Simulation based Control of Weld Line Movement in Tailor Welded Blanks

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Abstract. A Tailor welded blank (TWB) consists of sheet materials of different thicknesses or different alloy compositions that are welded together prior to forming. The weaker of the two sheets deforms more causing weld line movement. This paper proposes methods to predict optimum position of the weld line in a flat tailor welded blank so as to reduce weld line movement in formed tailor welded blanks. Two simulation based methods - back propagation and contour of minimum strain are studied to reduce weld line movement. These methods are based on blank shape modification.

1. INTRODUCTION

The automotive industry is constantly working on developing new cost effective methods of weight reduction to enhance the performance of the vehicle. A tailored blank consists of blanks of different sheet thicknesses or different alloys, which are welded together along a contour prior to forming. The welded blanks may differ in grade, gauge thickness, strength or coating. Tailor welded blanks (TWBs) ensure correct distribution of material. Hence, a thicker (or stronger) sheet would be used in load bearing regions while a thinner one would suffice elsewhere. This provides viable means of weight reduction in automotive parts. The TWB leads to benefits like reduction of manufacturing cost due to fewer forming dies, weight reduction, improved dimensional part consistency from the reduction of inaccurate spot welding process. Improved corrosion resistance through the elimination of lap joints by integration of reinforcement [1]. The tailored blank gives designer the opportunity to distribute the stiffness and thickness within the stamping.

During forming the thinner (or weaker) sheet deforms more leading to movement of the weld line towards the thicker sheet [1]. One may accommodate the movement into the design of the part, or arrest it to the extent possible. It is also important that the weld does not experience high tensile stresses perpendicular to the weld line. The important issue therefore is to control the weld line movement so that the final product is safe and weld line is in non critical part of product. Young Moo Heo et al. [2] investigated the effect of drawbead dimension on the weld line movement in tailor welded blank. They concluded that weld line movement decreases as the size and height of the drawbead increase. Thus weld line movement can be controlled by appropriate drawbead design.

Ahmetoglu et al.[3] proposed the use of differential blank holding pressure for reducing weld line movement. The thinner/weaker material is subjected to higher blank holding pressure, which results into a more uniform flow of material in the thicker as well as the thinner regions. The weld line movement is thus reduced.

In the present study, aluminum tailor welded blanks with different thicknesses were used in deep drawing simulation. Unlike the existing methods two novel based methods for reducing weld line movement have been proposed, namely, the ‘back propagation method’ and ‘minimum strain contour method’.

2. FINITE ELEMENT ANALYSIS

In order to examine the effectiveness of proposed methods for reducing the weld line movement, elasto-plastic FEM simulations were conducted using PAMSTAMP2G software. The tools namely, punch, blank holder and die are assumed to be perfectly rigid with surface to surface contact between the blank and the tooling. The commercially pure aluminum tailored blank of 1mm and 1.2mm thicknesses is used for weld line movement analysis. A constant friction condition ($\mu = 0.12$) is assumed at all tool interfaces. The deformation of the tailored blank was simulated under these conditions.

The proposed back propagation method is illustrated in the context of a deep drawn cup (Fig. 1) while the minimum thickness strain contour method is
illustrated with reference to rectangular box shaped part (Fig. 2).

Fig. 1 shows the sectional tool set up model for tailor welded cup and Fig. 2 shows the sectional tool set up for the box shaped part. Identical material and thickness combinations were used for both the cases. The mechanical properties of the base material are shown in Table 1. The processing conditions for the circular cup and the rectangular part are shown in Table 2 and in Table 3 respectively.

### TABLE 1 Material Properties

<table>
<thead>
<tr>
<th>Blank Material</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yields strength</td>
<td>70 MPa</td>
</tr>
<tr>
<td>Strength Coefficient</td>
<td>151 MPa</td>
</tr>
<tr>
<td>Strain hardening exponent</td>
<td>0.264</td>
</tr>
</tbody>
</table>

### TABLE 2 Process Conditions for example part simulated for back propagation method (Part 1)

| Punch size | Diameter=48mm |
| Blank size | Diameter=85 mm |
| Blank holding force | 10 kN |
| Blank type | TWB -1mmx 1.2mm (t) |

### TABLE 3 Process Conditions for example part simulated for tracing the line on minimum strain method (Part 2)

| Punch size | 320x232 mm² |
| Blank size | 480x360 mm² |
| Blank holding force | 25 kN |
| Blank type | TWB -1mmx 1.2mm (t) |

The weld is modeled as a line, i.e., the mechanical properties of weld bead are not considered assuming that it doesn’t lead to any significant loss of accuracy in the result.

### FIGURE 1

Finite element sectional tool model for tailor welded cup simulated for back propagation method (Part 1)

### FIGURE 2

Finite element sectional tool model for tailor welded box shaped part (Part 2).

## 3 PROPOSED METHODS

Two different simulation based methods—Back Propagation and Minimum Strain contour method are proposed in order to reduce weld line movement in tailor welded blank.

### 3.1 BACK PROPAGATION METHOD

This method is based on the concept of simulating the of tailored blank and identifying the position where exactly the weld line is required in final formed part. This weld line is back propagated in flat blank from the formed part. This gives the position of weld line in the flat blank for minimum weld line movement compared to the desired position. Simulation of deep drawing of a circular cup of punch diameter 48mm was performed to verify the back propagation method. Fig. 3 shows the formed cup and required position of weld line (center of blank) in formed cup which is back propagated to flat blank.
Nodes as shown in Fig. 3 are back propagated to flat blank so that contour of weld line for minimum weld line movement in flat blank is obtained. Fig. 4 shows the flat tailor blank with weld line after back propagation. If material properties, process parameters and intended position of weld line in formed part is known this method can give optimum weld position and blank shape design for minimum error in weld line position after forming.

3.2 MINIMUM THICKNESS STRAIN CONTOUR METHOD

This method is based on the concept that optimum position of weld line will correspond to the contour of minimum deformation, given by the minimum thickness strain. It is realized that the required position of weld line in the formed part and its position corresponding to the contour of minimum thickness strain may differ considerably, so that the appropriate method must be used for a given part.

In this method, the deformation of the part is simulated and the points of minimum thickness strain on the part are identified. These are back propagated onto a flat blank to get the contour of weld line at minimum strain. The box shaped part in Fig. 5 shows one half of the formed part (to save on the computational time) with the nodes corresponding to the minimum thickness strain points.

The nodes are back propagated to flat blank in order to find the position of proposed weld line on the flat blank. Fig. 6 shows the position of weld line in flat blank. This method is useful where one needs to reduce the chances of cracking in the weld that has comparatively poor ductility. In contrast, the back propagation method is useful where aesthetics are important and the weld line needs to fall in the region designated by the designer. Since there is no consideration to the magnitude of deformation experienced by the weld line, the back propagation method is suited to shallow drawn parts, those having very generous radii and where strain levels are generally very low, as in skin panels.
4. RESULTS AND DISCUSSION

4.1 Results for back propagation method

The back propagated position of weld line as shown in Fig 4, with a tailor blank of 1 and 1.2 mm thickness is simulated to investigate weld line movement.

FIGURE 6 Weld line position after back propagation in flat blank in Part 2.

The formed cup with weld line obtained from back propagation method is compared with formed cup with weld line at center. The flat blanks are shown in Fig. 7 and formed cups are shown in Fig. 8. It can be seen from Fig 8 that the deviation of the weld line from its desired position in formed part is greatly reduced by applying back propagation method.

FIGURE 7 Weld line position in flat blank. (Part 1) (A) weld line at center (B) Weld line position by back propagation method

Fig 9 shows deviation of the weld line position and it can be seen that the maximum weld line movement in weld line at the center is around 4mm while that in a cup formed from the TWB designed using the back propagation method is 1mm.

FIGURE 8 Weld line movement in formed Part (A) Center line weld (B) Back Propagation method.

FIGURE 9 Comparison of weld line movement.

As shown in Fig 7 (B) in back propagation method, weld line is at the offset towards the thinner blank side, this shift will accommodate extra drawing of thin sheet in tailor blank. Therefore, this method gives designer a freedom to reduce weld line movement by simulating and changing the blank shape.

4.2 Results for the Minimum Strain Contour Method

In order to examine the effectiveness of this method the weld line position after forming a TWB designed using this method is compared with a TWB whose weld line is at the center. It is emphasized here that this method determines the position of weld line for minimum strain in contrast to the back propagation method where the intended weld line position is determined by the designer. The weld position in a flat blank for two different cases is shown in Fig 10.
FIGURE 10 Weld line position in flat blank (Part 2). (A) weld line at center (B) Weld line position by the minimum strain contour method

Fig.11 compares the weld line movement in formed part for the two cases mentioned above. It can be seen that this method successfully determines a weld line position in a flat tailored blank so as to orient the weld to ensure minimum strain on it.

It is observed that there may be more than one line of minimum thickness strain but the line which is closest to the desired weld line position (based on aesthetic or similar consideration) has been selected in this work.

FIGURE 11 Weld line position in formed blank (Part2). (A) weld line at center (B) Weld line position by tracing the line of minimum strain method

Fig 12 compares the weld line position after deformation with the contour of minimum strain in the part. It is seen that the deviation in the final weld line position is greatly reduced on using this method. The maximum weld line movement is reduced from 11 mm to 7 mm.

4.3 COMPARISON OF PROPOSED METHODS

The two proposed methods are compared to identify the scope and application of these methods in actual stamping industry. For comparing these methods back propagation method is also applied to Part 2 which is symmetric but not axi-symmetric. It is assumed that intended position of weld is at the centre of part. The intended position of the weld line and that obtained from the contour of minimum strain in a flat blank is shown in Fig. 10. Modified weld position obtained from back propagation method is shown in Fig. 13.
Therefore by using these simulation based methods the weld line movement can be greatly reduced. Iterations using these methods will further reduce the deviation of the weld line from its intended position. The existing methods to reduce weld line movement are based on restraining the flow of the thinner/weaker material. The proposed methods enable bringing the weld line to an aesthetically favorable position or to a strain free contour as desired using Finite element simulation. Material is free to flow in die without restraining so formability and strain distribution is better in this method.

5. CONCLUSION

This paper demonstrates the application of two simulation based methods to minimize the deviation of the weld line from the desired position, namely, back propagation method and minimum thickness strain contour method. Aluminum tailored blank of 1mm and 1.2mm thickness was used to illustrate the two methods.

The results of the present paper are summarized as follows:

1. The deviation of the weld line from its desired position is considerably reduced using the two methods proposed.
2. The two methods determine the contour along which the flat sheets should be welded. Each has a specific domain of application.
3. Contour of minimum strain method leads to the position of weld line in a stress free region in the blank.
4. Back propagation method helps the designer to determine the weld line contour on the flat blank when the final position of weld line is fixed, as in aesthetically important parts.

REFERENCES


FIGURE 14 Comparison of weld line movement.

TABLE 4 Comparison of the proposed methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Back Propagation</th>
<th>Contour of Minimum Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position of weld line</td>
<td>Follow designer’s intent (aesthetics governs the position)</td>
<td>Technological advantage determines position of the weld line</td>
</tr>
<tr>
<td>Reduction in weld line movement</td>
<td>More for same no. of iterations</td>
<td>Less as compared to the Back Propagation method</td>
</tr>
<tr>
<td>Weld Failure</td>
<td>Weld might get severely stressed. Weld failure a distinct possibility.</td>
<td>Less possibility of weld failure because weld line follow minimum strain line</td>
</tr>
<tr>
<td>Application</td>
<td>Low forming severity and aesthetics overwhelmingly important</td>
<td>High forming severity in the formed product</td>
</tr>
</tbody>
</table>