SPRINGBACK DETERMINATION OF SHEET METALS IN AN AIR BENDING PROCESS BASED ON AN EXPERIMENTAL WORK

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ABSTRACT

The air bending process can be erroneously considered as an easy understanding process without complication, but this is a false judge. Several parameters have to be considered in order to avoid precision problems: material and process parameters. Among them, springback phenomenon has a significant role. Traditionally, springback has attempted to be expressed in handbook tables or in springback graphics. But both ways of giving expression to springback amount show shortcomings. This paper presents new springback graphics for air vee bent sheet metal parts. The developed experimental procedure has two main stages. First, the material identification by means of tensile test has been done. Next, bending tests for several specimens of different thicknesses have been carried out.

Hence, springback values for different bending angles (among 22 and 90 degrees) of aluminum and stainless steel specimens were obtained and converted into graphics for the air bending process. Moreover, the most of the theoretical influences related to springback has been ascertained and they are discussed in detail. The obtaining of these new graphics enlarges the data that a sheet metal designer can use either to obtain the final geometry values of an air bending part or to design of bending dies.

KEYWORDS: Springback, Bending, Air bending, Sheet metal

1 INTRODUCTION

The capability of predicting the sheet metal part final geometry as well as springback amount is an important feature in the sheet metal bending processes. Air bending process can be considered a flexible process. In other words, this process allows to obtain a wide interval of bent parts. With the same tool configuration, different bent angles are obtained as well as different curvatures or curvature radius.

The dimensional change generated in the shape part after punch removal due to material elastic recovery is an easy approximation to springback definition. Springback occurs not only in flat sheets or plate, but also in rod, wire, and bar with any cross-section. This recovery or springback causes deviations in the desired final shape; therefore the part after the springback may not be within tolerance limits, stopping of being suitable for the application for which it was designed.

Traditionally, springback amount in bending has attempted to be expressed in handbook tables [1, 2] (where springback allowances appear) or in springback graphics [3]. But both ways of giving expression to springback show shortcomings. On the one hand, usually these allowances refer only to 90 degrees bending angles; on the other hand, there are few springback graphics in the literature about bending and springback [4].

The final bent angle after springback (β_f) is smaller and the final bent radius (R_f) larger than loading situation.

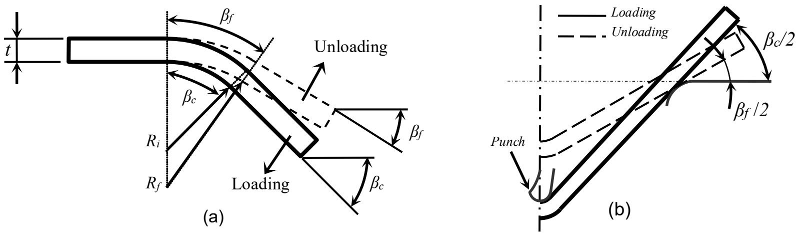


Figure 1 (a) Springback in bending process [5], (b) Vee bending geometry.

Springback amount can be defined either by a non-dimensional springback factor (K_r) , which is the ratio between the final bending angle (β_f, unloading) and the loading bending angle (β_c), or by a springback angle ($\Delta\beta$), which can be expressed by equation (1):

$$\beta_c = \beta_f + \Delta\beta \tag{1}$$

Angle and radius are intimately related one to each other; hence springback can be estimated approximately by Equation (2). This equation has turned into a simplified reference expression for springback computation [5, 6], assuming the hypothesis of constant thickness and arc length.

$$\frac{R_i}{R_f} = 4 \cdot \left(\frac{R_i S_Y}{Et} \right)^3 - 3\left(\frac{R_i S_Y}{Et} \right) + 1 \tag{2}$$

where R_i is the radius in loading state, R_f is the final radius, t is the thickness, S_Y is yielding stress and E is Young's modulus.

The springback increasing classical trends are related to radius decrease, yielding stress increase, bending radius increase and Young's modulus decrease [7]. These four parameters appear in Equation (2), the geometrical parameters used to be related by R/t ratio obeying the same previous trends. Springback is also considerably influenced by another geometrical factor defined by the bending angle which has to be obtained. So, springback increases when the expected bending angle increases.

2 EXPERIMENTAL PROCEDURE

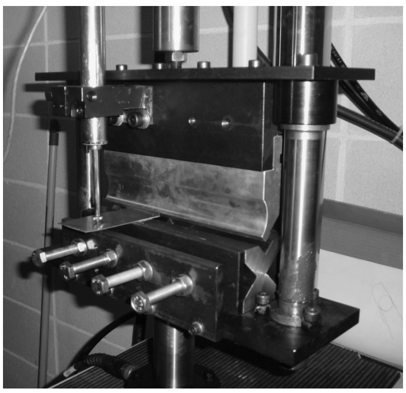
The developed experimental plan consists of obtaining bend parts within an interval of 22º and 90º as bending angle. The experimental procedure has two stages. In the first one, the experimental study consists of the material identification by means of tensile test. The adoption of a material model is important, because the material properties have influence over the bending process. The stress-strain model assumed is a strain hardening model, in

accordance with that material properties are given in Table 1. Two different common sheet metals, with different thickness, are formed: aluminum (very low work hardening) and stainless (high work hardening).
In the second stage, bending tests for several specimens have been performed on a laboratory testing machine, an MTS tensile testing machine. The dimensions of the bending specimens are 130 mm x 50 mm. Their thicknesses are 1 and 1.35 mm for aluminum samples, and 1, 1.5, 2 and 3 mm for stainless sheet metals. To be able to do bending tests, a bending sub-frame has been built, and as a unit, placed in the laboratory machine. This test machine allows a very accurate force-displacement registration. In the sub-frame, high quality industrial bending tools are used (MECOS tools). A punch of 0.8 mm radius and a 'V' type-bending die with 4 different widths (16, 22, 35 and 50 mm) were used as bending tools. Nowadays bending tool combination with a reduced die width are increasingly being used [4].

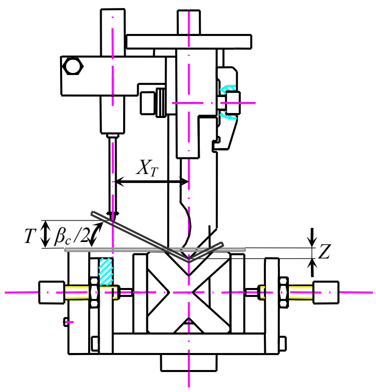
Table 1 Material properties

	t (mm)	*E (GPa)*	$S_{Y0.2}$ (MPa)	*K (MPa)*	*n*	S_{UT} (MPa)	e_u (%)	e_t (%)
Aluminum	1	215.412	311.624	1490.512	0.419	705.312	55.25	60.92
	1.5	224.392	292.531	1423.451	0.428	659.584	54.16	61.99
	2	214.236	292.729	1551.672	0.435	718.260	50.56	56.20
	3	203.189	326.931	1303.994	0.300	687.873	51.23	58.53
Stainless	1	48.288	92.488	122.457	0.048	102.064	4.5	10.35
	1.35	46.412	82.645	112.724	0.050	93.282	6.13	16.13

As well as bending sub-frame, a loaded bending angle measurement fixture was developed, because its determination is essential for the computation of the springback amount. By means of a clamp, a linear displacement transducer was added to a bending sub-frame side, Figure 2. The transducer leans on the internal surface of one of the bent sheet straights legs. The vertical displacement readings are directly recorded by the same MTS machine computer. Therefore, a geometrical expression can be defined for loaded angle determination (β_c), knowing: position of the transducer at the end of the bending process (T), location of transducer axis respect to the axis of the bending sub-frame (X_T) and punch penetration (Z).



(a)



(b)

Figure 2 Test set up with a MTS testing machine. (a) Specimen initial position. (b) Specimen final position.

The main performer parameter of the air bending process is the punch penetration (Z), each Z value corresponds with a different attempting bending angle. These both parameters are linked by the well-known geometrical formulation of the rigid-plastic model, which assumes an ideal geometry for a bent part (two straight legs joint by a circular bent) and a rigid plastic material behavior. Because of that, to carry out the tests, several values of Z are set, and by means of geometrical formulation the bending angle. With test conditions defined, next each sheet metal specimen is located on the die. Initially the sheet is no secure, Figure 2(a), but it is free in order to pivot on three points (two sheet-die contacts and one punch-sheet contact). By means of these three points the bending will be carried out. Before exerting the loading force, the proper alignment of the bending line with regard to the punch is checked. From this moment, punch penetration increases, the loading force is exerted and the sheet metal gets *in-process* the bent form, that is the final bent angle Figure 2(b).

During each bending test, three *in-process* measurements are recorded: the bending force, the punch penetration and the transducer vertical displacement. Attending Equation (1), the difference between two angles, angle under load (before springback) and final or unloading angle (after springback) is used to determine springback angle. Therefore, by means of *in-process* measurements, the load angle is computed, and the final bending angle, after springback, has also to be measured. The measurement of every bending part was done using two techniques. In the first one, a bevel protractor of 5 minutes approximation is used. Whereas in the second one, a digital image processing of the bending parts is used [8]. Both techniques show a very good agreement.

3 RESULTS

There were obtained 22 data groups grouped around die width parameter. Recorded measurement results were subsequently analyzed, and several springback graphics were obtained, a few appeared in this paper. Next, some of them for stainless are shown from Figure 3 to Figure 4 under the same die width and die radius (50mm. and 2mm. respectively) and different thicknesses.

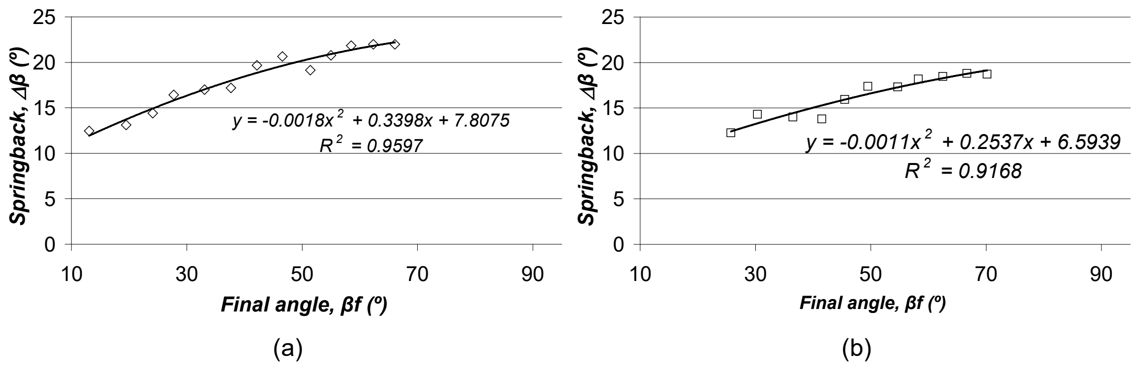
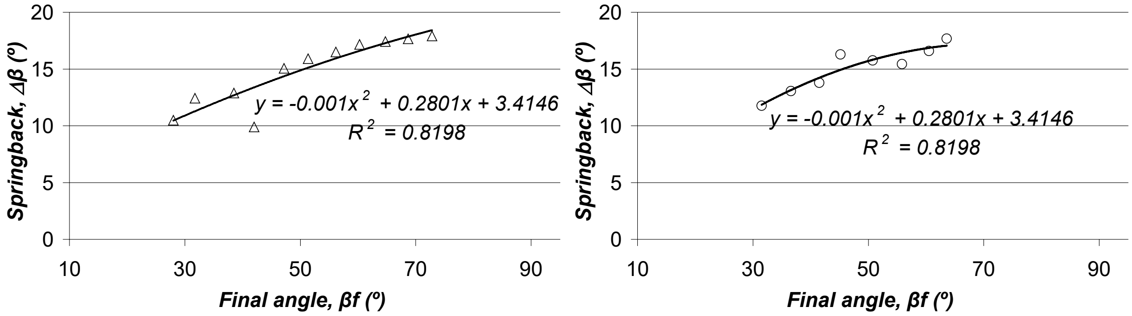


Figure 3 Springback versus final bending angle graphic of (a) 1mm. and (b) 1.5 mm. stainless.



(a) (b)

Figure 4 Springback versus final bending angle graphic of (a) 2 mm. and (b) 3 mm. stainless.

Springback values in air vee bending must be positive, negative values appearance means that bending has changed into bottom vee bending. This situation has occurred in some aluminum specimens when the die width (w_d) was the smallest (16mm). Because of that, these values have not been taken into account in this study. Figure 5 shows the values around zero for that experimental conditions, and the evolution of the springback for the other die widths (50, 35, 22 mm).

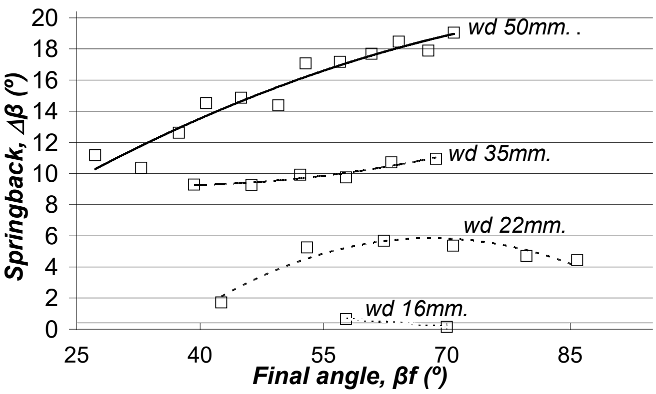


Figure 5 Springback versus final bending angle graphic of 1.35mm aluminum, different w_d.

4 DISCUSSION

The experimentation carried out in this work has allowed to state the basic influences of fixed parameters over the springback. These parameters can be grouped around the following sets:

- *Part geometry.* Springback has been related to bending angle itself, sheet thickness and the minimum bending radio.
- *Bending tool geometry.* The most influential parameter over the springback in this group is the die width.
- *Non-dimensional parameters.* These parameters are defined ratio that link some of the two previous set, i.e. die width-thickness ratio or die radius-thickness ratio.
- *Material properties.* The usual properties considered are yielding stress, Young's modulus, and the ratio yielding stress-Young's modulus.

Next, the obtained results to analyze the influences of each of them are described briefly. It is well known the larger is the bend angle the larger is the bending moment, and therefore bigger is the springback. This trend can be noticeable in both materials (Figure 3 to Figure 5) and it is more obvious when the die width is bigger. Regarding the thickness, if the graphics showed in Figure 3 and Figure 4 were superimposed, it could be observed to the extent the thickness reduces the springback increases. Minimum bending ratio increase correspond with a springback increase, although the graphics that usually gather this relationship express the springback amount as the non-dimensional springback factor (K_r)

With regard to the bending tool geometry, when the die width value rise increases clearly the springback angle value (Figure 5). It can be explained because the elastic displacements and rotations of the sections are more important when the distance between the die tool supports (width die) is bigger.

The influence of non-dimensional ratios over the springback is the same for the die width-thickness ratio and for the die radius-thickness ratio. When bigger is the ratio value, springback increases. This trend can be observed in Figure 6 for both materials.

Finally, as it can be observed in Table 1, the stainless yield stress is around 3 times bigger than aluminum, thus the tested aluminum presents a low level of hardening that means its behavior can get to consider a rigid plastic behavior. As a consequence, lower springback values should not surprise.

Therefore the trend about yielding stress has been the expected trend, Figure 6, the bigger is the yielding stress the bigger is the springback amount.

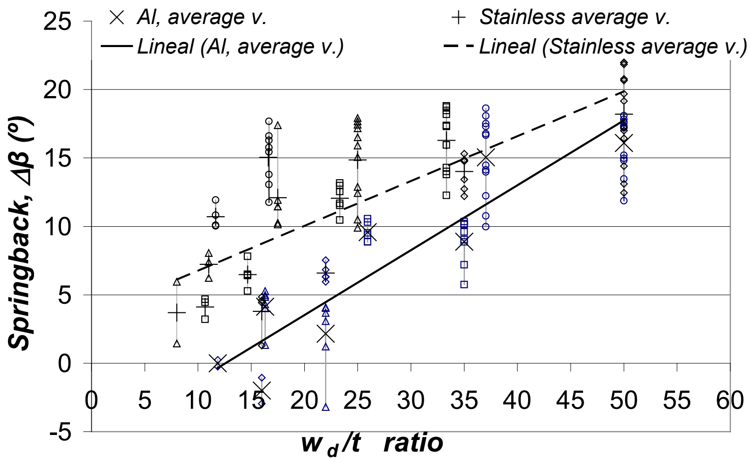


Figure 6 Springback versus w_d /t ratio graphic, aluminum and stainless

5 CONCLUSION

First of all, it has to be reminded that springback can be minimized by using suitable die designs but cannot be eliminated. For getting that reduction or compensation, springback graphics are used. This work presents some of this kind of useful graphics that relate springback with the main parameters that have influence over this phenomenon.

Secondly, the experimental study has allowed to observe the deficiency of the rigid-plastic model, although it continues being an easy way of approaching to the attempted final bending angle. Next, springback needs small radius whereas bigger radiuses are preferred in consideration of the mechanical properties of the bending parts. Subsequently, it is necessary establish compromises between all the parameters to get the parts of the desired accuracy.

Finally, this experimental work has been to carry out a prediction tool based on a neural network, so the developed tool can predict the springback amount, the final bending radius and the punch penetration.

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