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Approach for testing the material behavior in roll forming in a small scale

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Abstract. Roll forming of ultra-high strength steels (UHSS) and other high strength alloys is an advanced manufacturing methodology with the ability of cold forming those materials to complex three-dimensional shapes for lightweight structural applications. Due to their high strength, most of these materials have a reduced ductility which excludes conventional sheet forming methods under cold forming conditions. Roll forming is possible due to its low strains and incremental forming characteristic. Recent research investigates the development of high strength nano-structured aluminum sheet and titanium alloys, as well as their behaviour in roll forming with regard to formability, material behaviour and shape defects.

The development of new materials is often limited to small scale samples due to the high preparation costs. In contrast, industrial application needs larger scale tests for validation, especially in roll forming where a minimum sheet length is required to feed the sample through the roll forming machine. This work describes a novel technique for studying roll forming of a short length of experimental material.

DP780 steel strips (500mm – 1300mm length) were welded between two mild steel carrier sheets of similar width and thickness giving an overall strip length of 2m. Roll forming trials were performed and longitudinal edge strain, bow and springback determined on the welded samples and samples formed of full length DP780 strip before and after cut off. The experimental results of this work show that this method gives a reasonable approach for predicting material behavior in roll forming transverse to the rolling direction. In contrast to that significant differences in longitudinal bow were observed between the welded sections and the sections formed of full length DP780 strip; this indicates that the applicability of this method is limited with regard to predicting longitudinal material behavior in roll forming.

Introduction

In cold roll forming a metal strip is formed into long profiles of continuous cross-section by feeding a metal strip through successive pairs of rolls [1]. The process allows the forming of tight radii of materials that show limited elongation [2] and the minimum profile radii achievable in roll forming are generally lower compared to those that can be formed in simple bending [3]. Additionally to that springback in roll forming can be compensated for by very simple and cost effective approaches and a recent study has revealed that springback in roll formed sections can be up to 47% lower compared to those formed via V- die bending [4]. These advantages make roll forming a promising process for the forming of sheet materials that show high strength combined with low ductility and the roll forming process is increasingly used in the automotive industry for the manufacture of Advanced High Strength Steel (AHSS) to structural and crash components [5]. Current research at Deakin University focuses on the development of new high performance materials such as nano-structured metals, titanium and magnesium alloys and the testing of their material behavior in the roll forming process. Most of these materials are only available in low quantities due to high material costs and the limitations of production facilities with regard to
maximum sample size. This makes it difficult to investigate the material behavior of those novel sheet materials in the roll forming process where a minimum sheet length is required to feed the sample through the roll forming machine.

In this work the possibility of welding a small strip of high strength sample material in between two carrier sheets of lower strength conventional material to enable the feed-in into the roll former has been investigated. For this three different test sample sizes of DP 780 steel were welded in between two carrier sheets of mild steel giving a final strip length of 2 m. All sections were roll formed to a simple V-section and the longitudinal edge strain measured in the center of the DP780 section during forming. After forming the sample sections were separated from the carrier sheets using a band saw and transverse springback and longitudinal bow investigated for the DP780 sections and the mild steel carrier sheets before and after cut off. The longitudinal edge strains, springback and bow determined for the small scale DP780 sections were then compared to those measured on a section that was roll formed from a full length (2m) strip of DP780 steel.

Experiments

Materials. DP 780 steel strips of variable length were welded in between two carrier sheets of mild steel using the arc welding process; both steels had a material thickness of 2 mm. The true stress strain curves of the DP 780 and the Mild steel are shown in Fig. 1. Variable lengths of DP780 steel were used and the strip length of the carrier sheets was adjusted to give a final sample length of 2000 mm (Fig. 2). The length combinations investigated in this study are given in Table 1.

![Averaged true-stress-strain curves determined in the tensile test for transverse specimens.](image1.png)

**Figure 1:** Averaged true-stress-strain curves determined in the tensile test for transverse specimens.

![Welded sample](image2.png)

**Figure 2:** Welded sample

**Table 1:** Strip length combinations investigated

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>X (mm)</th>
<th>Y (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>S2</td>
<td>750</td>
<td>625</td>
</tr>
<tr>
<td>S3</td>
<td>1300</td>
<td>350</td>
</tr>
<tr>
<td>S4</td>
<td>2000</td>
<td>0</td>
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</tbody>
</table>
Roll forming trials. The roll forming trials were performed in a conventional roll forming line and V-sections with a 15 mm profile radius were formed in 5 forming passes in an un-lubricated operation. The “constant length of neutral line method” was applied in designing the rolls and the distance between the shaft centers in the roll former was 305 mm. The roll gaps were set to account for shaft deflection leading to roll gaps that were between 17 and 30 % lower than the initial material thickness depending on the forming station; both the top and the bottom rolls were driven. The forming sequence (flower pattern) is shown in Fig. 3a). The longitudinal edge strain of the strip was measured using electrical resistance strain gauges. The strain gauges were glued on the top of the strip edge at the location shown in Fig 3b) and the strain values recorded during testing using a data logger.

![Figure 3: a) Forming sequence of the roll forming process, b) Location of the strain gauge](image)

After forming the DP 780 test strips were separated from the mild steel carrier sheets using a band saw and the longitudinal bow investigated. For this the outer surface of the V-sections was scanned with the “ExaScan” surface scanning system and the final shape evaluated using the software package “Geomagic”. Bow was defined as the vertical displacement of the centerline of the formed section and measured over a length of 2000 mm for the welded sections and a sample length of 400 mm after cut off (Fig. 4a).

![Figure 4: a) Definition for bow, b) Springback measurement](image)

The springback angle $\theta_s$ between the two section walls was measured on 3 samples after forming. These measurements were taken before and after cut off at locations 100 mm apart using an angle gauge. Since it was not possible to determine the included angle $\theta_{incl}$ (Fig. 3a) under load in the final roll station, a final included angle of $\theta_{incl}=80^\circ$ was assumed. The change in angle $\Delta \theta = \theta_s - 80^\circ$ was taken as the measure for springback.

Results and Discussion

Longitudinal edge strain. The longitudinal edge strain versus strip movement and the longitudinal peak strain values measured for the four strip length combinations are shown in Fig. 5a) and b) respectively. There is only a slight variation in curve shape and edge strain maxima between the different length combinations and those are within the experimental error that has been observed in this study. This suggests that the sample length x does not have a significant effect on the longitudinal edge strain if the sample is supported at both ends by the carrier sheets.
**Transverse springback.** The springback determined for the welded strip is shown for sample type S1 \((x=500\text{mm})\) in Fig. 6a). This result is representative for the length combinations S2 and S3 (Table 1). The mild steel carrier sheets show a springback angle of \(-3\) degrees after forming which is lower than reported in previous studies [4]. The low springback observed for the mild steel carrier sheets is due to setting the roll gap to account for tool deflection when forming DP 780 and this material has up to four times the material strength compared to the mild steel (Fig. 1). End flair can be observed which leads to a springback angle of \(-2\) and \(+6\) degrees at the front and the back end of the welded section. The springback in the DP 780 section is 9 degrees before and after cut off (Fig. 6 a) and this suggests that the mild steel carrier sheets do not influence transverse springback in the DP780 sample section. Only a small amount of end flair can be observed in the DP 780 section after cut off leading to a springback angle of \(+8.25\) and \(+10\) degrees at the front and the back end respectively.

The averaged springback angles determined for the DP 780 sections before and after cut off are shown in Fig. 6 b) for the various test sample lengths. It can be seen that the test sample length does not have a significant effect on the transverse springback angle and that springback only slightly changes after cut off.
Longitudinal bow. The bow heights measured over the strip length of sample type S1 (x=500mm) before cut off and sample type S4 (x=2000mm) are shown in Fig. 7a). Sample type S4 shows a homogeneous curvature over the strip length followed by a slight reverse in curvature at the front end of the section. In contrast to that in sample type S1 bow varies over the sample length; in the DP 780 section of the welded sample bow is in the same direction as for sample type S4 while in the mild steel carrier sheets, especially at the back end of the section, bow is directed in the opposite direction.

Figure 7: a) Bow height measured over the strip length of sample type S1 (x=500mm) before cut off and sample type S4 (x=2000mm). b) Bow height measured after cut off over a section length of 400 mm for all sample types.

As can be seen in Fig. 7b) after cut off the sample sections S1 (x=500mm) and S3 (x=1300mm) show more than double the amount of bow compared to sample section S4 (full strip of DP780). In sample section S2 (x=750mm) bow is slightly lower but still significantly higher compared to that of sample section S4. The previous results have shown that there is no change in longitudinal edge strain with sample section length (Figures 5a, b). The opposite direction in bow observed for the mild steel carriers sheets compared to the DP780 section (Fig. 7a) indicates that the stress distribution over the strip length of the welded sections changes due to the differences in material strength between the DP780 and the mild steel. This suggests that the difference in longitudinal bow observed in Fig.6b) between the short sample sections (S1-S3) and the full strip of DP780 (S4) may be due to the lower material strength of the mild steel carrier sheets and the resulting change in stress distribution.

Summary

The possibility of welding a short section of high strength test material in between two carrier sheets of conventional low strength sheet to enable roll formability trials has been investigated. For this, three different test sample lengths of DP 780 were welded in between two carrier sheets of mild steel and roll formed to a simple V-section. Key parameters such as longitudinal edge strain, transverse springback and longitudinal bow were investigated on the DP780 sections before and after separation from the carrier sheets and compared to results obtained for sections that were roll formed from a full strip of DP780 steel. The result suggests that the material behavior in roll forming transverse to the feed-in direction can be successfully represented by a small sample section. In contrast to that significant differences in longitudinal bow were observed between the full strip of DP 780 and the small sample sections of DP 780 after cut off and this suggests that the material behavior in longitudinal direction cannot be represented by a small scale sample section that is welded in between two carrier sheets.
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