L-BENDING ANALYSIS WITH AN EMPHASIS ON SPRINGBACK

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ABSTRACT: The aim of this paper is to study the springback that occurs in L-bending process after unloading, by means of ABAQUS, a finite element code. The material's anisotropy is considered during simulations. The forming process is simulated in ABAQUS/Explicit while the springback simulation is preformed in ABAQUS/Standard. The influence of die radius and die clearance on springback for an aluminum alloy, AA6111-T4, has been investigated considering final amount equivalent plastic strain achieved in blank and a relationship between them has been explored. The obtained results show that the higher amount of equivalent plastic strain causes the smaller amount of springback at the end of process. The relation of die radius and die clearance with amount of required maximum punch load is investigated as well. The effect of three different hardening models utilized in the FE simulation on springback prediction is studied. Finally, the springback of various materials are compared to each other.

KEYWORDS: L-bending, springback, finite element

1 INTRODUCTION

As a fundamental and traditional process in metallic forming technologies, sheet metal forming is widely being employed in almost all industrial fields. Needless to say, it is because a final sheet product of desired shape and appearance can be quickly and easily produced with relatively simple tool set [1]. One of the most widely used sheet metal forming process is bending. This is employed in automobile industry, construction of large spherical and cylindrical pressure vessels, curved structural components in aerospace industry, etc. Bending is a process in which a planer sheet is plastically deformed to a curved one [2].

In the bending process, after removing the load by withdrawal of the punch, an elastic recovery occurs because of the release of the elastic stresses. This elastic recovery is called springback. Springback is an important and decisive parameter in obtaining the desired geometry of the part and design of the corresponding tooling. In manufacturing industry, it is still a practical problem to predict the final geometry of the part after springback and to design appropriate tooling in order to compensate for springback. Conventional approaches, which involve using empirical formula and several trial-and-error procedures, result in wastage of material, time and efforts. In recent years, finite element analysis (FEA) has been considered as an effective way of simulating bending operations and predicting springback. FEA provides numerical trial and error procedures, which lead to a less-time-consuming and more economical way of designing and producing dies. In particular, some commercially available FEA programs provide effective and powerful tools and environments to model and simulate various operations, such as metal-forming applications. These programs include useful and user-friendly graphical user interfaces, which facilitate pre- and post-processing stages. Also, as aluminum is a relatively expensive material, FEA is employed in the design stages in order to reduce material and production costs. The springback prediction of bending operation using FEA has been employed by many researchers in the past. For instance, Cho et al. [3] carried out numerical investigation on springback characteristics in plane strain 'U' bending process by thermo-elastoplastic FEA. Li et al. [4] mainly dealt with material hardening and modulus to analyze 'V' bending by simulation and showed that the material-hardening model directly affects the springback simulation accuracy. Bui et al. [5] utilized the enhanced assumed strain technique for locking removal in numerical simulation of springback. Papeleux and Ponthot [6] discussed numerically the effect of blank holder force, friction, spatial integration, etc. on the forming response. Chou and Hung [7] carried out FEA of several springback reduction techniques such as

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over bending, stretching, arc bottoming, pinching die, spanking and movement (double bend) techniques used in 'U' channel bending. Math and Grizelj [8] reported springback and residual stresses of bent plates, designed for assembling spherical tanks made of steel, using elastic–plastic incremental FE calculations and experimental validation. Lei et al. [9] analyzed the free bending and square cup deep drawing to predict the springback, stress distribution, etc. for stainless steel using finite element method (FEM). Springback is caused by the release of internal stress during the unloading phase in sheet metal forming, so factors affecting the stress calculation accuracy will affect the springback calculation. It is indicated that the finite element dimensions and the material's hardening model have greater effects on the stress calculation. The material's hardening model, viz the material's stress–strain relationship, expresses the basic properties of the material during plastic deformation. It is important to correctly select and reasonably pre-digest the stress–strain curve to enhance the accuracy of the springback simulation of bending with FE codes [10,11].

In this paper the finite element simulation of the springback in L-bending process using FE code, ABAQUS, is studied. The influence of die radius, die clearance and material on springback is investigated by considering the required maximum punch load and the achieved amount of equivalent plastic strain in sheet. Also, three different hardening models are utilized in the simulations in order to study their effects on springback prediction.

2 FE SIMULATION

In this part, the computer simulation of the stamping process is conducted in two major steps. Firstly, a forming analysis is conducted, including the blank and tooling, in order to determine the sheet metal deformation during the stamping process and, secondly, the sheet metal springback deformations following the removal of the stamping tooling are computed using the forming stress distribution and the deformed geometry along with thickness distribution. There are some fundamental differences in the characteristics of both computation phases. The forming process is controlled by the time-dependent interactions of the blank and stamping tooling through a frictional contact-interface, and results in gross shape changes of the sheet metal. Consequently, the computational modeling of the forming process necessitates an incremental formulation due to the geometrically non-linear kinematics of sheet metal deformation involving large displacements, large rotations and finite plastic strains. On the other hand, the springback deformations of a typical stamping part are comparatively small, on the order of sheet thickness, and are mainly caused by the unbalanced through-thickness stresses of the sheet once it is taken out of stamping tooling. With the progress of FE methods along with the computational hardware and software technologies, the explicit and implicit incremental formulations have been developed for the process modeling and analysis. The explicit dynamic and static incremental methods have found widespread use in the modeling and analysis of 3-D sheet metal forming due to its ability of better contact handling and relatively low computational cost when compared to the implicit static incremental method. In the forming analysis phase, an initially flat sheet is placed between the stamping die elements usually involving the die, punch and blankholder. It is common, in sheet metal forming analysis, to include only the surface of the tooling in the FE model, rather than the complete geometry, as rigid geometric entities.

The L-bending process as shown in Figure 1 is a case studied in this paper for three materials: AA5754-O, AA6111-T4 and DP-Steel. The materials basic properties are summarized in Table 1. To increase the computational efficiency, the simulation of the L-bending process is modeled in the finite element program ABAQUS\Explicit, while the springback analysis is simulated in ABAQUS\Standard as it would take a long time to obtain a quasi-static solution of springback analysis in ABAQUS\Explicit. Half of the blank is modeled with a total of 300 shell elements (S4R) and 9 integration points through the thickness. For definition of contact in ABAQUS/Explicit, the general contact algorithm was utilized. The Hill48 anisotropic yield function is utilized to consider the material anisotropy. Mass densities used for dynamic explicit code are 2.7 gr/cm^3 for the aluminum alloy and 7.8 gr/cm^3 for the high strength steel. The initial dimension of the sheet was 127mm (length) × 25.4mm (width) × 1.016mm (thickness) with the 70mm total punch stroke. The contact between tools and the sheet blank is simulated as a frictionless choice in the FE code, while lubricant is used in experimental procedure. The punch velocity was speeded up to 3 m/s in the dynamic explicit code. The change in parameter θ after unloading is considered as springback. Simulations are preformed for three different die radiuses (R_d), die clearances (d) and hardening models.

3 RESULTS AND DISCUSSION

3.1 EFFECT OF DIE RADIUS

Three different values for die radius, say 12.7mm, 9.525mm and 4.7625mm are considered in our simulations while other parameters are assumed to be constant. The variation of springback with changes in die radius for the aluminum alloy, AA6111-T4 and 1.55mm die clearance is summarized in Figure 2. The results are presented in two manners: before springback (BF) and after springback occurrence (AF). Therefore, the greater difference of BF and AF indicates the larger springback. It is found that decreasing the die radius causes the reduction of springback, which means less variation in amount of θ. Therefore, decreasing the die radius up to a limit value would guarantee the reduction of springback. One of the important factors that limits the amount of die radius, is the maximum punch load applied in the process. Figure 3 shows the required maximum punch load for the three values of die radius. The obtained results show that using smaller die radius requires higher value of punch load. The reason of this fact, springback reduction by decreasing the die radius, may be attributed to the equivalent plastic (characteristic) strain achieved in the sheet for the different values of die radius through the process. In Figure 4 distribution of the equivalent plastic strain along Path1, located along the sheet length on the front side and top layer of the sheet, is shown. As it can be observed, decreasing the amount of die radius causes the level of the equivalent plastic strains to ascend. Consequently, the plastic strains, especially axial plastic strain, increases. It is noticeable that the area under the equivalent plastic curve for the smaller die radius is larger which justifies the larger required maximum punch load for it.

Table 1: Basic materials' properties

	AA5754-O	AA6111-T4	DP-Steel
Young's Modulus (GPa)	73.25	75.25	205.35
Poisson's ratio	0.33	0.33	0.3
Yield strength (MPa)	102.4	149.1	358.7
Ultimate tensile strength (MPa)	234.2	279.3	570.9

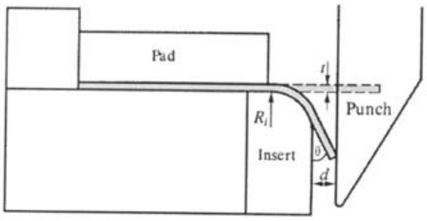

***Figure 1:** Schematic view of tools*

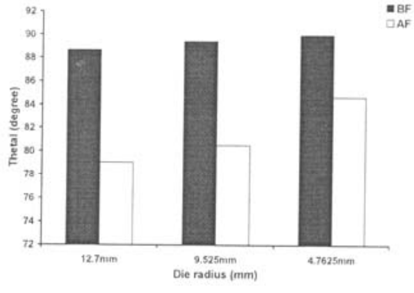

***Figure 2:** Effect of die radius on springback*

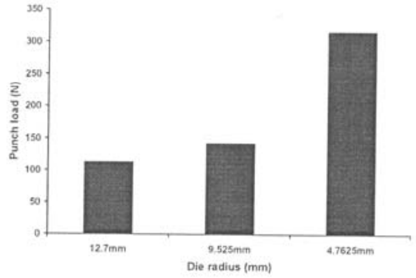

***Figure 3:** Maximum punch load for different values of die radius*

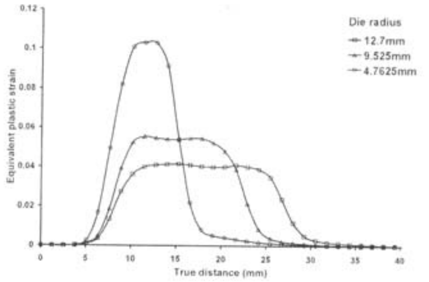

***Figure 4:** Distribution of equivalent plastic strain along Path1 for different values of die radius*

3.2 EFFECT OF DIE CLEARANCE

In order to study the influence of die clearance on springback in the L-bending process, three different values are chosen which are 1.55mm, 1.35mm and 1.1mm. The obtained results by the FE simulation for AA6111-T4 are shown in Figure 5, while the die radius is assumed to be 12.7mm. Referring to the figure, springback increases while the die clearance is enlarging, although some restrictions take place during this enlargement. One of the most important limitations that occur is the maximum required punch load, similar to the die radius as shown in Figure 6. It is observed that the smaller die clearance requires the larger maximum punch force during the process.

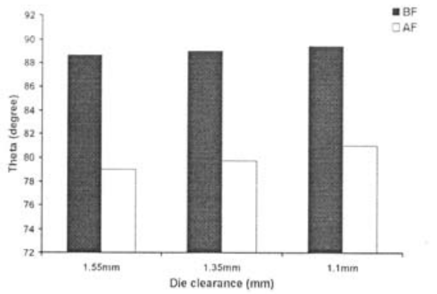

Figure 5: *Effect of die clearance on springback*

This diversity, also for springback angle, is considerable for 1.1mm in comparison with the two other values. It should be noted that, naturally when the punch go farther into the die, less moment is required to bend the sheet. Reviewing the distribution of the equivalent plastic strain along the Path1 achieved by the sheet for the three die clearances during the process, as presented in Figure 7, helps us to understand the detail. The sheet has gained of highest level the equivalent plastic strain at the end of the process when the die clearance is 1.1mm, which is the smallest value.

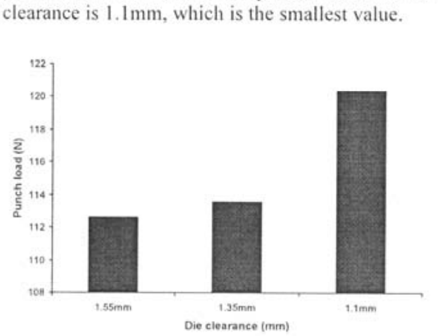

Figure 6: *Maximum punch load for different values of die clearance*

3.3 EFFECT OF HARDENING MODEL

On of the remarkable factors in the simulation of sheet metal forming is the hardening model type utilized in finite element code. The classic isotropic hardening model does not consider the Bauschinger effect; therefore, when elements of the sheet undergo reversal loading it confounds leading to a reliable result, but inaccurate springback is predicted. The linear kinematic hardening proposed by Prager [13] and Ziegler [14] can only be applied into materials with linear stress-strain curve and it usually under-predicts the springback.

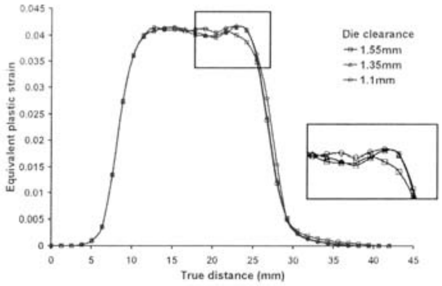

Figure 7: *Distribution of equivalent plastic strain along Path1 for different values of die clearance*

A non-linear kinematic hardening rule was first used by Armstrong and Frederick [15]. The non-linear kinematic hardening rule presented by Lemaitre and Chaboche [16] introduced a recall term to realize the smooth elastic-plastic transition upon the change of loading path. Three hardening models are utilized in our simulations: isotropic hardening model (ISO), linear kinematic hardening model (KIN) and combined hardening (ISO-KIN). Figure 8 demonstrates the springback results for the hardening models where the 12.7mm radius and 1.55mm clearance is considered for the die in the process. According to the figure, the isotropic model has predicted the largest variation in parameter θ, while the kinematic model predicted the smallest one. Because the elements of the sheet do not undergo reversal loading in this process, the difference between obtained results is not significant. Therefore, the achieved results by utilizing the isotropic model in FE simulating still are reliable.

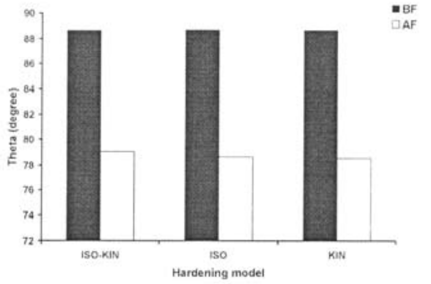

Figure 8: *Effect of hardening model on springback prediction*

Required maximum punch loads predicted by different hardening model are compared to each other in Figure 9. The kinematic hardening has predicted the largest required maximum punch load applied through the process. Investigating the distribution of the equivalent plastic strain along the Path1 predicted by the hardening models reveals that the higher level of the equivalent plastic strain prediction leads to the higher amount of maximum punch load anticipated by the hardening model.

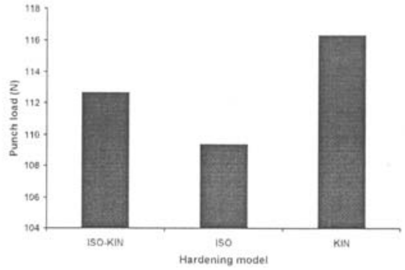

Figure 9: Maximum punch load predicted by different hardening models

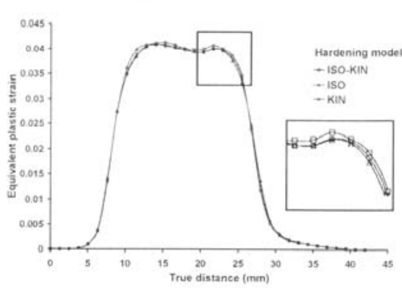

Figure 10: Distribution of equivalent plastic strain along Path1 predicted by different hardening models

3.4 EFFECT OF MATERIAL TYPE

Relation between the springback and material type, like the relation between the springback and other material properties such as weight and strength of the material, affects the applicability of the materials in the industry. Aluminum alloys and high strength steels have been found expanding usage in automotive industry. On the other hand, body panels stamped from these materials exhibit more profound springback characteristics than those made from mild steels. Therefore, a thorough understanding of their springback behaviors is critical to the design and manufacturing of the vehicle components. In Figure 11 the obtained results of springback for three different materials, i.e. AA5754-O, AA6111-T4 and DP-Steel are compared to each other, when the die radius and die clearance are assumed to be 12.7mm and 1.55mm, respectively. As it may be observed from the figure, AA5754-O demonstrates less springback, whereas AA6111-T4 and DP-Steel almost result in the same variation of parameter θ, although the aluminum alloy leads to a little bit more springback. Besides, the superiority of AA5754-O may be probed in the amount of maximum required punch load, as shown in Figure 12. It may be observed clearly that the bending of AA5754-O requires less maximum punch force than the other two materials which means less amount of energy is needed for performing of the process.

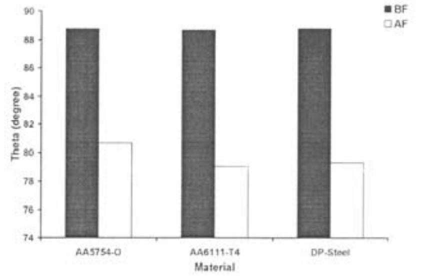

Figure 11. Effect of material type on springback

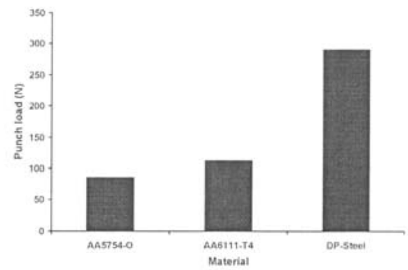

Figure 12: Maximum punch load for the different materials

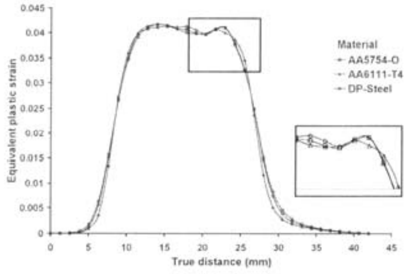

Figure 13: Distribution of equivalent plastic strain along Path1 for different materials

The maximum required punch load for DP-Steel has a considerable difference with the aluminum alloys because of about a two times larger yielding stress. Distributions of the equivalent plastic strain for the materials are compared in Figure 13. AA5754-O approximately has the highest level of the equivalent plastic strain whereas AA6111-T4 has the lowest one. This relation can also be found in the springback angles for the three materials (Figure 11).

4 CONCLUSIONS

A numerical study of springback phenomenon in the L-bending process utilizing the FE code, ABAQUS was provided in this paper. Effects of different factors such as die radius, die clearance and material type on springback have been investigated. Also, the influence of different hardening models on predicting springback was presented.

Decreasing the die radius causes the reduction of the springback, because the process let the blank achieve higher level of equivalent plastic strain after the forming stage. On the other hand, the required maximum punch load increased for the higher values of die radius. Similar event occurred for the die clearance. The investigation was extended for different types of materials where AA5754-O lead to smaller springback by reaching to the higher amount of equivalent plastic strain. Comparing the results of springback for the different materials revealed that AA5754-O required less maximum punch load through the process. After all, the influence of hardening models on springback prediction was investigated. It was found that results were so close to each others because the elements of the blank did not undergo reversal loading.

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