Experimental and Numerical Investigations on the Effect of Weld Zone on Springback in V-Bending of Tailor Welded Blanks of High Strength Steel

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Abstract

Springback behaviour in tailor welded blanks is very complex due to the differences in properties and thickness and the effect of the weld zone. The presence of weld zone is one of the challenging issues in numerical simulations for accurate prediction of springback in tailor welded blanks. Consideration of weld zone properties in Finite Element simulations enhances the accuracy of the results although simulation time increases. In this paper, experimental and numerical studies on the effect of presence of weld zone on springback behaviour of longitudinally welded tailor welded blanks in a V-bending operation are presented. Tailor welded blanks, prepared by laser welding of high strength steel sheet specimens with three different thickness combinations, have been used in the experimental studies. Two different punch profile radii of 10mm and 12.5mm have been used to characterize the springback. FE simulations have been performed using ABAQUS with Hill's plasticity model and the results showed good agreement with experimental results.

Keywords: Springback, Tailor welded blanks, Weld zone, V-bending.

1 Introduction

Tailor welded blank (TWB) is a combination of two or more blanks of different thickness or properties welded in a single plane prior to forming. Weight reductions to address environmental problems and enhancement in crashworthiness for occupant's safety are the major advantages offered by TWBs of high strength steel. However, with the increase in the application of various high strength steels in TWBs, automotive industries are facing challenges due to batch inconsistency, higher press capacities, reduced tool life and larger complex springback in sheet metal forming. Springback, most pronounced in sheet metal deformation, is defined as the elastic recovery after deformation of a material possessing finite elastic constants. Springback causes change in the geometry of formed components after the removal of forming loads and necessitates adequate measures to deal with increased elastic recovery of high strength steel sheets at room temperature. Springback behaviour in TWBs is a complex problem due to the presence of a narrow weld zone between two or more parent materials. Bayraktar et al. (2008) and Merklein et al. (2014) reported that TWBs have weld zones characterized with higher strength and hardness but lower ductility than the parent materials. Ciubotariu and Brabie (2011) emphasized on the quality of weld line as a major factor affecting the quality of formed components. The difference in strengths between tailored materials and high strength weld region can cause the concentration of deformations in the softer material affecting the springback behaviour in TWBs. Accurate prediction of springback in TWBs is necessary in sheet bending to allow optimum die design incorporating springback compensation as a corrective measure. Numerical simulation is most economical and dependable in the prediction of springback in industrial production as compared to conventional trial and error approach. Shi et al. (2008) investigated the behaviour of weld line under realistic impact loading and suggested that inclusion of weld zone properties in numerical simulations enhances the accuracy of results although simulation time increases. However, the inclusion of weld zone is one of the challenging issues in the forming simulation to understand the springback behaviour of TWBs. In the present study, experimental and numerical investigations on the effect of the weld zone on springback in V-bending of TWBs welded in longitudinal direction are presented.

2 Methodology

In order to determine the springback behaviour of TWBs, a series of bend tests were conducted for parent materials and TWBs. Three thickness combinations (in mm) of high strength steel, i.e. 0.9: 1.2, 0.9: 1.6 and 1.2: 1.6 were used in the bending experiments using a V-bend die-punch set with two different punch profile radii of 10mm and 12.5mm.

2.1 Properties of parent materials and TWBs

The present study is based on high strength steel which is preferred in automobile body structural parts due to its increased energy absorption in a crash and good formability. The chemical composition was obtained by optical emission spectrometric analysis and is shown in Table 1.

Table 1 Chemical composition of High Strength steel (in wt%)

Sheet metal thickness	C	Mn	Si	Al	Ni	Cr	S	P
0.9mm	0.077	1.451	0.028	0.044	0.026	0.034	0.007	0.026
1.2mm	0.068	1.509	0.028	0.038	0.021	0.026	0.008	0.022
1.6mm	0.070	1.420	0.020	0.044	0.014	0.023	0.011	0.023

The sheets were laser welded with required thickness combinations at a speed of 4.8mm/sec in an inert atmosphere of Argon with a flow rate of 10lt/min by a 4kW capacity, Nd-YAG Laser. During laser welding the rolling direction of sheet was kept perpendicular to the weld line, as is the regular practice in the preparation of TWBs.

The tensile test specimens of parent materials were prepared by laser cutting and tests were carried out as per ASTM E8M standard on a 50kN UTM at room temperature with a cross head speed of 5mm/min. The sub-sized tensile specimens of TWBs with weld orientation in both longitudinal and transverse directions were prepared by wire cut-electric discharge machining (EDM) and were tested in uniaxial tension.

2.2 Micro hardness test and tensile properties of weld region

Small samples containing the weld region and parent material on both the sides of it were carefully cut by diamond abrasive wheel and were mounted using Bakelite for optical metallography. The mounted specimens were fine polished and etched with 2% Nital solution (2% Nitric acid + 98% Methyl alcohol) to reveal the microstructure. The mounted specimens were also tested for Vickers hardness by making a series of micro indentations under a load of 100g, after a set interval of 0.5mm across the parent materials and weld region to reveal the extent of weld zone as shown in Fig. 1.

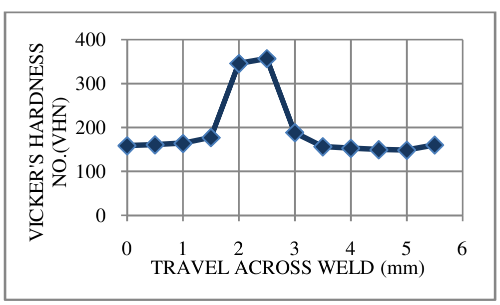

Figure 1 Variation of micro hardness across the weld region

On the basis of microstructural studies and Vickers Hardness Number (VHN), tensile specimens of very small width (equal to the width of the weld zone), as shown in Fig. 2, were cut by wire-EDM in such a way that the weld line was parallel to the loading direction and coincided with the symmetry of the specimens. However, due to very small size of the weld zone it was not possible to use standard size tensile specimens. Rojek et al. (2012) presented different methods which can be used to determine mechanical properties of weld zone in TWBs and suggested that tensile method is one of the best methods. Therefore, specimens of the weld zones were tested for tensile properties in uniaxial tension on a 50kN UTM.

Figure 2 Tensile specimens of weld zone

2.3 Experimental set up for springback

The experimental set-up consists of V-dies and punches with profile radii of 10mm and 12.5mm as shown in Fig. 3 with an included bend angle of 90°. The clearance between the punch and the die was kept equal to the sheet thickness in order to prevent any kind of localized compressive stresses. The die and punch sets fabricated from AISI-D2 steel were air hardened and tempered.

Figure 3 Die and punch set

The V-bending experiments were carried out on a 50kN UTM by securing the punch in the jaws of movable cross head and the die clamped to the stationary wedge grips as shown in Fig 4.

Figure 4 Experimental set-up for determination of springback in V-bending

The punch was displaced with a cross head speed of 20mm/min under the control of dedicated software. Each experiment was repeated thrice to account for any scatter in results. The size of the bend specimens of parent materials and TWBs, was 150X25mm to ensure plane strain bending condition for which the width should be at least 10 to 15 times the sheet thickness.

2.4 Measurement of springback

A vision inspection system with a probe was used to measure the final included bend angle in tested bend specimens with an accuracy of 5µm of linear table movement. Each specimen was secured in a magnetic V-block and measured twice for the final included bend angle (θ_f). The initial included bend angle (θ_0) was measured on the die. Springback (i.e. $[\alpha_0 - \alpha_f]$) on one side of the tested specimen was determined by subtracting final half angle $(180^o - \theta_f)/2$ from initial half angle $(180^o - \theta_0)/2$ as shown in Fig. 5. The tested specimens of TWBs are shown in Fig. 6.

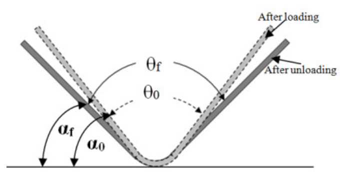

Figure 5 Measurement of springback

Figure 6 Tested bend specimens of TWBs with three thickness combinations

2.5 Modelling and simulations

In the present study, all the simulations were performed using ABAQUS software in two steps of loading and unloading. The punch and the die were modelled as analytical rigid shell whereas blank was deformable shell planar with S4R shell elements, which is a 4-node doubly curved thin shell with reduced integration, hourglass control and finite member strains. The maximum number of elements and nodes in the model were 4202 and 4381 respectively and the total numbers of variables in the model were 26286 for the bending simulation. The TWB was modelled containing three different regions i.e. two different parent materials and a weld zone. The meshing in the weld zone was kept finer compared to parent regions for better results. Hill's plasticity model for anisotropic materials is used in FE modelling due to ease of formulation given by Hibbit et al. (2007). The true stress- true strain data points after yield, obtained from tension tests, were used to model the material following power law of hardening. For comparison of springback results, TWBs were also modelled without the weld zone (i.e. with two regions of parent materials).

For the springback simulations, the procedure adopted was static-general with non linear geometry. After removing all the constraints in the model, the blank was assigned initial state of previous bent data file containing history of loading. A central node in the blank was assigned a zero velocity so that the results are contained about the same node. For springback measurement, node coordinates were captured for loaded and unloaded frames. The coordinate points for both the frames were plotted in CAE interface and the difference between the two gives the springback. The change in bend angle due to springback as obtained in simulations is shown in the Fig. 7.

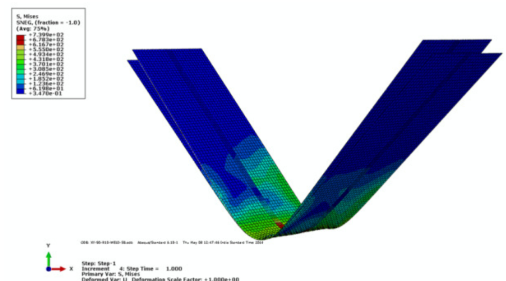

Figure 7 F.E. simulation of V-bending showing springback in TWBs

3 Results and discussions

Tensile properties of high strength steel of different thickness are given in Table 2. The yield strength and tensile strength of the steel are approximately 300MPa and 440MPa respectively. The percentage elongation and strain hardening coefficient of the steel are 25% and 0.18 respectively suggesting good formability characteristics. Although some variations are seen in yield and tensile strengths in specimens oriented at 0°, 45° and 90° with respect to the rolling direction but high strength steel is not highly anisotropic. Therefore influence of anisotropy on springback is predicted to be negligible, although it was incorporated in the material model.

Table 2 Tensile properties of high strength steel

Thickness (mm)	Orientation w.r.t. rolling direction	Yield stress $\sigma_y(0.2\%)$ (MPa)	Ultimate Tensile strength (MPa)	% Elongation	Strain Hardening Coefficient	Strength Coefficient (MPa)
0.9	0°	345	475	26.2	0.18	772
	45°	363	466	26.5	0.18	754
	90°	382	479	25.2	0.17	772
1.2	0°	304	441	28.2	0.20	751
	45°	316	439	27.6	0.19	720
	90°	338	457	26.9	0.18	741
1.6	0°	287	428	28.7	0.20	730
	45°	310	433	28.0	0.19	713
	90°	317	434	24.0	0.18	718

The engineering stress-engineering strain curves of TWBs obtained from uniaxial tensile tests are illustrated in Fig. 8 which clearly shows that yield and tensile strengths of the TWBs have increased to 400MPa and 550MPa respectively.
The percentage elongation and strain hardening exponent of TWBs, given in Table 3, are reduced to 17% and 0.15 respectively as compared to the parent material, which shows reduced formability, although the tensile specimens consist of the weld zone and parent materials.

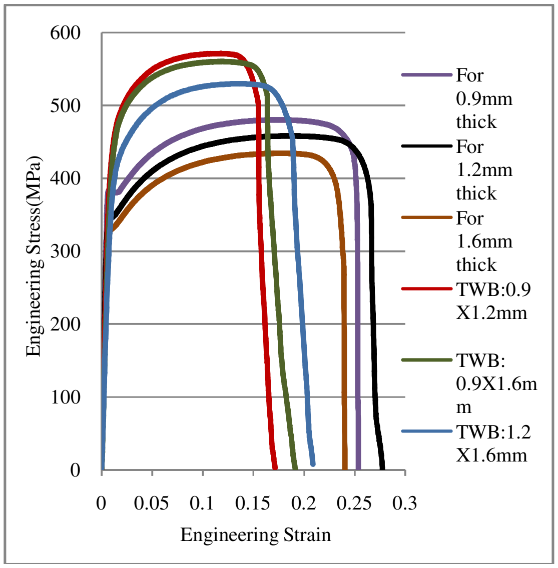

Figure 8 Engineering stress - strain curves of high strength steel and TWBs samples

Table 3 Tensile properties of TWBs

S. No.	Thickness combination (mm)	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	% elongation	Strain Hardening Coefficient	Strength Coefficient (MPa)
1	0.9X1.2	425	566	17.1	0.15	854
2	1.2X1.6	399	549	20.9	0.15	880
3	0.9X1.6	412	565	19.1	0.14	870

Determination of the weld zone was done on the basis of microstructural studies and hardness test. The engineering stress-engineering strain curves obtained from tensile tests on specimens prepared from the weld zone are shown in Fig. 9. The yield strength and tensile strength of the weld given in Table 4, are much higher than the parent materials which confirms that the weld zone is solely responsible for increased strength in TWBs. Lower ductility and strain hardening coefficient of weld zone adversely affect the overall forming characteristics of TWBs.

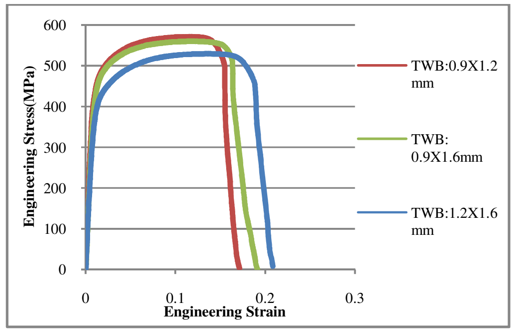

Figure 9 Engineering stress - strain curves of the weld zone with three thickness combinations

Table 4 Tensile properties of weld zone of TWB

Thickness combination (mm)	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	% elongation	Strain Hardening Coefficient	Strength Coefficient (MPa)
0.9X1.2	567	717	13.4	0.14	1114
1.2X1.6	517	713	16.1	0.13	1096
0.9X1.6	512	685	17.0	0.13	1039

The springback results obtained from the experimental work and numerical predictions of V-bending of parent materials are presented in Table 5.

Table 5 Springback results of V-bending of high strength steel

Thicknes s (mm)	Orientatio n w.r.t. rolling direction	Punch Corner Radius-10mm		Punch Corner Radius-12.5mm	
		Experimental -Results(deg)	Simulation - Results (deg)	Experimental -Results(deg)	Simulation - Results (deg)
0.9	90°	6.08°	4.95°	6.78°	6.17°
1.2	90°	4.48°	2.03°	5.95°	3.64°
1.6	90°	3.04°	1.50°	4.17°	3.12°

Simulation results are in good agreement with the experimental results. Fig. 10 shows that increase in the sheet thickness reduces the springback whereas increase in the punch corner radius increases the springback and the same trend is seen in simulation results as well.

The springback results of TWBs obtained from experimental and simulations are summarized in Table 6. The springback results showed good repeatability in case of both experimental and simulation studies and the springback values of TWB specimens lie in between the values of parent materials. In simulations, the effect of incorporation of weld properties on the springback of TWBs is shown. Simulation results with incorporation of weld zone fall closer to the experimental results as compared to the simulation results without incorporation of the weld zone. This clearly demonstrates that the accuracy of springback prediction in TWBs is enhanced by incorporation of weld properties at the interface of two parent blanks. Accurate prediction of springback helps in precise calculations of springback compensation in the design of dies for bending.

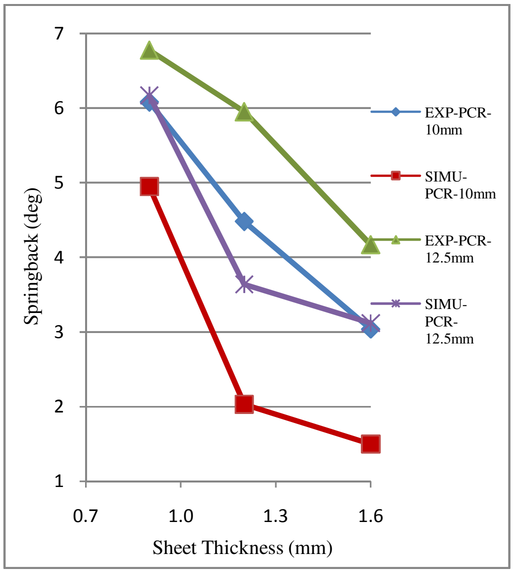

Figure 10 Experimental and simulation results for springback for parent materials

Table 6 Springback results of TWBs of different thickness combinations

S. No.	Thickness combinations (mm)	Punch Corner Radius-10mm			Punch Corner Radius-12.5mm		
		Experimental Results (deg)	Simulation Results Without weld zone(deg)	Simulation Results With weld (deg)	Experimental Results (deg)	Simulation Results Without weld (deg)	Simulation Results With weld (deg)
1	0.9X1.2	3.72°	3.47°	3.50°	5.34°	4.94°	5.49°
2	0.9X1.6	3.23°	1.51°	2.34°	4.04°	2.94°	3.97°
3	1.2x1,6	2.26°	1.51°	2.30°	2.93°	2.78°	2.82°

4 Conclusions

In the present work the effects of weld zone on springback behaviour in V-bending of TWBs has been presented. The following conclusions emerge from this study:

1. There is an overall increase in the strength of TWBs as compared to the parent materials. However, the ductility is reduced.
2. Increase in the sheet thickness reduces the springback whereas increase in the punch corner radius increases the springback and the same trend has been observed in simulations as well.
3. The bending test results showed fairly good repeatability and the springback values of TWB specimens lie in between the values of parent materials except in a few cases.
4. Predicted simulation results with incorporation of weld zone showed a good agreement with the experimental results as compared to the simulation results without incorporation of the weld zone. Hence incorporation of the weld zone properties in simulations would help in improvement of the accuracy of springback prediction. This would be helpful for design of the bending dies with springback compensation.

References

Bayraktar, E., Kaplan, D. and Yilbas, B.S. (2008), Comparative study: Mechanical and metallurgical aspects of tailored welded blanks (TWBs), *Journal of Materials Processing Technology*, 204(1–3), pp.440-450.

Ciubotariu, V. and Brabie, G. (2011), Weld line behaviour during uniaxial tensile testing of tailor welded blanks, *Archives of Civil and Mechanical Engineering*, 11(4), pp.811-824.

Hibbit, karlsson and Sorensen (2007), ABAQUS/ Standard 6.7 User's Manual, Hibbit, Karlson & Sorenson Inc., Pawtucket, RI.

Merklein, M., Johannes, M., Lechner, M. and Kuppert, A. (2014), A review on tailored blanks-Production, applications and evaluation, *Journal of Materials Processing Technology*, 214(2), pp.151-164.

Rojek, J., Hyrcza-Michalska, M., Bokota, A. and Piekarska, W. (2012), Determination of mechanical properties of the weld zone in tailor-welded blanks, *Archives of Civil and Mechanical Engineering*, 12(2), pp.156-162.

Shi, Y., Lin, Z., Zhu, P. and Han, S. (2008), Impact modeling of the weld line of tailor-welded blank, *Materials & Design*, 29(1), pp.232-238.