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Springback determination of sheet metals in an air bending process based on an experimental work

M.L. Garcia-Romeu [a,*], J. Ciurana [a], I. Ferrer [b]

[a] Department of Mechanical Engineering and Industrial Construction, University of Girona, Campus Montilivi P-II, Girona 17071, Spain

[b] Department of Production Management and Product Design, University of Girona, Campus Montilivi P-II, Girona 17071, Spain

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°) 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 one hand, usually these allowances refer only to 90° 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 (Fig. 1).

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 Eq. (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 Eq. (2). This equation has turned into a simplified reference expression for springback computation [5,6], assuming the hypothesis of constant thickness and arc length.

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

* Corresponding author.

E-mail addresses: mluisa.gromeu@udg.es (M.L. Garcia-Romeu), quim.ciurana@udg.es (J. Ciurana), ines.iferrer@udg.es (I. Ferrer).

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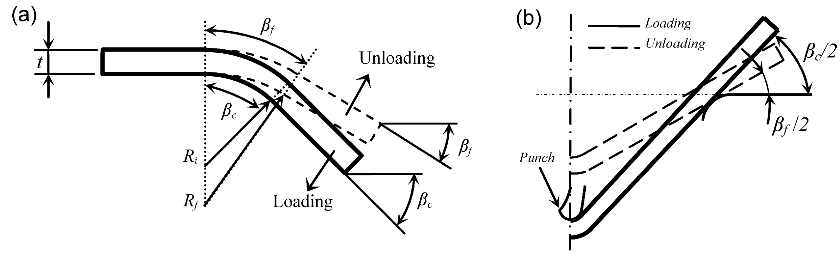

Fig. 1. (a) Springback in bending process [5] and (b) vee bending geometry.

where $R_{\rm i}$ is the radius in loading state, $R_{\rm f}$ the final radius, t the thickness, $S_{\rm Y}$ the yielding stress and E is the 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 Eq. (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 22° and 90° 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 × 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 four different widths (16, 22, 35 and 50 mm) were used as bending tools. Nowadays, bending tool combinations with a reduced die width are increasingly being used [4].

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, Fig. 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 ($\beta_{\rm c}$), 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 ($X_{\rm T}$) and punch penetration (Z).

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, Fig. 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, Fig. 2(b).

During each bending test, three *in-process* measurements are recorded: the bending force, the punch penetration and the transducer vertical displacement. Attending Eq. (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 min 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 Figs. 3 and 4 under the same die width and die radius (50 and 2 mm, respectively) and different thicknesses.

Table 1
Material properties

t (mm)	E (GPa)	$S_{\rm Y0.2}$ (MPa)	K (MPa)	n	$S_{\rm UT}$ (MPa)	$e_{\rm u}$ (%)	$e_{\rm t}$ (%)
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