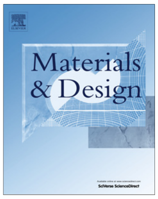
Materials and Design 56 (2014) 613–619

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes



Technical Report

Experimental determination of spring back and thinning effect of aluminum sheet metal during L-bending operation

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ARTICLE INFO

Article history:
Received 4 February 2013
Accepted 19 November 2013
Available online 5 December 2013

ABSTRACT

In automotive industry, significant efforts are being put forth to replace steel sheets with aluminum sheets for various applications. Besides its higher cost, there are several technical hurdles for wide usage of aluminum sheets in forming. Major problems in aluminum sheet metal forming operations are deformation errors and spring back effect. These problems are dependent on the number of parameters such as die and tool geometry, friction condition, loading condition and anisotropic properties of the metal.

To predict the exact shape, the geometry based punch contact program must be used. The shape changes once the punch is withdrawn, because of the materials elasticity. Prediction of such a spring back effect is a major challenging problem in industry involving sheet metal forming operations. It also needs applying appropriate back tension during the forming complex shapes. Slight deformation of the metal leads to non-axisymmetric loading. One can predict the residual stress by determining plastic and elastic deformation. Thus appropriate spring back effect can be investigated.

The present investigation was carried out to determine the spring back and thinning effect of aluminum sheet metal during L-bending operation. Number of specimens with thickness varying from 0.5 mm to 3.5 mm were prepared. The experiments were conducted for different clearances between punch and die. It is observed that, beyond a particular clearance for each thickness of the sheet metal, the spring back and thinning effects were linearly increasing. However, below the critical clearance, scratches on the surface of the sheet metal were seen due to wear. The scratches were analyzed through Scanning Electron micrographs. As the clearance between punch and die reduces further, more wear on the punching surface was observed. And, as the clearance increases it leads to increase the spring back effect and fracture propagation.

1. Introduction

In typical sheet metal forming process, the shape of the blank obtained at the end of the forming step closely conforms to the tools geometry. However, as soon as the loads are removed, elastically-driven change in the blank shape takes place. This process is termed spring back [1]. The most important task in sheet metal forming design is to define such a tool geometry that geometry of the actual product coming out from the manufacturing process is as close as possible to the one prescribed by the design [2]. In sheet metal forming, there are two regimes; elastic and plastic deformation. Forming a sheet to some shape obviously involves permanent 'plastic' flow and the strains in the sheet could be quite large. To minimize the spring back effect several methods are applied [3]. The comprehensive compensation (CC) method considers the fact that large rotation and displacement would occur during spring back, which is more common for automotive panel stamping [4]. The displacement adjustment (DA) method in which compensation magnitude and compensation direction are the two important aspects, has been proved in practice to be successful [5]. However, no theory behind the DA method is present, tests of industrial case also shows that the effectiveness of the method depends on various parameters including the part geometry, material and process settings [6,7].

Anisotropy is an important parameter to be considered in simulating the bending process. The anisotropy of the function was introduced in formulation using two linear transformations on the Cauchy stress tensor. This new formulation is expected to be particularly suitable for finite element (FE) modeling simulations of sheet forming processes for aluminum alloy sheets [8,9]. To set the process of spring back compensation on solid physical

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0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.11.047

and mathematical grounds, Flavio et al. [8] proposed a new method, in which a set of shape function bases has been employed to express the displacements of both the die and the sheet. However, the numbers of function evaluations are too high for complex geometries. More work has been done to improve the precision of spring back based on DA method [9–11].

1.1. Method

In present work, focus was on L-bending operation of aluminum sheets of various thicknesses. In this, a thin sheet metal blank of thickness t_0 was held between a blank holder and die. When a punch moves down at a velocity U_0, the material under the blank holder will bend and deform into L-shape. The bending process can be considered as V-shape bending or L-bending as shown in Fig. 1. For L-bending and V-bending, empirical methods and analytical models have been developed and successfully utilized to predict spring back [12]

In this paper, L-bending operations and its thinning and spring back effects were investigated. The L-bending process is limited to certain clearance to thickness ratio before rupture [13]. Rupture is usually manifested by strain localization followed by disintegration. A closer look at the evolution of the L-bending reveals two major phases: embossing and drawing. Once the embossing phase has been completed the L-bending process begins in which the blank is bent and compressed over the die, then straightened and pulled down to form L-shape. For the purpose of predicting strain distribution and deformation region in L-bending process, one can adopt an upper bound analysis which provides an analytic solution.

Fig. 2 shows the geometric zone on the work piece surrounding the punch and along the die. The thickness in zone i.e. $t(\ell)$ is assumed to be a function of the initial position ℓ_0 of a point in the blank.

$$T(\ell) = \left[\ell n\left(\frac{\ell_0}{\ell}\right)C_t + 1\right]\ell_0 \tag{1}$$

where $\ell_0 = \sqrt{L_0^2 - L_c^2 + \ell^2}$, is the initial location of a point in the material, L_0 is the outer length of the blank, L_c is the stamp out length of the blank, C_t is a constant depend on the clearance between the die and punch and t_0 is the initial thickness of the sheet metal.

The material element with maximum thickness is the one that the presses out position $\ell = \ell_0$ and remains in its maximal thickness at the end of the zone where $\ell = x_d$. The zone below the bending work piece thickness does not change since there is no velocity along the thickness direction. However, zone II is subjected to tensile stress under the resisting frictional forces. Once the flow stress is exceeded, then zone is stretched causing thinning in zone I.

In L-bending operation thinning take place in zone I, hence, the thickness change in the zone I are taken into account. The thickness of the work piece at the end of the zone I, t_β is a function of the punch position and $t(x_d)$ [14]

$$T_\beta = t(x_d) + p_d\frac{t(x_d) + p_d}{x_d - p_d} \tag{2}$$

where p_d is the radius of curvature in L-bending transition zone and x_d is the distance between the U_0 and the die face.

The region of the sheet wrapped around the punch face and fillet will be subjected to tensile stress under resisting fractural forces. Once the flow stress gets exceeded, the zone I will be stretched and thinning of the wall takes place. In order to avoid eventual plastic instability, one should check the zone I for its non-work hardening. In the plane strain approach, the height at failure is related to the thickness strain of the material when compressibility is assumed. Fig. 3 illustrates the thinning effect in the zone I for a sheet metal of thickness 3.5 mm. The unit in the y-axis is in microns, which is the difference between initial thickness and final thickness after bending. The values L_0 = 60 mm, L_c = 30 mm and clearance of 3.7 mm were selected for the computation. For the experimental results elasto-plastic modeling is used. Eqs. (1) and (2) are used for computing the thinning. An experimental observation of L-bending operation shows the same pattern of thinning. The detailed analysis on thinning for various thicknesses was investigated experimentally.

Considering the membrane strains, the plane stress assumption for a principle direct coordinate system was used [15] to determine the plastic deformation and elastic strain. Lagrange description of motion is applied to the finite deformation analysis of the thin sheet structure. The application of simulation models for sheet metal forming in automotive industry has proven to be beneficial to reduce the tool costs in the design stage and for optimizing current processes [16].

The model treats plastic flow by modified Von Mises rule which satisfy Hill's rate insensitivity normal isotropic relationship [17,18]. The total strain consists of an elastic part and plastic part given by [19,20]:

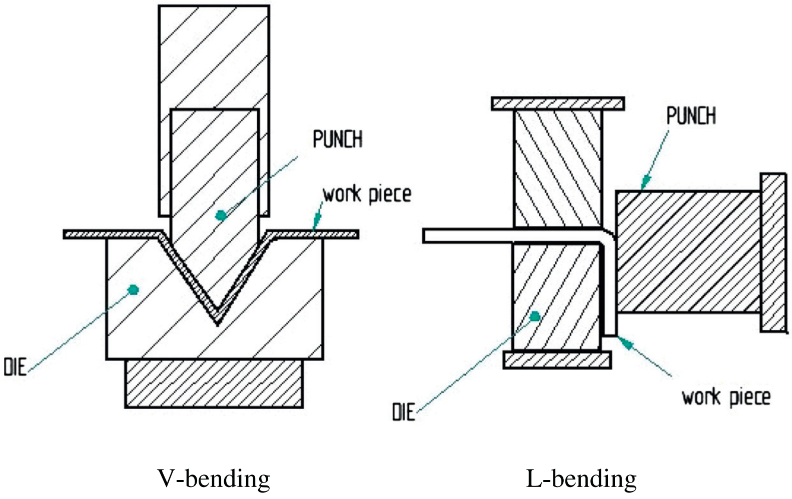

Fig. 1. V-bending and L-bending operation.