Effect of Blank Holder Force Schemes on Weld-Line Movements in U-Draw Bending of Tailor Welded Blanks

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ABSTRACT

In the present paper, a simplified finite element-based procedure is developed, to determine a proper blank holder (binder) force (BHF) scheme for the draw bending process of tailor welded blanks (TWBs). Under constant BHF, significant weld-line movement is observed. Tearing of TWB is encountered at high values of BHF. Careful analysis of weld-line movements and various numerical experiments show that a constant maximum-then-decreasing BHF scheme on the weaker blank side would eliminate weld-line movement without the need for a counter punch without resort to using stepped counter punch. The developed finite element model, integrated with the rational of carefully correlating the weld-line movement to the applied BHF, presents a simplified procedure for suggesting proper BHF schemes, rendering itself for use in various industrial applications.

KEYWORDS

U-draw bending, tailor welded blanks (TWBs), finite element analysis, weld-line movement, blank holder (binder) force (BHF).

INTRODUCTION

A major objective of the automotive industry is to reduce weight and fuel consumption while maintaining higher standards of safety and performance. To meet these requirements, new light weight materials, innovative design, and manufacturing techniques for automobile chassis and body have to be developed. Among these developments, tailor welded blanks (TWBs) offer several benefits including decreased part weight, reduced manufacturing costs, and improved dimensional consistency. However, in the forming of a TWB with two different thicknesses or materials combinations, the thicker or the stronger part in a TWB tends to resist deformation, while the thinner or the weaker part is susceptible to excessive material flow leading eventually to weld-line movements and wrinkling/splitting failures [1].

Many studies on the problems related to weld-line movements of tailored blanks during deep drawing process are presented. Most published results show that the thinner or weaker part of TWBs dominates the majority of deformation and a large BHF of need be applied to control the material flow. Several approaches are used to alleviate these problems including the use of draw beads, unequal blank holder force (BHF), and direct weld-line constraining using clamping pins and stepped or segmented punch/counter punch arrangements, see e.g. [2-8]. Kinsey et al. [2-4] adopt a modified deep drawing process where segmented dies with local adaptive controllers clamp adjacent to the weld-line are used during the forming operation leading to an increase in the draw depth and reduction in weld-line movement. Tang et al. [5] use hydraulic controlled pads combined with blank holder and draw bead to clamp the weld-line during the deep
drawing process which resulted in significant weld-line movement reduction. Padmanabhan et al. [6] propose a segmented blank holder to allow the application of different forces on aluminum and steel sheet segments in TWBs. The application of BHF that is inversely proportional to the material's strength is found to enhance the formability. Morishita et al. [7] propose the use of counter punch technique to reduce the weld-line movement during square-cup drawing of tailored blank composed of thick/thin sheets. The movement of the weld-line during forming is strongly constrained by the counter punch pressure. Panda et al. [8] show that more uniform strain distribution in both sides of the TWB is observed due to application of both counter pressure and lubrication.

However, to our knowledge no much investigation is presented for the role of blank holder (binder) force in the weld-line movement of the draw bending process of tailored blanks. In addition to its importance as a benchmark problem that could be used to enhance the understanding of the nature of weld-line movement during forming of tailored blanks, draw bending process is also used in many industrial applications, see e.g. [9].

The present paper focuses on using the finite element method on the search for a proper blank holder (binder) force schemes that eliminate weld-line movements in U-draw bending process of tailor welded blanks without using counter punch. U-bending process is experimentally investigated on tailored blanks with combination of low carbon steel and stainless steel having different thicknesses. The experimental results are adopted in developing and verifying a finite element simulation model. This model, integrated with the rational of carefully correlating the weld-line movement to the applied BHF, presents a simplified procedure for developing a proper BHF schemes without resort to expensive finite element optimization methodologies.

**EXPERIMENTAL WORK**

Two parent (base) blank materials are used in this study, namely low carbon and 304 austenitic stainless steels. Tensile tests are carried out according to ASTM-E8 standards [10] for specimens cut parallel to the rolling direction. The parent blanks are welded prior to forming process using TIG welding operation with argon shielding gas according to ASME standards [11]. The tensile properties of the base blanks as well as the weld materials are shown in Fig. 1. The yield strength for low carbon steel is 264±11 MPa, for stainless steel 304 is 350±16 MPa for 2 mm sheet thickness and 405±7 MPa for 1 mm sheet thickness and for weld material is 480±15 MPa. The weld material shows higher strength but lower ductility as compared to the base materials. To determine the extent of the weld zone to be used in the finite element models, micro hardness indentation are performed on polished specimens. The high hardness region defines the weld zone as shown in Fig. 2 and is determined to be 7 mm.

![True Stress-Strain curves for base metals and weld zone material.](image1)

**Figure 1.** True Stress-Strain curves for base metals and weld zone material.

![Microhardness indentation on TWB of different materials.](image2)

**Figure 2.** Microhardness indentation on TWB of different materials.

To obtain experimental results for the verification of the finite element model described in the following section, U-bending operations are carried out for two types of 100 x 40 mm TWBs (A and B). Type A is composed of different materials (stainless steel-low carbon steel) with the same thickness. Type B is made of two sheets of the same material, namely stainless steel, but with different thicknesses (1 mm and 2 mm). A 100 kN test rig shown in Fig. 3 is used. The punch used in the present work has a width of 15 mm and nose radius of 4 mm. The die has a cavity of 20 mm depth, a profile radius of 5 mm at the top, and 2 mm at the bottom. The punch displacement is controlled at 10 mm/min. The U-bending experiments show that all the TWBs considered in the present work
suffer from significant weld-line movement as depicted in Fig. 4.

Figure 3. Punch-die tooling and experimental set up for U-bending process.

DEVELOPMENT AND VERIFICATION OF FINITE ELEMENT MODEL

The U-bending operation is modeled by Simulia-ABAQUS™ version 6.11-2 commercial software using the explicit solver. TWBs are modeled using either 3D or plane strain 2D solid elements. The 3D models are developed for U-bending process and used mainly for verification purposes. Coulomb friction law combined with penalty method is chosen to represent contact surfaces between punch, die, blank holder, counter punch, and blank. An average overall coefficient of friction is assumed to govern the contact at all tool/metal interfaces. To validate the modeling of the weld zone and to decide for a proper friction coefficient at the tooling/metal interfaces, various experimental and finite element results are compared as shown in Figs. 5-7 and Tables 1 and 2.

Fig. 5 shows the experimental and finite element load-punch movement curves for TWBs of type A for different coefficient of friction. It should be noted that the determination of an accurate value for the coefficient of friction is rather difficult and is beyond the scope of the present study. Some discrepancy is observed between FE and experimental results up to the peak load which could be attributed to the possible discrepancy in punch-weld zone interaction in the experimental setup at the early stages of punch movement. Nevertheless, it seems that the model with an overall friction coefficient of 0.17 give a reasonable fit for the experimental results at the peak load and subsequent region as shown in Table 1. This choice of the coefficient of friction is further supported by observing the close similarity between the experimental results in Fig. 4 (a) and (b) that are closely simulated in finite element analysis (FEA) as shown in Fig. 6 (a) and (b), respectively. To quantify these agreements, Table 2 shows a comparison between experimental and FE parameters shown in Fig. 6(c). The predicted results from FEA are in good agreement with those from the experiments. These agreements give confidence in the finite elements models for subsequent studies.

![Figure 4. Weld-line movement in TWBs in U-Bending (a) different materials-same thickness and (b) same materials and different thicknesses.](image)

**Table 1.** FE Peak Load for different friction coefficient.

<table>
<thead>
<tr>
<th>Friction Coefficient</th>
<th>Peak load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>18.47± 1.27</td>
</tr>
<tr>
<td>0.1</td>
<td>17.02</td>
</tr>
<tr>
<td>0.17</td>
<td>18.91</td>
</tr>
<tr>
<td>0.2</td>
<td>19.7</td>
</tr>
<tr>
<td>0.25</td>
<td>20.7</td>
</tr>
</tbody>
</table>

**Table 2.** Comparison between Experimental and FE parameters of U-bent specimen.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Experiment</th>
<th>Finite Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 (mm)</td>
<td>20.8</td>
<td>20.6</td>
</tr>
<tr>
<td>L2 (mm)</td>
<td>12.8</td>
<td>13.2</td>
</tr>
<tr>
<td>R (mm)</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>α (degree)</td>
<td>80</td>
<td>78</td>
</tr>
</tbody>
</table>
Moreover, a comparison between the 3D model and the plane strain 2D model is performed as shown in Fig. 6 (d). The close agreement between the 3D and plane strain models in predicting the deformation process suggests that the use of plane strain models for subsequent analyses is expedient from the computational point of view.

To this point, the developed and verified finite element modeling procedure will now be extended and applied to the process of draw bending of tailored blanks. This process represents an important bench mark problem for the study of deformation and weld-line movements. It is also a known process in many industrial applications [9]. The major objectives of the finite element analysis of the draw bending of TWBs are to investigate the role played by the BHF on the weld-line movement and to search for a proper BHF scheme that would eliminate such weld-line movement without resort to the application of counter punch. Towards that goal, a simplified rational procedure is developed based on careful analysis of the weld-line movement without resort to using stepped counter punch. No attempt is made, to use of sophisticated and expensive finite element optimization algorithms. This renders the suggested procedure easy for use in industry.

A SIMPLE PROCEDURE TO DETERMINE A PROPER BLANK HOLDER (BINDER) FORCE SCHEME FOR DRAW BENDING OF TWBs

Role of Blank Holder Force in Draw Bending of TWBs

Previous studies in deep drawing showed that BHF could reduce weld-line movements but did not entirely prevent it [1-2, 12-13]. Similar observations seem to exist in draw bending process as depicted in Fig. 7 which shows weld-line movement for TWBs of the same materials and different thicknesses models (Type B). Different constant BHF schemes of 15, 50, and 100 kN are applied on the flange of the thin part while the thick part’s flange is kept under constant 15 kN BHF (minimum force required to keep flange in contact with die). For the cases of 15 and 50 kN, weld-line movement is clearly visible while for the 100 kN BHF, excessive deformation and localized necking are observed. It is well know that such problem can be solved by the conventional use of counter punch [7, 8]. In the present work, simultaneous constant BHF schemes and counter punch force are shown to reduce and eliminate weld-line movements as depicted in Fig. 8. The BHF and counter punch force applied are constant during the drawing process and of equal magnitudes. Fig. 8 shows weld-line movement for three force levels of BHF of 5, 10, and 15 kN. The weld-line movements are found to decrease with increasing both the BHF and counter punch forces.

Obviously, the application of counter punch would call for additional cost on tooling and press control system. In the present paper, an attempt is made to develop BHF schemes that eliminate the need for this counter punch and yet alleviate the problem of the weld-line movement. The rational used here is based on a careful analysis of the weld-line movement developed during draw bending process.

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Figure 5. Load-punch movements curves for experimental and FEA results with different coefficients of friction.

On the Search for a Proper Blank Holder (Binder) Force Scheme in Draw Bending of Tailored Blanks

To have better understanding of the weld-line movements, the weld-line and punch displacements are considered versus time in Fig. 9 for the case of constant BHF. The first 0.01 second of the simulation is used to ramp the BHF to its maximum working value prior to punch travel. Moreover, smooth step amplitude is used for punch movement to minimize inertia effects and obtain quasi-static simulations. The weld-line vertical movement is always higher than the punch travel due to unequal bending of TWBs at early stage of punch travel. Points (A), (B), and (C) in Fig. 9 mark the start of three distinct deformation stages for side weld-line movements, shown in Fig. 10. Before point (A), there seems to be no side weld-line movement. In the stage between (A) and (B), the specimen bends and deforms on the die profile radius with low side weld-line movement. At the stage after point (B) and up to point (C), the bending around the die profile radius is completed and the side walls develop during which maximum side movement occurs. After point (C), the draw process continues with no further weld-line movement.
Based on the above analysis and the fact that weld-line movement occurs during early punch travel in U-draw bending operation, a proper BHF scheme is suggested. In this scheme, the BHF is ramped to its maximum working value at start before any punch movement. To prevent weld-line movement, BHF is kept constant up to point (A). After this point the BHF is gradually decreased in two different rates up to points (B) and (C) as shown by the BHF curves in Fig. 11. The gradual decrease of the BHF is crucial to prevent thinning in the side walls. The proposed BHF could be implemented by a hydraulic system such as those described by Reddy et al [14] and Qin et al. [15].

To this point, finite element numerical experiments carried out for different BHFs combinations are considered in the present study. The BHF on the thicker part of the TWB is kept fixed at 15 kN and the BHF on the smaller thickness part is varied following the suggested BHF schemes with maximum start working force of 50, 75, 100, 125, and 150 kN as shown in Fig. 11. The duration of this maximum start of working BHF is determined by point A in Fig. 9. The final shape of the draw bend part as a result of the BHF schemes are shown in Fig. 12. The weld-line side and vertical movements decrease as the maximum BHF on the thin section is increased. The minimum weld-line movement is observed at BHF of 150 kN. However, the wall thickness is no longer uniform with a minimum thickness of 0.63 mm. Increasing the BHF beyond this point leads to localized deformation and failure.

It is worth noting that the weld-line movements occur at the early stage of punch movement with seemingly no changes until the end of the drawing process as shown in Figs. 13 and 14 for BHF of 125 and 140 kN, respectively. This observation justifies the adoption of the BHF scheme suggested in the present paper. Moreover, the advantage of the suggested constant maximum-then decreasing BHF scheme over that when using a continuously decreasing BHF scheme is reflected in Fig. 15. Here, the weld-line movement for the case of maximum BHF of 150 kN that is continuously decreased to zero during the punch travel is shown. The weld-line movement is considerably large as compared to that obtained using suggested BHF scheme having the same maximum BHF. Note that in Fig. 15, the flange of the thinner sheet is no longer in flat contact with the die towards the end of the process.

Fig. 16 shows the decrease in the weld-line movement with the increase of the constant maximum-then decreasing BHF at start of the suggested scheme. However this is accompanied by a reduction in the minimum wall thickness. Such thinning is of course inevitable; however linking between the proposed procedure and a proper optimization algorithm can help obtaining more uniform thickness distribution. Such investigation is underway by the authors and results will be shown elsewhere.
CONCLUDING REMARKS

The present work has carefully studied the weld-line movements in U-draw bending process. Under constant BHF schemes, welded blanks suffer from weld-line movements under all BHF levels considered. The analysis has indicated that the weld-line movement occurs mainly at the early stage of punch travel with seemingly no further changes afterward.

A finite element based simplified rational procedure has been successfully used to develop a proper BHF scheme that eliminates weld-line movement with no need for a counter punch. Here, the weaker blank is subjected to a constant maximum (start of working)-then decreasing BHF scheme. This procedure has minimized the weld movement in the cases under investigation.

Figure 7. Weld-line movement under constant BHF of (a) 15 kN, (b) 50 kN, and (c) 100 kN.

Figure 8. Counter Punch used for different force levels of 5, 10, 15 kN.

Figure 9. Weld-line movement along with punch travel versus time.
Figure 10. Deformed shape for the stages defined by the starting points (a) A, (b) B and (c) C indicated in Fig. 10.

Figure 11. Suggested BHF schemes simulated in the numerical experimentation of the present analysis.

Figure 12. Weld-line movement for fixed BHF of 15 kN on large thickness sheet and for different BHF on small thickness sheet, (a) 50 kN, (b) 70 kN, (c) 100 kN, (d) 125 kN, and (e) 150 kN.

Figure 13. Development of weld-line movements under maximum BHF of 125 kN.

Figure 14. Weld-line movements under maximum BHF of 140 kN of the suggested scheme.

REFERENCES


June 13, 2013

To Whom It May Concern,

It is my pleasure to inform you that Bishoy Dawood attended the 8th ASME International Manufacturing Science and Engineering Conference and 41st Annual North American Manufacturing Research Conference, from June 10-14, 2013, at the Monona Terrace Community and Convention Center.

Bishoy Dawood presented the paper: Effect of Blank Holder Force Schemes on Weld-line Movements in U-Draw Bending of Tailor Welded Blanks; #NAMRC41-1530

Please feel free to contact me if you need additional information or verification.

Best regards,

[Signature]

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