B. GRIZELJ, J. CUMIN, D. GRIZELJ

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EFFECT OF SPRING-BACK IN V-TOOL BENDING OF HIGH-STRENGTH STEEL SHEET METAL PLATES

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This paper deals with the effects of technological parameters used in the V-die bending process, on the obtained product properties and dimensions. By variation of the tool geometry, several cases of steel sheet bending process are observed through the FEM simulations. Also by variation of different mechanical material properties, effects on product geometry are observed. Since the automobile manufacturers mostly use the high strength steel sheet metal plates, there is a need for the successful tool construction and optimization in order to produce quality products.

Key words: V-tool, bending, sheet, spring-back

INTRODUCTION

The high-strength steel sheet metal plates are used for the production of light-weight high-strength products such as automobile body parts, motorcycle parts, ammunition storage cartridges, electronic boxes in airplanes, etc.In the production of these parts, the sheet metal plates are cut or stamped to desired shape and then bent, drawn or punched to a desired shape. Afterwards, they are assembled into a product by using screws, rivets, welding or brazing.

In this paper, the operation of air bending with different process parameters, different tool geometries, different materials and material thicknesses was modeled by the FEM. According to [1], the shape of the sheet metal during bending does not depend on the geometry of the tool. It depends on the relative position of tools, material properties such as the flow curve and the sheet thickness. The authors [1] described how plastic deformation during bending occurs underneath the punch where it is maximal, and propagates towards the sheet ends. During this process, the radius of curvature of the sheet is independent of the punch geometry, but it is a function of bending moment,the bending die,the sheet thickness and the flow curve [1].

Afterwards, by constant moving of the tool, the radius of sheet plate beneath the punch is reduced until the contact between two tools is made. When the tool is closed, the sheet metal plate has exactly the same geometry as the tool, and after opening of the tool, the sheet metal plate has mechanical elastic spring back and it forms other shape.

Figure 1 illustrates different V-tool geometries which are used for bending. There are two types of tools

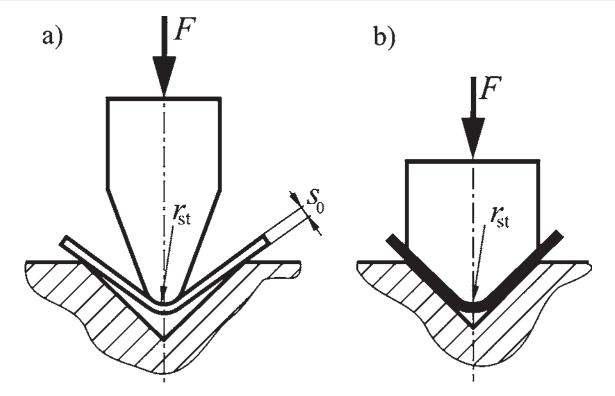

Figure 1 Different V-tool geometries [2]

shown: first (a) in which the punch has 75 degree angle and the lower tool is 90 degrees, and (b) other tool, which both have 90 degree angle. Theradius of punch is denoted as r_{st} in mm, s_0 – thickness of the sheet in mm.

W. M. Chan et al. [3] investigated the effect of spring-back with the FEM analysis and concluded that the spring-back reduces with the increased punch angle and punch radius. They also determined that with a larger deformation zone, the effect of spring-back is also reduced [3]. Z. T. Zhang and S. J. Hu investigated stress and residual stress in the plane strain bending, and concluded that the stress distribution of a part before unloading determines the amount and direction of the elastical unloading [4]. W. L. Xu et al. investigated the parameters which had the most influence on the results in the FEM spring-back simulations [5]. They concluded that the FEM analysis is very complicated because of various input parameters such as: material constitutive law, strain hardening curve, FEM element type, contact model, friction law, material and geometrical nonlinearities [5]. S. Thipprakmas and S. Rojananan investigated the spring-back and spring-forward effects with the FEM method. They have concluded that the phe-

B. Grizelj, J. Cumin, Mechanical engineering Faculty in Slavonski Brod, Slavonski Brod, Croatia
D. Grizelj, Siemens, Zagreb, Croatia.

nomenon of spring-forward was rarely investigated in the past, and that this phenomenon needs to be further researched [6]. When the sheet metal plate is bent, the outer «fibers» are under tension, and the inner «fibers» are under compression. The neutral line divides the tension and compression areas [6]. When the sheet metal plate is released of loads – the fibers under tension try to contract, and the fibers under compression try to expand, thus the sheet metal plate opens until the remaining stresses are in equilibrium. This is the effect of spring-back. According to [6], the phenomenon of spring-forward yet needs to be investigated.

MATERIAL, MODEL AND EXPERIMENT DESIGN

For the FEM experiment, two types of tools were chosen (Figure 2); two types of materials – St1403 (DC04), and dent resistant steel DR180 used for automobile hoods, lids, etc., two types of punch radius, r_{st} = 0,4 and 2 mm respectively, and two sheet thicknesses as 0,75 mm and 1,5 mm respectively.

Figure 2 shows the tool geometry and measurements for one of the cases observed through the FEM simulations.

Figure 3 shows the plan of parameters which were used for the FEM simulations. It can be seen that the plan is made for two materials, two tool geometries, two punch tip radii and two metal sheet thicknesses.

Figure 4 shows the FEM models used for simulations based on the technical drawing from Figure 2. Steel St1403 is German DIN designation, European norm BS EN 10130:1999 is old designation for the same material. The new EU norm is EN DC04 (1.0338) [7]. This material has the following mechanical properties [8]:

- yield stress, R_{p02} = 157 MPa
- ultimate tensile stress, R_m = 310 MPa
- n value, n = 0,242

The flow curve is approximated with the expression [8]:

$$k_f = 556\left(0,0058+\varphi\right)^{0,246}, \text{ MPa} \quad (1)$$

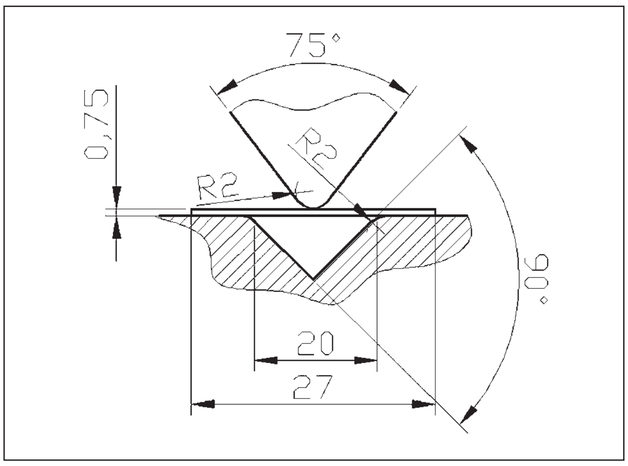

Figure 2 Measures of V-tool with 75° angle of punch and radius r_{st}=2 mm

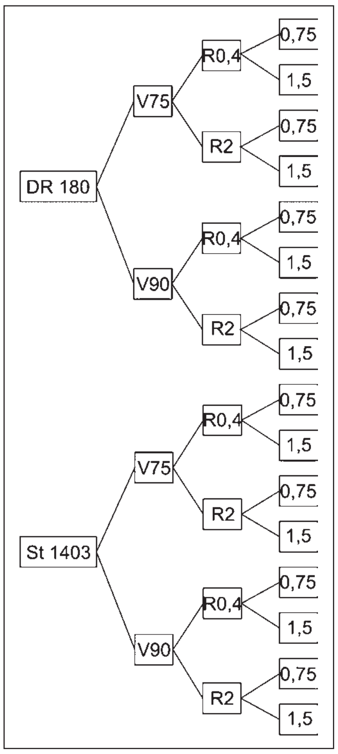

Figure 3 Plan of parameters for FEM simulations

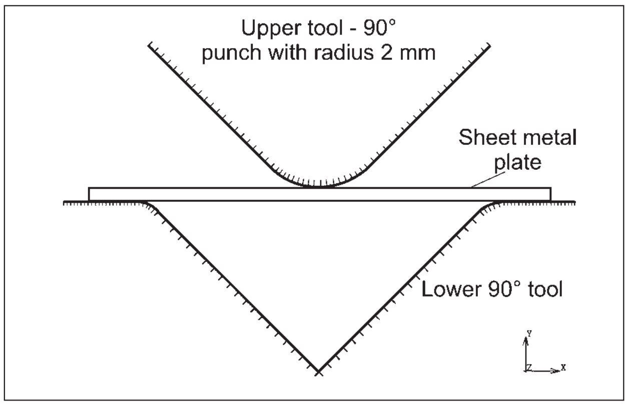

Figure 4 FEM model

The strain hardening curve is supposed to be entered in the form of plastic portion of true strain/true stress. These calculations are done by the following expression:

$$\varphi_p = \varphi - \frac{k_f}{E}, \quad (2)$$

where E represents Young's modulus of elasticity. For the steel sheet metal plate St1403 Young's modulus of elasticity is E = 210 GPa. The flow curve for St1403 material is shown in Figure 5.

Steel DR180 is dent resistant steel used for the parts which should withstand possible dents such as the hand dents on the car hoods and doors. DR 180 or SAE J2340 Type 180A has the mechanical properties [9] of yield strength R_{p02} = 157 MPa and ultimate tensile strength of R_m = 310 MPa, Young's modulus of elasticity E=200000 MPa, strain hardening exponent of n=0,17-0,21 [10,11]. The material flow curve was described by Ludwik-Hollomon's law:

$$k_f = 410,46\,\varphi^{0,21}, \text{ MPa} \quad (3)$$

and it is shown in Figure 6.

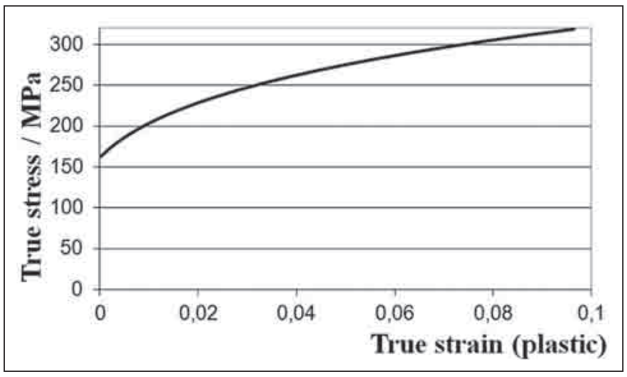

Figure 5 Strain hardening curve for St1403 material [8]

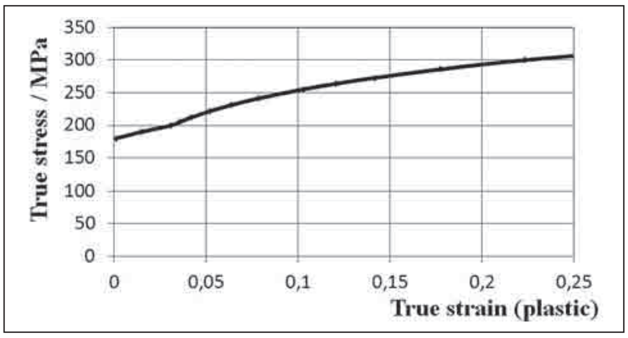

Figure 6 Strain hardening curve for DR180 material [9]

The sheet metal material was modeled in the FEM code as 27 mm wide, and respectively 0,75 mm, and 1,5 mm thick with the average element length 0,18x0,15 mm thus keeping the element ratio of 1,2. Five elements were modeled through thickness of the sheet with the alternate interpolation function which is modified in such a way that the strain variations can be better represented [12]. Since the recommendations for Marc elements were to use a larger number of lower order elements (especially through thickness), with alternate interpolation functions, the element 11 was chosen [13].

Higher order elements are a bad choice in the contact analysis and plastic deformation problems, although they show the accurate representation of the strain fields in the elastic analyses [13]. In the area of punch radius, a mesh was refined two times for the finer representation of bending strains.

As a result, primarily bending error was observed, and it was measured as the relative bending error between the angles before the sheet was released ($\alpha_{1,}$ °), and after the sheet was released ($\alpha_{2,}$ °).

The relative bending error:

$$O_a = \frac{\alpha_2 - \alpha_1}{\alpha_1} \qquad (4)$$

RESULTS

In the FEM simulation, the material (sheet metal plate) is modeled as deformable; the upper and lower tools are modeled as the rigid bodies. The upper tool – punch had controlled travel dependent on time. The motion of punch was modeled in a way that in any model derived from Figure 3, the punch at the end of its displacement fully presses the sheet metal plate in order to achieve the calibration (coining) to reduce the amount of elastical spring-back after unloading.

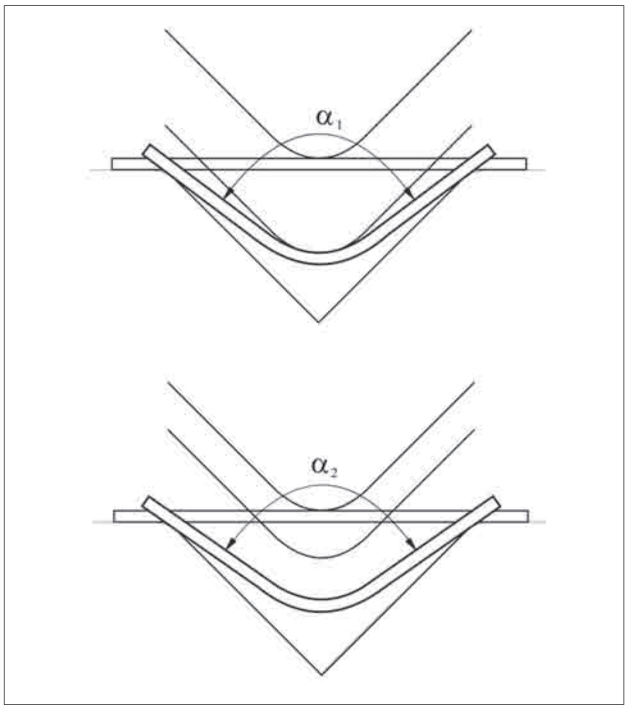

Figure 7 Angles before and after unloading

Figure 7 shows the angles before the punch was unloaded ($\alpha_{1,}$ °), and after the punch was unloaded ($\alpha_{2,}$ °). Since the sheet metal plate is subjected to the pure moment during air bending (before the sheet plate touches the lower tool), and it takes various bending radii which changes with the upper tool motion, only the sheet ends are taken into consideration and the angles are measured between the sheet ends.

Figure 8 shows the calculated relative bending errors for the different cases shown in Figure 3. It can be seen that for the same punch radius, the same material and the material thickness but different tool geometries, the bending errors follow the same curve up to the point in which the full contact of the sheet with the lower tool happens. Afterwards, the bending error changes because of the different tool geometries which causes different stress zones in a combination with the different touching zones between the sheet and both tools. At the end, a calibration (coining) process was modeled in order to

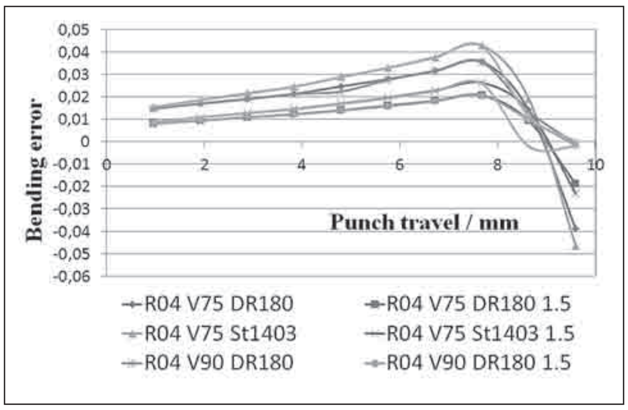

Figure 8 Relative bending error for punch radius r_{st}=0,4 mm

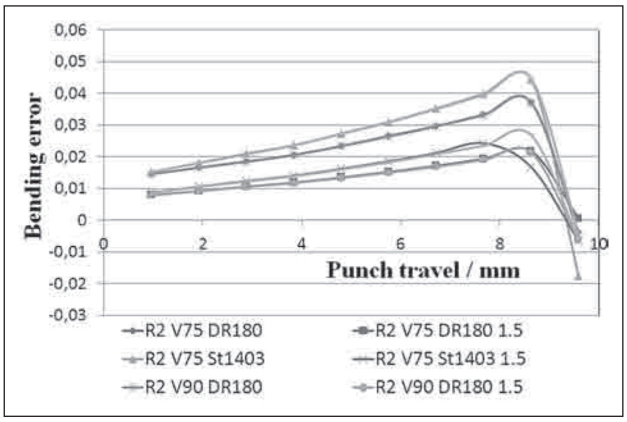

Figure 9 Relative bending error for punch radius r_{st}=2 mm

observe the minimal bending error at the end of punch displacement. These cases are shown in Figure 8 (with relative bending error zero value at the end of punch travel for 90° tool geometry). Furthermore, it can be seen that the relative bending error is achieved even before the end of punch travel for 75° tool which was expected. It can be also seen that the cases with 75° punch tool geometry have the negative relative bending error which means that the angle after the punch unloading is even lower than before unloading. This effect is called spring-forward, as the "spring-back" effect in these cases is continued in the same direction of bending.

Figure 9 shows the relative bending errors for the different cases shown in Figure 3. Also, as in the former case, it can be seen that for the same punch radius, the same material and the material thickness but different tool geometries, the bending errors follow the same curve up to a point in which the full contact of the sheet with the lower tool happens. But as opposed to the former case, it can be seen that at the punch travel end, the relative bending errors are more grouped than in the case with punch radius r_{st}= 0,4 mm. Also looking at the amount of relative bending error from Figure 9, it can be concluded that with the larger punch radius, the relative bending error is lower.

CONCLUSION

The high-strength steel sheet metal plates are used for the production of light-weight high-strength. For the FEM simulations in this paper, two types of tools, two types of materials, two types of punch radius, and two sheet thicknesses were chosen. The relative bending error after the tool release was observed for all planned cases. The results were grouped in two groups by the amount of punch radius and shown in diagrams in Figures 8 and 9.

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Note: English language: Rosandić Željka, Mechanical Engineering Faculty in Slavonski Brod, Croatia