Experimental study into the correlation between the incremental forming and the nature of springback in automotive steels

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Abstract: Bending in a V-die has been well covered in the literature and the results have been used to indicate the out-come of bending in cold roll forming. However, recent work comparing springback between roll forming and single step bending has found lower springback in the roll forming process compared to single step bending. Roll forming is an incremental bending process and in this study a V-section was formed in a single operation and in multiple steps and the springback determined. The springback in V-die forming was significantly reduced by incremental forming. This suggests that the lower springback determined in roll forming compared to single step bending may be related to the incremental nature of the roll forming process.

Keywords: bending; springback; incremental bending; automotive steels; roll forming.

Reference to this paper should be made as follows: Badr, O.M., Rolfe, B., Hodgson, P. and Weiss, M. (2013) 'Experimental study into the correlation between the incremental forming and the nature of springback in automotive steels', *Int. J. Materials and Product Technology*, Vol. 47, Nos. 1/2/3/4, pp.150–161.

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This paper is a revised and expanded version of a paper entitled 'Experimental investigation of the effect of incremental bending on springback in auto-motive steels' presented at the AMPT 2012, Wollongong, Australia, 23–26 September.

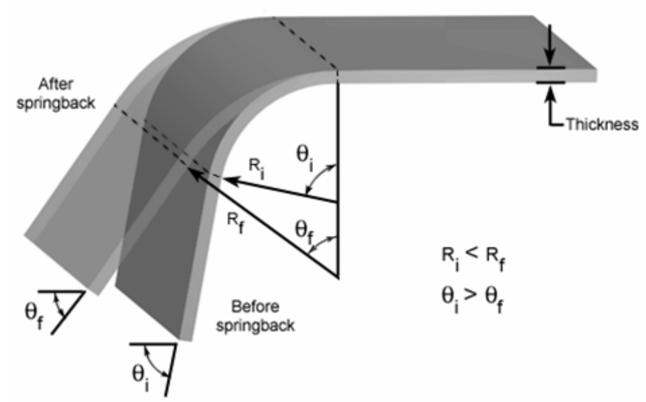
1 Introduction

Roll forming is a metal forming process that allows the manufacture of complex shapes from materials that show high strength combined with limited ductility such as Advanced High Strength Steels (AHSS) (Salonitis et al., 2009) and is gaining increasing interest in all areas of daily life such as automotive, aircraft, construction and general manufacturing industries (Semiatin, 2006; Mynors et al., 2006; Sweeney and Grunewald, 2003).

One major concern in the forming of AHSS is springback (Lawanwong and Premanond, 2010; Tekiner, 2004). Due to their high material strength AHSS and UHSS generally show higher springback than conventional steels which can lead to part dimensions that are out of tolerance (Garcia-Romeu et al., 2007). After springback, the final bent angle (θ_f) is smaller and the final bent radius (R_f) is larger upon unloading than during loading (Lawanwong and Premanond, 2010; Tekiner, 2004; Tekaslan et al., 2006) as shown in Figure 1.

A literature survey has shown that the experiments carried out in simple bending allow the main factors that influence spring-back to be stated (Liu et al., 2007). Although they all affect the springback level to some extent, their individual influence varies. These factors can be grouped in the following sets:

Figure 1 Springback phenomenon in bending process



Source: Lawanwong and Premanond (2010) and Tekiner (2004)

- Part geometry: springback has been correlated to the bending angle, the sheet thickness and the minimum bend ratio (Tekiner, 2004; Garcia-Romeu et al., 2007).
- Forming/bending tool geometry: Punch radius and die opening have been shown to significantly influence springback (Vasudevan et al., 2011).
- Process conditions: The usual process parameters considered are applied load and the contact condition between the tool and the metal strip (Zhang et al., 2007; Andersson, 2005; Huang and Leu, 1998), i.e., friction, contact time (Tekaslan et al., 2006), tool gap as well as speed and the travel distance of the forming tools (Vasudevan et al., 2011).
- Material properties: the most significant properties considered are yield strength, Young's modulus and the ratio of the yield strength to the Young's modulus, the strain hardening component (Lawanwong and Premanond, 2010; Sadagopan and Urban, 2003) and plastic strain ratio (anisotropy) (Verma and Haldar, 2007).
- Interaction effect among above parameters: the link between some parameters is significant to springback; this includes the ratio of the die opening (Garcia-Romeu et al., 2007) and the bend radius to the materials thickness as well as the coupled effects of material properties and process parameters (Jiang et al., 2010).

In roll forming springback can be compensated for by simple approaches. However, to account and compensate for springback in roll forming the amount of springback needs to be estimated in advance so that compensation can be incorporated in the process design.

In a recent study Weiss et al. suggested to use a simple bending test to estimate springback in roll forming. In their study, a V-section was formed using a five-station roll forming process and by single step V-bending. They observed higher springback in single step bending compared to roll forming (Weiss et al., 2012).

One can suggest that the difference in springback between roll forming and the single step V-bending processes may be due to the incremental nature of the roll forming process where the sheet is bent into shape by successive roll stands. To investigate this, in this study incremental V-bending tests were performed on the same steel types as used in the study of Weiss et al and the springback determined. The results show that springback in bending reduces with increasing number of forming steps. This suggests that the differences in springback between single step bending and roll forming reported by Weiss et al. is indeed to some extend due to the incremental nature of the roll forming process.

2 Experiments

2.1 Material characterisation

Six types of automotive steel having thicknesses in the range of 1.6 to 2.0 mm were tested; the thickness and yield strength levels of all steels are given in Table 1.

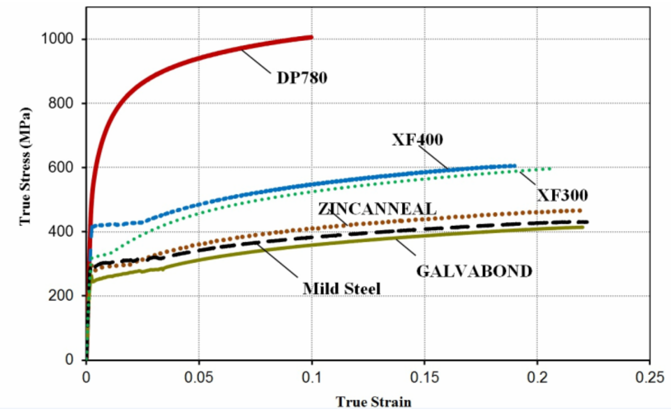
Table 1 Material yield strengths and thicknesses of the six steel types investigated in this study

Steel type	*Yield strength (MPa)*	*Thickness (mm)*
Galvabond (GVZ): hot-dipped zinc coated commercial forming steel	245	1.9
Zincanneal (GVA): hot-dipped zinc/iron alloy coated commercial forming steel	278	1.9
Mild steel	288	2.0
XF300: extra formable steel	322	1.60
XF400: extra formable structural steel	418	1.80
DP780: dual phase steel	580	2.0

The chemical composition of above steels is given in Weiss et al. (2012).

A 100 kN Instron was used to carry out the tensile tests according to the Australian standard AS 1391–1991. All specimens were tested in the transverse direction with a gauge length of 50 mm and a cross-head speed of 2 mm/min using a non-contact extensometer. Three replicas were performed and the true stress – strain curves are shown in Figure 2.

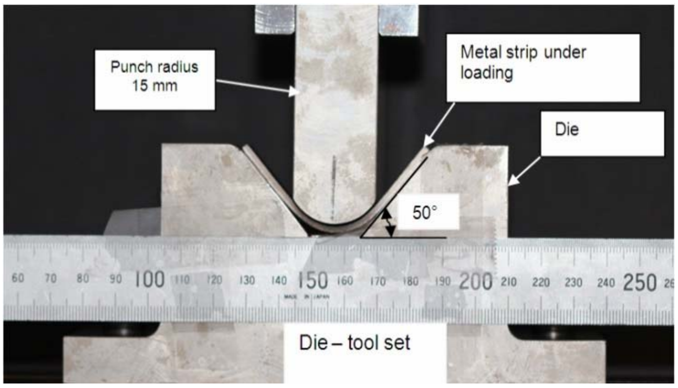
Figure 2 True stress-strain curves for all steels tested in tension in the transverse direction (see online version for colours)



2.2 *V-die forming*

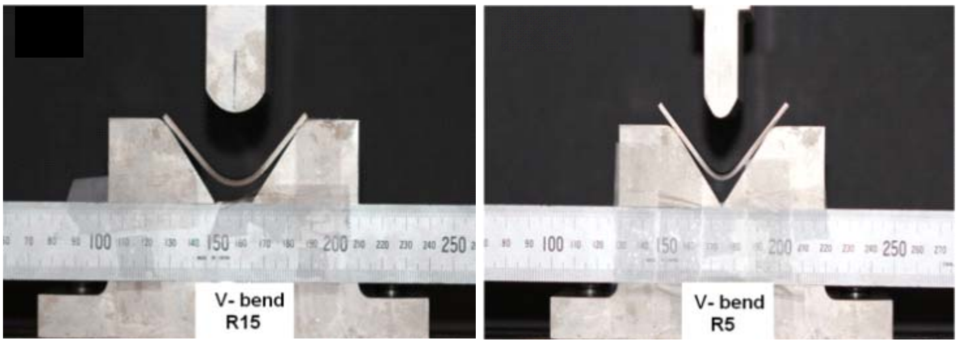
The single step V-die bending tests were performed in an Instron testing machine, 30 kN SD with the tool set shown in Figure 3. Two profile radii 5 and 15 mm were formed. Specimens were cut in the transverse direction with a length of 75 mm and a width of 20 mm. Three samples from each material were tested for each condition in an unlubricated operation. Coining was excluded by pre- tests in order to obtain the correct punch displacement. The samples were positioned on the top of the die surface and then forced into the die with a crosshead speed of 0.1 mm/ min (Figure 3).

Figure 3 V-bending test under loading (see online version for colours)



The springback was determined using an optical method; for this photograph was taken under loading (Figure 3) and after release (Figure 4). The angles under load, θ_1, and after release, θ_u were, measured using the CAD software package ‘SOLIDWORKS’.

Figure 4 V-bending test after releasing punch load, (a) punch radius 15 mm (b) 5 mm (see online version for colours)



(a) (b)

The springback was calculated using equation (1) as shown in Figure 5.

$$\Delta\theta = \theta_u - \theta_l \tag{1}$$

For the incremental bending tests, the radius was formed through sequential bending steps, eight steps in total. For this, the punch was moved down in a number of forming steps N followed by the release of the sample at the end of each step (Figure 6).

Figure 5 Schematic of angles measured before and after unloading to determine springback

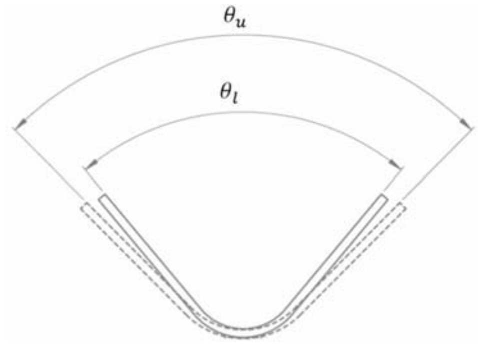
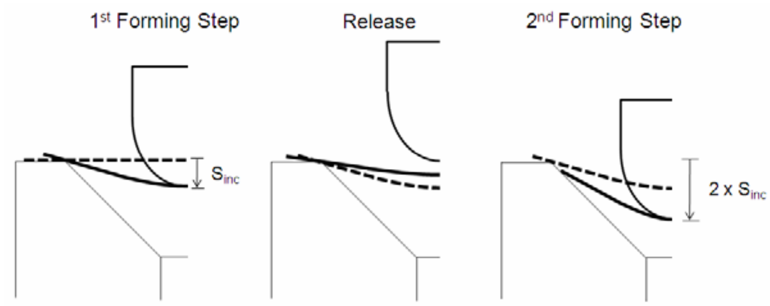


Figure 6 Representative diagram for the multi-step V-die bending test



The incremental punch strokes s_{inc} were evenly distributed over the full punch displacement s_d and calculated using the equation (2). One set of incremental forming steps is shown in Table 2, for the DP780 steel and a full punch stroke $s_d = 26.5$ mm.

$$s_{inc} = s_d / N \tag{2}$$

Table 2 Schematic of sequential V-bends with incremental punch displacement; $s_d = 26.5$ mm for DP780 steel

N	*S_{inc} (mm)*							
1	S_d							
2	13.25	S_d						
3	8.33	17.67	S_d					
4	6.63	13.25	19.875	S_d				
5	5.3	10.6	15.9	21.2	S_d			
6	4.42	8.84	13.26	17.86	22.1	S_d		
7	3.78	7.57	11.34	15.12	18.90	22.68	S_d	
8	3.31	6.3	9.93	13.25	16.56	19.87	23.2	S_d

Note: $S_d = 26.5$ mm for DP780 and the mild steel and 26.6 mm for GVZ and GVA, while 26.7 and 26.9 mm for XF400 and XF300 respectively.

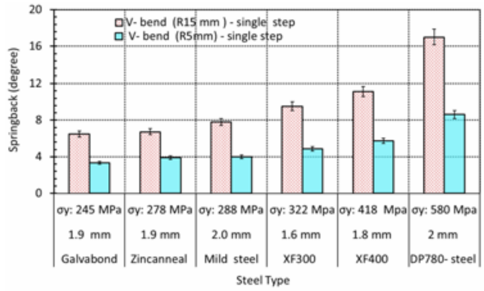
Springback was determined after the final forming step using the same optical technique mentioned above.

3 Results and discussion

3.1 Single V-bend

The experimental results for the single step V-die bending tests are shown for both bending radii in Figure 7. It can be seen that springback increases with increasing bend radius. The magnitude of increase in springback between the 5 and the 15 mm radius is around 50% for all steels tested. Additionally to that springback increased with the yield strength of the material being formed (Table 1) and this agrees with the literature (Frącz and Stachowicz, 2008). Even though R5 is one-third of R15, the springback only decreases by 50% and not by 33.33% as would be predicted by a simple bending and springback model.

Figure 7 Springback comparison in a single V-bend between R15 and R5 mm (see online version for colours)



3.2 Incremental deformation

The springback angles determined in the incremental V-bend tests are shown for both bending radii in Figures 8 and 9. For all steels, springback decreased with increasing number of forming steps. However the reduction in springback depends on the steel type. It can be seen that the DP780 steel shows the highest reduction in springback (degree) with increasing number of forming steps compared to the other steel types.

Springback seems to reduce in a linear manner with the number of forming steps used to form the radius. However, especially for the profile radius R5 the magnitude of springback reduction achieved with increasing the number for forming steps reduces significantly when using more than 5 incremental forming steps. Close investigation of the incremental bending tests shows (Figure 10) that at the end of each bending step the bending angle is larger than the supposed bending angle given by the tooling which is 80° (Figure 10 – single step). The final difference in bending angle after eight incremental forming steps, determined for the DP780 is 2.3° for a formed profile radius of R15 and 1.9° for R5 [Figure 10(a) and Figure 10(b) respectively]. This indicates that during incremental bending the material is slightly coined causing the bending region to be flattened and the profile to be over-bent. Even though the degree of over bending achieved is small it results in the reduction of springback possibly due to the accumulation of plastic strain in the bending region.

Figure 8 Change of springback with incremental V-bending for R15 (see online version for colours)

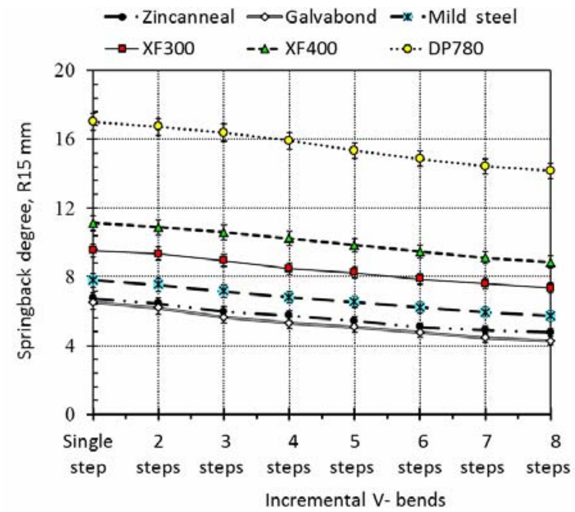
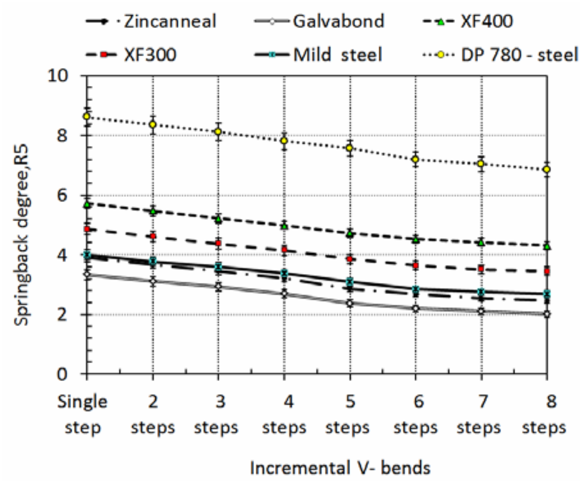


Figure 9 Change of springback with incremental V-bending for R5 (see online version for colours)

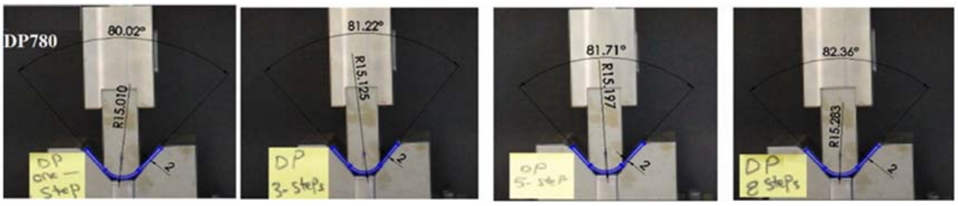


Investigation of the variation of springback for both profile radii as can be seen in Figures 11 and 12 shows that the reduction % in springback with increasing number of bending steps increases with decreasing material strength. This means that the milder steels grades such as the Zincanneal and the Galvabond show a higher sensitivity to incremental bending compared to the higher strength steels grades DP780 and XF400. This could be the result of lower levels of plastic strain accumulated during overbending in the higher strength steel grades due to their high yield strengths.

However, the reduction in springback with incremental bending is apparently to be limited to the maximum over bending angle produced. It can be seen in Figure 10(a) and Figure 10(b) the augment with the overbending angle after five steps 0.06° for Galvabond and 0.65° for DP780 can be ignored compared to that the first five steps 2.16° for Galvabond and 1.7° for DP780. This accounts for the major reduction and % variation in springback is obtained with six multi steps V-bending in R15 (Figures 8 and 11) and likewise with five multi-steps in R5 (Figures 9 and 12).

Figure 10 A comparison between bending angle in single, three, five and 8 incremental bends at instant of full loading, (a) Galvabond (b) DP780 (see online version for colours)

(a)



(b)

Figure 11 Variation (%) in springback with incremental V-bending for R15 (see online version for colours)

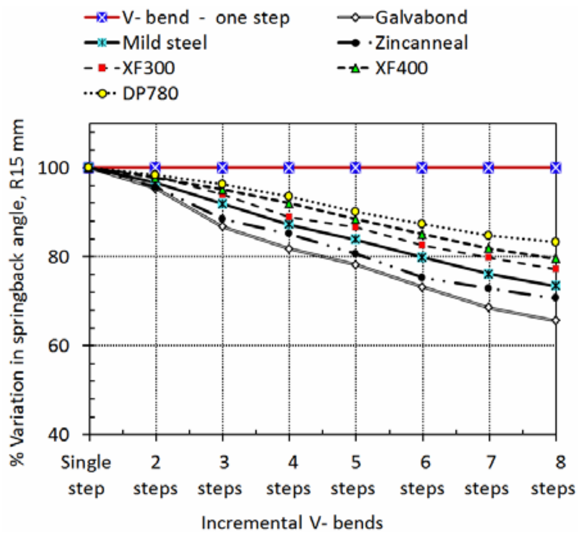
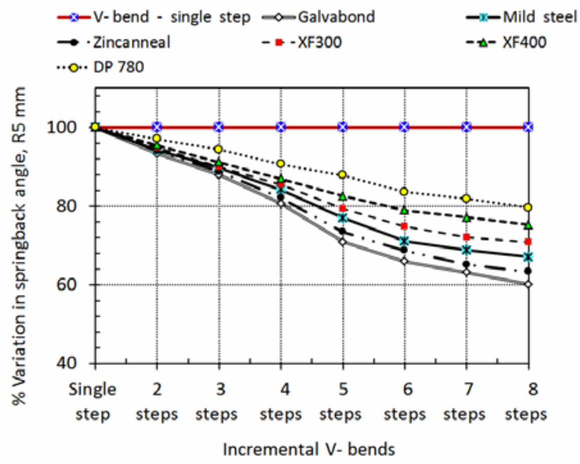


Figure 12 Variation (%) in springback with incremental V-bending for R5 (see online version for colours)



Overall this study has shown that bending in multiple steps leads to lower springback compared to bending in one single forming operation. This reduction in springback may be due to the accumulation of plastic strain in the bending zone as a result of overbending.

The major deformation mode in cold roll forming is transverse bending and the metal strip is formed by feeding a metal strip through successive pairs of rolls. The material is incrementally bent to shape in the individual forming stations and partially released in between the forming passes; this is a similar forming sequence as in the multi-step V-bending test described above (Figure 6). Therefore, this work suggests that part of the reduction in springback determined in roll forming compared to single step V-die bending may be due to the incremental nature of the roll forming process where the sheet is bent and released in numerous steps in the successive roll stands.

4 Conclusions

Six samples of automotive steels were bent in a V-die and the springback after release was determined. The forming of two different profile radii was investigated for two forming conditions. In the first the V section was formed in a single step while for the second multiple forming steps were used. In the single bending test springback increased with the profile radius and the yield strength of the material being formed. The multi-step bending tests showed that springback reduces with the number of forming steps that are used to form the section due to the accumulated plastic strain in the bending zone generated during consecutive bending steps. This suggests that the lower springback observed in roll forming compared to single step bending may be partly due to the incremental nature of the roll forming process. This also indicates that springback in roll forming cannot be estimated by experimental tests that are based on single step bending test. It further implies that springback in roll forming may be influenced by process parameters such as pass distance and the number of forming passes used.

Acknowledgements

The authors would like to acknowledge Emeritus Prof. J.L. Duncan for his help in writing this paper. The authors further appreciate the financial support of the Australian Research Council (ARC Linkage grant – LP0883399), Data M Sheet Metal solutions and Australian Roll Forming Manufacturers.

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