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AN INVESTIGATION INTO THE INFLUENCE OF BLANKHOLDER FORCE ON SPRINGBACK IN U-BENDING

BADANIE WPŁYWU SIŁY DOCISKACZA NA SPRĘŻYNOWANIE PRZY ZAGIĘCIACH TYPU „U"

Springback is the main defect in U-channel forming process. Applying the blankholder force is one of the ways of solving the problem. On the other hand the value of the blankholder force should be chosen carefully. In this paper the relation of the blank-holder force and final springback, taking a benchmark of NUMISHEET'93 2-D draw bending and using a commercial FEM code has been studied. The simulations are pre-formed for AA5754-O and DP-Steel. In order to probe the relation, five different values are utilized in simulations. It is found that springback increases for the middle values of the blankholder force where the stretching and bending have equal effects on the blank. The maximum required punch loads are compared for the different values of blankholder force.

Keywords: blankholder force, springback, U-bending

Sprężynowanie jest głównym mankamentem w procesie formowania zagięć typu „U". Zastosowaie siły dociskacza jest jednym ze sposobów rozwiązania tego problemu. Z drugiej strony, wartość siły dociskacza powinna być precyzyjnie wyznaczana. W niniejszej pracy omawiany jest związek siły dociskacza i końcowego sprężynowania, przy zastosowaniu wzorca NUMISHEET'93 2-D oraz wykorzystaniu dostępnego na rynku kodu FEM. Symulacje zostały wykonane dla stali DP i AA5754-O. W celu przetestowania wspomnianego związku, w symulacjach wyznaczono pięć różnych wartości. Zaobserwowano, iż zginacze mają taki sam wpływ na materiał. Porównywane są maksymalne wymagane obciążenia tłocznika dla różnych wartości siły dociskacza.

1. Introduction

Springback is generally defined as the additional deformation of sheet metal parts after removing the load. In recent years, the high strength steels and aluminum alloys are increasingly used for sheet metal parts in the automotive industry to reduce mass. However, during using materials with higher ratios of yield strength to elastic modulus, precise prediction and control of springback become essential [1]. The precision in dimension is a major concern in sheet metal bending process because of the considerable elastic recovery during unloading leading to springback. The elastic recovery is influenced by a combination of various process parameters such as tool shape and dimension, contact friction condition, material properties, thickness and so on. U-bending process is often used to manufacture sheet parts like channels, beams and frames. In this process, the sheet metal usually undergoes complex deformation history such as stretch-bending, stretch-unbending and reverse bending. When the tools are removed, in addition to springback, sidewall curl often happens, which makes the prediction of springback become more difficult. Different methods, such as analytical method, semi-analytical method and finite element method (FEM), have been applied to predict the sheet springback of U-bending.

Samuel [2] used a finite element (FE) program, MARC package to analyze the axi-symmetric U-bending process. He investigated the effect of tool geometry and blankholder force on the final shape after springback. Experimental prediction of springback and determination of final geo-metry within a reasonable tolerance is time consuming and expensive. Lee and Kim [3] focused on the evaluation of springback occurring in the sheet metal flange drawing by controlling some process factors like punch corner radius (PR), die corner radius (DR), and blank holding force. Esat et al. [4] carried out springback analysis of different aluminum sheets with different thicknesses and explored the relation between the amount of springback and total equivalent plastic

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strain and also equivalent plastic stress. They concluded that the material with higher yield strength and smaller equivalent plastic strain has higher amount of springback than the material with lower yield strength and higher equivalent plastic strain.

In recent years, the rapid development of computer technologies enables numerical simulation of sheet metal forming operations and finite element codes to be used in an industrial environment. The springback prediction in sheet metal forming processes using FEA has been studied by many researchers in the past. Cho et al. [5] carried out a numerical investigation on springback equivalent plastics in plane strain 'U' bend-ing process by thermo-elastoplastic FEA. Li et al. [6] mainly dealt with material hardening to analyze 'V' bending and showed that the material-hardening model directly affects on springback simulation accuracy. Choudhry and Lee [7] accounted inertial effects in the FEA of sheet metal forming process. Papeleux and Ponthot [8] dis-cussed numerically the effect of blank holder force, friction, spatial integration, etc. on the forming response. Chou and Hung [9] carried out FEA of several springback reduction techniques such as over bending. stretching. arc bottoming, pinching die. spanking and movement (double bend) techniques used in 'U' channel bending. Math and Grizelj [10] reported springback and residual stresses of bent plates, designed for assembling spherical tanks made of steel. using elasticplastic incremental FE calculations and experimental validation. Lei et al. [11] analyzed the free bending and square cup deep drawing to predict the springback, stress distribution. etc. for stainless steel using finite element method (FEM). Ragai et al. [12] investigated the effect of sheet anisotropy on the springback of stainless steel 410 draw-bend specimens experimentally as well as through finite element simulations. Furthermore, they studied the influence of blankholder force and coefficient friction on the amount of the final springback.

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 the springback. Liu et al. [13] proposed a method to control the forming process of a U-shaped part by that a reasonable blank-holder force curve can be easily gained. Comparing with constant blankholder force, higher forming quality can be obtained in both avoiding cracking and improving dimension accuracy. Hama et al. [14] proposed new techniques of the sheet metal forming simulation utilizing the Nagata patch for describing the tool surfaces. They performed a two-dimensional draw bending process using Nagata and polyhedral patches for tool model and studied the tool modeling accuracy on springback simulation. Yoshida et al. [15] investigated springback behavior and shape control techniques for high strength steels. They studied effects of different parameters such as applying reverse bending in die gap, applying compression in thickness direction, etc.

The aim of this paper is to investigate the relation between the springback and blank-holder force in U-bending process by means of the finite element program. ABAQUS. For this purpose. different values of blankholder force are preformed for two different materials.

2. Fe modeling

In this part a computer simulation for 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. Secondly. the sheet metal springback deformations following the removal of 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 which results in some 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 relatively small compared with the 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 the surface of the tooling in the FE model, rather than the complete geometry as rigid geometric entities.

TABLE 1

Basic material properties for the three test materials

	AA5754-O	DP-Steel
Thickness (mm)	1.5	1.2
Young's Modulus (GPa)	73.25	205.35
Poisson's ratio	0.33	0.3
Yield strength (MPa)	102.4	358.7
Ultimate tensile strength (MPa)	234.2	570.9 3

The 2D draw-bending problem in NUMISHEET'93 as shown in Figure 1 is a case studied in this paper for two materials: AA5754-O and DP-Steel. The materials basic properties are summarized in Table 1. To obtain numerical efficiency, the simulation of the U-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. It was found in the literature that several authors (Hibbit [16]; Jiang [17]; Lee [18]) used shell elements in their modeling of sheet metal forming processes. This type of element accounts for the change of thickness in its output variables, unlike solid and plane strain elements. This facilitates getting the final thickness after deformation in sheet metal forming processes. For instance, half of the blank is modeled with a total of 300 shell elements (S4R) for a blank strip, about five millimeter width and 9 integration points through the thickness [19], with the symmetry boundary condition along the Y axis. Mass densities used for the dynamic explicit code are 2.7 gr/cm^3 for aluminum alloy and 7.8 gr/cm^3 for high strength steel. The punch velocity was speed up to 10 m/s in the dynamic explicit code without mass scaling and resulted in very small oscillation in the kinetic energy which is acceptable for a quasi static process. The springback parameters θ_1 and θ_2 studied by this benchmark are shown in Figure 2.

3. Results and discussions

Applying force on blankholder is a traditional way to compensate springback by making the blank becomes more plastic (increasing the plastic strains) and causing higher stretching in the blank. On the other hand, increasing the amount of this factor carelessly may lead to undesirable enlargement of maximum required punch load in the forming process. Therefore, an appropriate simulation of the process using different values of blankholder force and a thorough investigation of their influences on the amount of springback may help the designer to choose the optimum value. In order to study the relation between the blankholder force and springback, six different values are selected that consists of: 2.5, 5, 10, 15, 20 and 25 kN.

In Table 2 the results of springback for different values of blankholder force and two materials are presented. It should be pointed out that the higher amount of θ_1 and smaller amount of θ_2 expresses the higher springback. It is found that for the DP-Steel, increasing the force up to 10 kN, lead to the higher amount of springback. After passing this value, the springback starts to decrease and for 25 kN reaches to its minimum amount. This fact is clearly shown in Figure 3. As it can be observed, 10 kN and 5 kN are the critical values of blankholder forces for DP-Steel and AA5754-O, respectively.

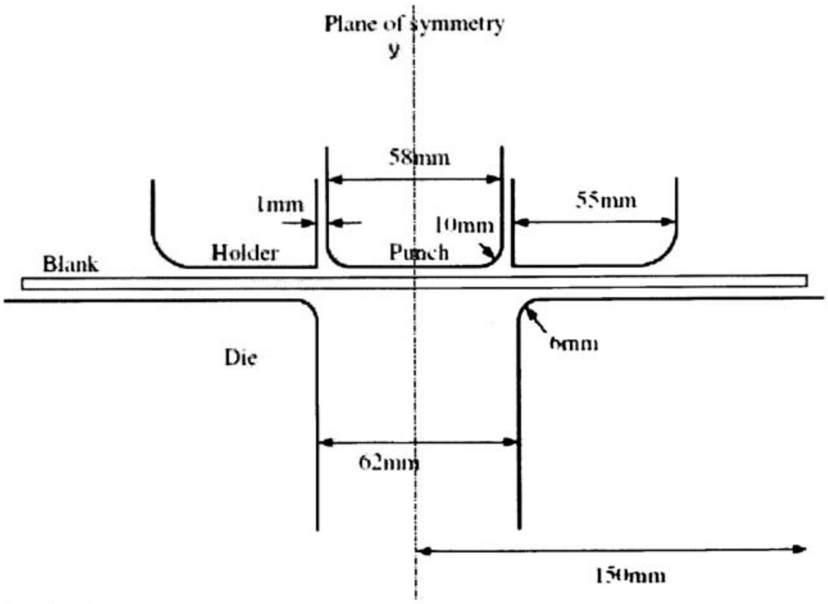


Fig. 1. The 2D draw bending

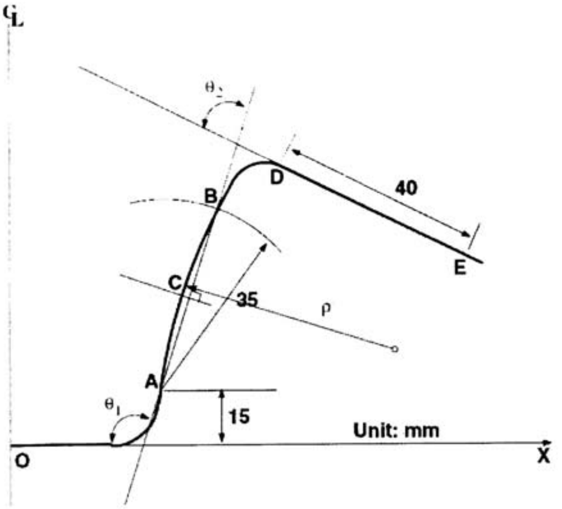
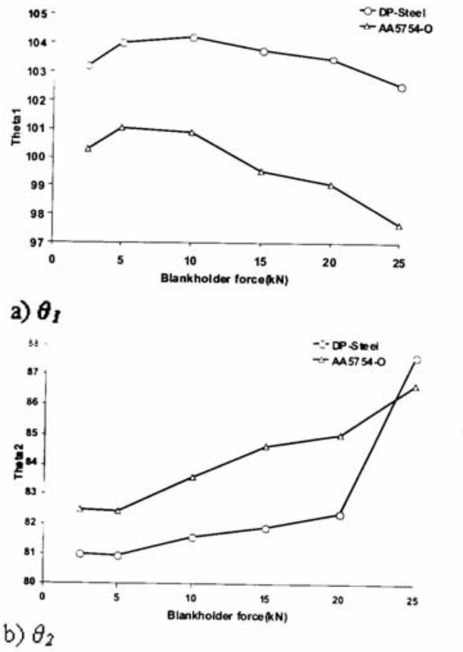


Fig. 2. The springback parameters (at the punch and die corners)

Paying more attention to the results shown in Figure 3, displays that for the variation of θ_2 with the blank holder force, 5 kN is the critical point for the both materials. Increasing the force from 5 kN to 25 kN results in 2.6% and 0.6% variation for θ_1, and 5% and 8% variation for θ_2 for AA5754-O and DP-Steel, respectively. As the initial blank thickness is larger for the aluminum alloy, AA5754-O considerably exhibits smaller amount of springback after unloading. It should be noted however that with the same initial blank thickness, DP-Steel will have smaller springback [20].

TABLE 2
Springback results for different values of blankholder force

BF (kN)	$\theta_1(^\circ)$		$\theta_2(^\circ)$	
	AA5754-O	DP-Steel	AA5754-O	DP-Steel
2.5	100.27	103.22	82.48	81
5	101.02	104	82.45	80.92
10	100.88	104.2	83.57	81.56
15	99.54	103.75	84.66	81.92
20	99.05	103.48	85.03	82.4
25	97.66	102.53	86.68	87.66



a) θ_1

b) θ_2

Fig. 3. Springback parameters versus blankholder value

Four elements on the top layer of the sheet are selected in order to investigate the evolution of plastic strain during the process, Figure 4. The characteristic number of each element specifies the distance from the centerline. Figure 5 displays the history of equivalent plastic strain for the selected elements when the blankholder force is assumed to be 2.5 kN and the material is DP-Steel. It may be observed from the figure that the elements number 62 and 30 attain the highest and the lowest amount of equivalent plastic strain at the end of process, respectively.

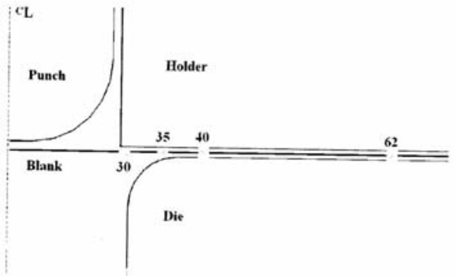


Fig. 4. Sample elements which are considered in order to investigate the deformation regime

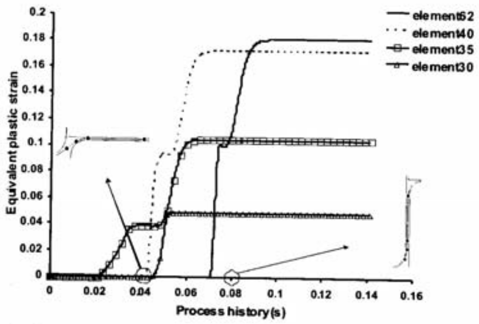


Fig. 5. History of equivalent plastic strain for the specified elements during the forming process

The process consists of simultaneous bending and stretching where for lower values of blankholder force bending is dominant. By enlarging the force, the influences of bending and stretching become almost equal, hence, springback increases. For larger forces, stretching will be more dominant. As the blank becomes more plastic (plastic strains increases), the portion of elastic strains decreases, consequently springback reduces. In order to understand the process more precisely, the values of elastic strain for a sample element located 62mm away from the center line, on top layer of the blank is shown in Figure 6. It is found that for the lower blank holder forces the elastic strain increases initially while for the higher amounts, 25 kN, it reaches to a minimum value. For instance, for the DP-Steel, the elastic strain is 0.00172, 0.0019 and 0.0007 for 2.5 kN, 10 kN and 25 kN, respectively. One of the important parameters that should be taken into consideration while increasing the blankholder force is the maximum punch load. Naturally, applying larger force on holder causes larger punch load through the process. Therefore, regarding the variation of springback, increasing the blankholder force should be preformed in a manner that the required load for the punch be reasonable. In Figure 7 the required maximum punch loads for the different values of blankholder forces applied in the process are shown. As it can be observed, the punch load for 25 kN is approximately more than three times of the load for 2.5 kN. For each case, DP-Steel needs a considerable higher punch load through the process than the AA5754-O.

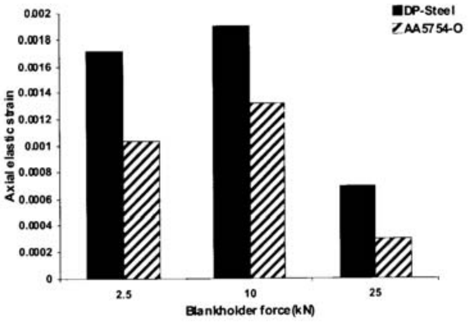


Fig. 6. Amount of axial elastic strain for different values of blankholder force

The springback phenomenon depends basically on the through-thickness stress gradients [21]. Figure 8 demonstrates the distribution of axial (longitudinal) stress through the DP-Steel blank thickness. The difference in amount of stress for two points located in front of each other on top and bottom of the blank is the smallest when the blankholder force is 25 kN and is the largest when it is 5 kN.

4. Conclusions

The influence of blankholder force on springback through the finite element method by means of ABAQUS is studied in this paper. Simulations were preformed for two materials, i.e. AA5754-O and DP-Steel. It was found that enlarging the blankholder force did not always guarantee the reduction of springback and the middle values can increase the springback. Both stretching and bending existed during the process where act in opposite directions. For some mid-values of blankholder forces, their effects become close to each other and reduce the plastic zone; hence, springback will be increased. Investigating the history of strain during the process for a sample element revealed that for the mid-values of force, portion of the elastic strain increases undesirably, whereas continuing enlargement of the force led to reduction of this portion. Finally, the obtained results showed that increasing the blankholder force inaccurately may result in augmentation of the maximum required punch load significantly.

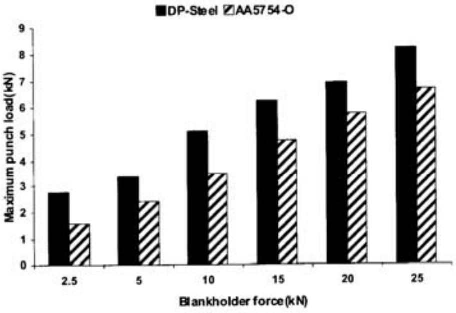


Fig. 7. Maximum required punch load for the two materials

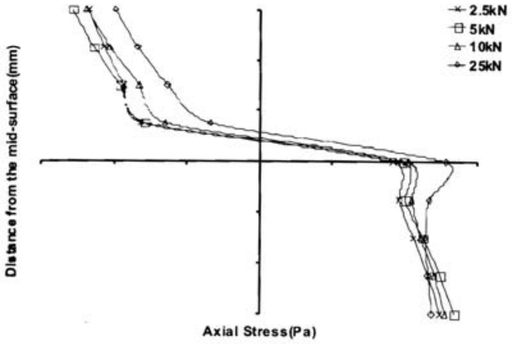


Fig. 8. Distribution of the axial (longitudinal) stress through the blank thickness for the elements located 62mm away form the centerline

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