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Evaluation of springback under the effect of holding force and die radius in a stretch bending test

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ABSTRACT

In this work, we evaluate springback using U-form stretch bending tests. Tests are carried out on aluminum alloy test pieces using an experimental set up made in our laboratory. This apparatus can be mounted on a tensile testing machine and gives the possibility to vary several parameters. We show the role played by certain factors such as die radius of curvature, blank holding force (BHF) and stretching depth. Springback and sliding at extremities are strongly influenced by these technological and geometrical parameters. In this work we also show the gradual decrease of springback with the increase of stretching depth. The radius of curvature of the die can remarkably influence the two stages of springback.

1. Introduction

Springback is a phenomenon which takes place during the last stage of sheet forming operations under the action of internal residual stresses which are non-uniformly distributed throughout the specimen thickness. This is why the study of the influence of the different technical factors and physical and metallurgical parameters on springback is important for the design and manufacture of forming tools [1,2]. In the last 10 years or so, researchers in the field have intensified their efforts to achieve a better understanding of the phenomenon. Several studies have been done to show the influence of mechanical factors on springback. Some authors showed that high strength metals always exhibit greater springback in comparison with ductile metals. For instance, Panthi et al. [1], Jiang et al. [3] and Mori et al. [4] have concluded in their works that springback increases with increase of yield stress. The increase in elastic modulus and in strain hardening exponent leads to a decrease in springback [3,5,6].

Mkaddem and Saidane [7] have shown, using bending tests, that the smaller the die radius of curvature the smaller the springback. Lee and Kim [8] have concluded that an increase in die radius of curvature with smaller clamping force gives greater springback. For U-forming, an increase in die entrance radius can only reduce springback [2]. This was also validated by the works carried out by Verma and Haldar [9]. Yoshida and Uemori [10] have studied, numerically and experimentally, the residual curvature of a U-form lateral wall under the influence of the die entrance radius. They found that a small die radius gives big curvature of this lateral part, and consequently, big overall springback of the specimen.

Blank holder force (BHF) is another technological factor which has a non-negligible effect on springback [11]. Liu et al. [12], Kim and Koç [13], Lee and Yang [14] have shown, through tests carried out on steel and aluminum alloys, that an increase in BHF gives a reduction in springback. Indeed, for a greater BHF, tensions in the stretched part are greater thus creating greater strain hardening and considerable plastic deformation throughout the entire thickness of the specimen, with a small difference in stress between the top and bottom faces of the metal sheet [15,16]. These observations are also sustained by the work of Chen and Koç [17] carried out on high strength steels. The progressive variation of BHF, as done by Liu et al. [15], is another technique which results in the stress throughout the specimen wall to be uniform, and reduces or eliminates springback.

Anisotropy is another plasticity factor which was introduced in some models to numerically evaluate springback [2,9,18]. Verma and Haldar [9] observed in their work that springback is greater for normal anisotropic value R greater than 1 or smaller than 1. They also found that springback is small for isotropic materials ($R = 1$). Leu [18], however, found that springback increases linearly with R (no minimum for $R = 1$).

Recovery is also another important factor which can reduce springback after deformation at high temperature. In their high temperature bending tests on a high strength steel, Yanagimoto and Oyamada [19] showed that springback falls remarkably for testing temperatures greater than 750 K. This was explained by reduction of the strength under the action of temperature and the influence of creep. Moreover, the experimental verification

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on a U-bent aluminum 1050 sheet, carried out by Moon et al. [20], showed that the combination of a hot die and a cold punch can reduce the amount of springback by up to 20% when compared to a conventional room temperature bending test.

Springback is sensitive to the width and thickness of the sheet to be formed [21–23]. Garcia-Romeu et al. [21] have shown, through bending tests on steel and aluminum sheets, that the greater the width the greater the springback. As to the effect of thickness, the work of Serkan et al. [23] revealed that the decrease in springback becomes significant with increase in thickness. This was backed by the results of a numerical simulation carried out by Albut [24].

Friction due to surface roughness of both sheet and die can also reduce springback, since in this case the different parts of the test piece are well stretched and well deformed (no sliding of the sheet between the tools). Li et al. [16] and Kadkhodayan and Pourhasan [25] have shown in a simulation study that an increase in friction coefficient provokes a net decrease in springback angle. It can thus be said that friction plays a role similar to that of BHF. It is worth mentioning at this point that Samuel [2] has experimentally shown a decrease in springback as a result of a progressive increase of die/specimen coefficient of friction.

Numerical simulation has taken an important role in the study of springback during the last 15 years. This allowed the forming process to be optimized by the introduction of geometrical, metallurgical and technological parameters to reduce springback to a minimum [2,13,16,26,27]. In order to predict springback, it is necessary to know precisely the distribution of internal stresses. This is difficult because obtaining a piece by forming sometimes requires complex cyclic loading. In order to find solutions to these problems, the deformation history was taken into account and the Bauschinger effect was introduced in a number of simulations [10,27–29]. In an experimental investigation, Gau and Kinzel [30] have confirmed that the Bauschinger effect on springback is significant.

In a first step of this experimental work we built a device that fits easily on a tensile machine. The clamping of the test parts on this device can be controlled using a dynamometric key. The stretching height and the springback are measured during the loading and unloading phases of the test using an LVDT displacement captor. This study aims to show the influence of the tightening force, the stretching height and radius of curvature of the tools on the springback. This factor is evaluated after unloading and after total liberation of the test parts.

2. Experimental procedure

In the present work, the test parts are of a rectangular form of dimensions 126 mm, 18 mm and 0.8 mm (thickness). The piece is held in place at its two ends (extremities) over a surface of 600 mm^2 at each end. The material studied is an aluminum alloy having the chemical composition given in Table 1.

Springback tests were carried out using a set up made in our laboratory. The lubricant was industrial oil. The set up consists of a die, a stretching piece and a blank holder which exerts a pressure on the extremities of the sheet (test piece). Table 2 gives the relationship between BHF and the pressure developed on each end of the piece. The die can be fixed on the mobile crosspiece of the tensile machine. The superior stretching piece is fixed to the fixed crossbar of the tensile machine. This piece, which plays the role of a punch, is crossed by two parallel cylindrical rods which serve as upper stretching rods (Figs. 1 and 2). The two ends of the sheet (test piece) are maintained under pressure by the blank holder and stretching is obtained with a displacement speed of 3 mm/min. This setup gives the possibility of varying the BHF on both ends of the test piece using a dynamometric key. By exerting a tightening couple on each bolt, the key allows the sheet, which slides between the die and the blank holder, to be held with a certain force (BHF). The tightening force for each bolt is calculated from the tightening couple using the Kellermann–Klein formula. The clamping pressure is calculated by dividing the clamping force by the contact surface between the extremity of the test parts and the blank holder.

Another interesting characteristic of this set up is that it possesses interchangeable dies which allow the entrance radius R_d to be changed (Fig. 1). An LVDT displacement captor adapted to the setup and linked to an electronic reader (SOLARTRON C-53) can record at every instant the stretching depth h and the primary springback Δh_1 just after suppression of the stretching load. The final springback, after suppression of the charge and freeing the test piece from the set up, can be quantified in two ways using a MP320 profile measurer having a precision of 0.001 mm. This apparatus is used to measure Δh_2 and $\Delta\theta$ which are the two parameters that characterize the final springback. The primary springback, Δh_1, is calculated from the difference between h and h_1, which are measured during the stretch bending test by the displacement captor during charging and discharging respectively without liberating the two ends of the test piece. The final springback, Δh_2, is calculated from the difference between h which is measured by the displacement captor, and h_2 which is measured by the profile measurer.

For a good evaluation of the springback we have also calculated the mean deformation of thickness ε_t in the four critical regions A, B, C and D, using the relationship $\varepsilon_t = \Delta t/t_0 = (t_f - t_0)/t_0$, where t_0 and t_f are the thicknesses of the sheet before and after the stretching test as measured using an MP320 profile measurer. ε_t, a negative quantity which characterizes thinning and plastic deformation, decreases in the different zones of the sheet when the stretching effort increases under the effect of the BHF.

3. Results and discussion

3.1. Evaluation of deformation in different regions of the test piece

In order to understand the evolution of the springback, we present three important zones as shown in Fig. 3. This schematic representation has been adopted by many workers [2,11,13,14,17]. The first zone AB is curved and takes the shape of the cylindrical stretching rod. The second zone BC is slightly curved due to the residual stresses which vary with the sheet thickness. The third zone CD is highly deformed by the stretching effort and bending due to the entrance curvature of the die. Springback is due to the fact that each of the three zones has two layers of different mechanical states, knowing that bending and stretching produce simultaneously a compression and a tension in the first layer and two tensions in the second layer. To calculate springback, Zhang et al. [31] used a stretch-bending formulation considering five zones for U shaped specimens. However, the three zones represented in Fig. 3 were considered in their work to be the most important zones with different deformation histories. The middle

Table 1
Composition of the material studied.

Elements	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Ni	Pb	Sn	Na	Al
(%)	0.401	0.375	0.161	0.162	0.664	0.223	0.018	0.006	0.004	0.011	0.005	0.001	97.97