Springback and end flare compensation in flexible roll forming

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Abstract. Flexible roll forming enables the forming of complex automotive components from Advanced High Strength Steels (AHSS) and Ultra High Strength Steel (UHSS) but common shape defects such as end flare and springback occur and need to be compensated. In flexible roll forming a pre-cut blank is fed through a set of rolls which are computer numerically controlled (CNC) to follow the 3D contour of the part. The company, dataM Sheet Metal Solutions, have established a new 3D flexible roll forming facility at Deakin University which allows the manufacture of flexible roll formed prototypes. In this study, Deakin’s flexible roll forming facility is employed to implement an approach to overcome springback and end flare defects in a flexible roll formed automotive component of variable width. To do this, the flexible roll forming process is simulated using the commercial software package Copra FEA. Non-uniform springback due to end flare is observed and a variable overbending approach developed and implemented to overcome this defect. Experimental validation is performed on Deakin’s flexible roll forming facility and the results suggest that the flexible overbending approach can be used to control final shape in flexibly roll formed components.

1. Introduction
Advanced High Strength Steels (AHSS) and Ultra High Strength Steel (UHSS) are increasingly used in the automotive industry. Their higher strength enables the manufacture of lighter vehicles using lower thickness sheet while maintaining the same part performance and strength. Due to their higher strength and limited formability, the forming of AHSS and UHSS with conventional cold stamping methods is difficult [1].

Flexible Roll Forming (FRF) has been developed as an alternative and flexible method to form AHSS and UHSS. In conventional roll forming, a long strip of sheet is formed into a long component with a simple cross section by a set of fixed consecutive profiled rollers. In flexible roll forming, those forming rolls can move to follow the contour of the component to form a more complex shape where the cross-section changes over the length of the part. The forming rolls are CNC controlled and this allows the forming of multiple component shape variations on one roll forming line with minimum change in tooling required. This promises higher process flexibility and reduces tooling costs.

Abee et al. [2] have demonstrated the FRF of several prototype profiles with variable cross-sections while in [3] various automotive components such as crash barriers, frame and panel members, window
components, seat adjusting parts and bumpers were suggested as potential candidates for the technology. A bus frame was successfully formed using FRF in [4].

Recently, Deakin University has developed a prototyping FRF facility that enables the forming of variable depth and width profiles from AHSS and UHSS. This prototyping facility simulates the forming conditions present in FRF and can be used to develop new forming approaches and to manufacture prototype components to prove process feasibility [5].

Web warping which is the deviation of height in the web area of the profile as well as wrinkling in the flange, are the two most critical problems in the FRF field. Both increase with material strength [6]. There are numerous studies regarding web warping compensation which include the heating of critical flange regions [7], the use of a blank holder [2, 8] and over-bending [9]. Wrinkling compensation using special rolls [6, 10] and a blank holder has also been studied [5].

In this study Deakin’s flexible roll forming facility has been used to manufacture a simplified automotive component of variable width. While web-warping and wrinkling issues were overcome, significant shape issues in the form of end flare and springback were observed. A new overbending approach is introduced and successfully applied to compensate for springback and end flare.

2. Material and part geometry
A 1mm CR2 cold-rolled mild steel (per Ford Material Specification WSS-M1A365-A12) was used in this study. Standard tensile tests were performed in an Instron 5967 machine with a 30kN load cell according to ASTM E8/E8M [11] with a cross head speed of 0.025mm.s⁻¹. The resulting averaged true stress strain curve along the rolling direction is shown in Figure 1(a). The original automotive component considered in this work and the simplified version that was flexibly roll formed are shown in Figure 1(b) and (c) respectively. The dimensions of the front cross section and the front half of the unfolded pre-cut blank are shown in Figure 2(a) and (b) respectively.

Figure 1: (a) Averaged true stress strain curve along the rolling direction for Ford WSS-M1A365-A12 (a) geometry of the original part to be formed (c) geometry of the simplified part for flexible roll forming
3. Flexible roll forming experiments

The flexible roll forming prototyping facility developed by dataM Sheet Metal Solutions was installed at Deakin University in 2017 [12]. The facility can be used for “proof of concept” studies in both conventional and flexible roll forming. A schematic of the facility is shown in Figure 3(a). The pre-cut blank is held between the top and bottom clamps. The clamps and the blank are then driven back and forth by a servo motor driven leadscrew. The two forming rolls are located on either side of the carriage on two robotic aims. A forming roll has 6 degrees of freedom which allow it to change the orientation as directed by the control programme and to form the part incrementally in several passes. The control programme uses a contour to define the tool orientation and movement. This “tool path” is defined by the shape of the component in the longitudinal direction (Figure 3(a)).

The forming sequence and the corresponding symmetric halves of the tooling are shown in Figure 3(b) and Figure 4 respectively. According to the forming sequence, the left flange is formed up to 43° in the first 4 passes with the tools shown in Figure 4(a) and then the top hat is formed completely in 5 passes. To accomplish this, the tools shown in Figure 4(b) and (c) were used. After that the left flange with the top hat is fully formed up to 90° in the last 4 passes using the tooling shown in Figure 4(d). The right flange is gradually formed in the first four passes and the last four passes with the same angle increments as the left flange. For the single bottom roll shown in Figure 4(a) was used.

Figure 2: Dimensions of the (a) front cross section (b) front half of the pre-cut blank

Figure 3: (a) Schematic of the flexible roll forming prototyping equipment at Deakin University (b) forming sequence
After forming, the outer surface of the flexibly roll formed parts was scanned with a HandySCAN 3D [13] and in three different locations (Figure 5(a)) the critical angles measured (Figure 5(b)).

4. Finite element analysis (FEA)
The finite element simulation of the flexible roll forming process was performed with Copra RF/FEA [14] which uses an implicit solver. In the actual process, the rolls are stationary and the carriage moves back and forth. However in the FEA, the pre-cut sheet was kept stationary and the rolls move along the specified path to incrementally form the flanges (see Figure 6(a)). The assigned tool paths for the left and right tools are shown in Figure 6(b). The rolls were modelled as rigid bodies and the pre-cut sheet was discretised as full integration, hexahedral, type 7 arbitrarily distorted brick elements [15]. Two elements through the thickness were used and a longitudinal half of the blank was modelled due to symmetry. The effect of friction was neglected. The Young’s modulus and the Poisson’s ratio were taken as 200GPa and 0.3 respectively while the von Mises criterion was used to define plastic material behaviour using the plastic part of the true stress strain curve shown in Figure 1.

Figure 6: (a) FEA model (b) tool path used for left and right tool movement
5. Results and discussion

The final formed part is shown in Figure 7(a) and the modelled symmetric half is shown in Figure 7(b). Figure 8(a) shows the experimental results for the final angles measured at 3 locations. By design, all angles $\alpha$, $\beta$ and $\theta$ should be 90° (see Figure 5(b)). However, a significant deviation of angle $\beta$ in the front and the back cross section (S1 and S3) can be observed. Angles $\alpha$ and $\theta$ also show some deviation from the ideal shape but at a lower magnitude compared to angle $\beta$. In the centre blank location, S2, angle $\beta$ after springback is very close to the required angle of 90°. The situation for angle $\beta$ with larger springback on both component ends is very similar to the end flare defect observed in conventional roll forming [16]. Here flaring out of two ends is generally a result of the bending moment created by the longitudinal residual stresses [17].

Figure 7: Final formed part in (a) experiments (b) FEA result

![Figure 7: Final formed part in (a) experiments (b) FEA result](image)

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Figure 8: Angle measurements at different locations in (a) experiment (b) experiments and FEA result

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Overbending is an approach which is commonly used in conventional roll forming to compensate for springback. However, if springback varies from one cross section to another due to end flare, a flexible overbending approach may be required; such a technique can be implemented in Deakin’s flexible roll forming facility where the tool movement is numerically controlled. The tool orientation for the regular overbending is shown in Figure 9(a). If the tools follow the regular tool path, then it will produce the same overbending angle along the whole length of the part. To have more overbending at the ends and less at the centre, the tool path needs to deviate from the part contour towards the component centre as it is shown in Figure 9(b). For this approach the top roll shown in Figure 9(a) needed to be removed since otherwise the change in tool path would have affected the bend line of the top hat. The simplified roll tooling and the changed tool path are illustrated in Figure 9(b).
Figure 9: (a) Tool orientation for regular overbending (b) schematic of flexible overbending approach

The measured angles after the overbending pass are shown in Figure 10(a). It can be seen that the angle $\beta$ has been significantly improved in both component end locations S1 and S3. However comparing Figure 8(a) and 10 (a), it can be seen that the deviation of angle $\alpha$ from the ideal 90° has now increased. This is likely due to angle $\alpha$ being unsupported during overbending given that the top roll could not be used. To compensate for this, forming pass 13 (see Figure 3(b)) was repeated after the variable overbending pass with the top roll included. The final result is illustrated in Figure 10(b). It can be observed that angle $\alpha$ has been improved due to the additional support provided by the top roll and all angles are within ±1° to the ideal 90° (see Figure 10(b)).

Figure 10: Angle measurement (a) after overbending and (b) repeated pass 13

6. Conclusion
- A simplified automotive cross member was successfully formed by flexible roll forming from 1mm Ford WSS-M1A365-A12.
- Springback and end flare were observed to be the main shape defects.
- A flexible shape compensation approach has been proposed and experimentally validated.
- This approach can be applied to complex parts formed from AHSS and UHSS where the end flare and the springback are more prominent.
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