Y is higher than that of 15B22+440W. For the transverse TWB samples, the punch is fully in contact with the hard zone's material, causing the energy absorption capability to be dominated by 15B22. This explains why the punch force of transverse TWB samples is higher than longitudinal TWB samples. Table 2 lists the experimental results for the transverse and longitudinal TWB samples. Compared to the 15B22 single property sample, transverse TWB samples still keep 97.6% of maximum force and 98.2% of energy absorption. For the longitudinal TWB samples, the peak force for the 15B22+440W and 15B22+590Y drops to 68.4% and 77.6%, respectively.

The energy absorption capability drops to 72.2% and 80.9% accordingly. Transverse TWB samples show a better three-point bending performance than the longitudinal TWB samples.

3.3 CAE simulation results

Figure 8(a) shows the CAE simulation results for the single property samples. The trend is in accordance with the experimental results as shown in Fig.6(a). Higher material strength causes higher punch force. The simulation results for the transverse and longitudinal TWB samples are shown in Fig.8(b). Similar to the experimental results, transverse TWB samples show a higher peak force compared to that of longitudinal TWB samples. The CAE prediction for the punch force is higher than the experimental data. The difference in the magnitude prediction may be affected by the friction between the rollers and the sample, the material property of the welding line and the range of the heat affected zone. Nevertheless, for the TWB related part design purpose, the simplified CAE model developed in this study is sufficient to predict the effect of material grade and welding line's orientation on the energy absorption capability.

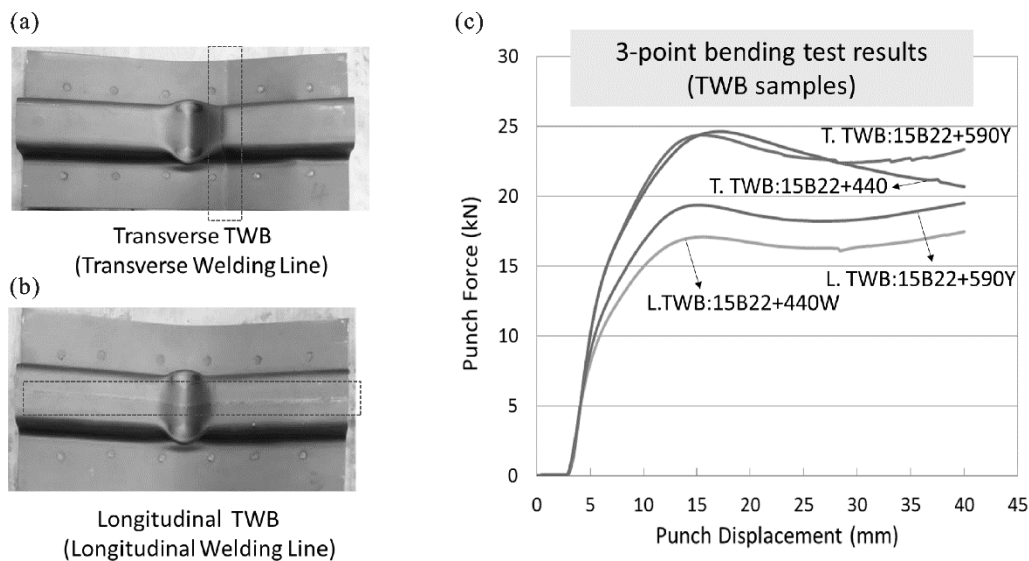


Fig.7. Schematic illustration for the transverse and longitudinal TWBs and test results.

Table 2 Three-point bending test results for the transverse and longitudinal TWB samples

Blank	15B22	15B22+590Y Transverse TWB	15B22+590Y Longitudinal TWB	15B22+440W Transverse TWB	15B22+440W Longitudinal TWB
Max. Force (kN)	25 (100%)	24.4 (97.6%)	19.4 (77.6%)	24.6 (98.4%)	17.1 (68.4%)
Energy Absorption (J)	783 (100%)	780 (99.6%)	634 (80.9%)	769 (98.2%)	566 (72.2%)

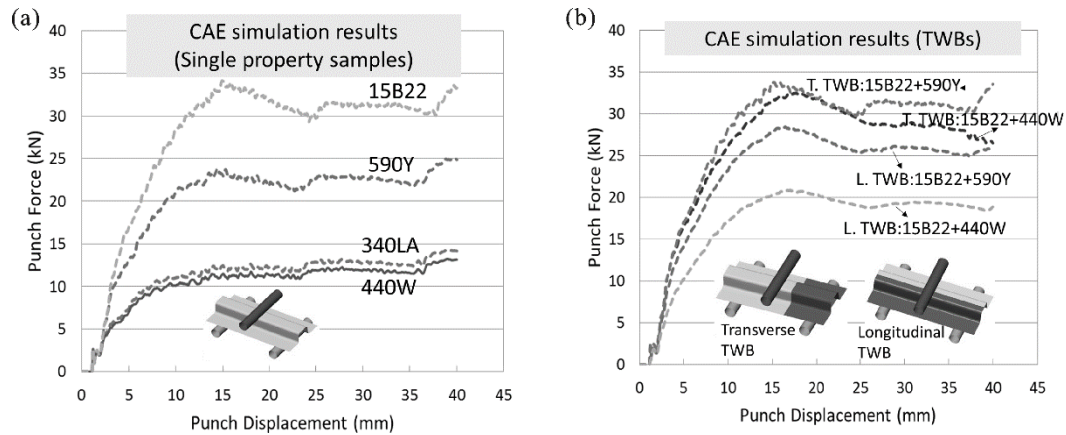


Fig.8. CAE simulation results for the single property and TWB samples.

4. CONCLUSIONS

1. For the hot stamped single property hat-shaped samples, the three-point bending test results show that the energy absorption capability is proportional to the material's strength. The ranking of the energy absorption capability is : 15B22 > 590Y > 340LA > 440W.
2. The punch force-displacement curves of transverse TWB 15B22+590Y and TWB 15B22+440W are very close to the curve of single property 15B22. The material grade in contact with the punch dominates the magnitude of punch force.
3. The energy absorption capability for the longitudinal TWB samples are lower than that of transverse TWB samples. For the longitudinal TWB samples, the punch is half in contact with the soft zone's material, causing a decrease in the energy absorption performance.
4. The simplified CAE model developed in this study is sufficient to predict the effect of material grade

and welding line's orientation on the energy absorption capability for the hot stamping parts design.

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