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Springback simulation of friction aided deep drawing process

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Abstract: In the recent years the friction-actuated blank holding technique has been developed for drawing cylindrical cups. A new technique on friction aided deep drawing using tapered blank holder divided into eight segments has already been proposed. A metal blank holder was designed to be of two layers: stationary layer or base with 5 degree taper angle and moving layer divided into eight tapered segments. The main function of this developed blank holding device is adopting the frictional force between the blank and the blank holder to work in the useful drawing direction. Using this method, successful deep cups with high drawing ratio up to 3.67 can be produced without any defect only in one die set. This paper discusses a finite element analysis of springback and the effects of different process parameters in the friction aided deep drawing process of an aluminium alloy sheet. Effects of different process parameters such as initial sheet thickness, punch profile radius, blank holder force, friction coefficient and hardening models on springback prediction are studied. Simulation of springback is performed by the ABAQUS software.

Keywords: "Friction aided deep drawing", "Springback", "Three-Dimensional simulation", "ABAQUS /Explicit".

Introduction

Springback is a phenomenon that occurs in many cold working processes. When a metal is deformed into the plastic region, the total strain is made up of two parts, the elastic part and the plastic part. During removing the load, a stress reduction will occur and accordingly the total strain will decrease by the amount of the elastic part, which results in springback [1].

Oliveira et al. [2] evaluated several work hardening models in order to determine their influences on the numerical prediction of the springback phenomenon. They investigated the effect of different constitutive models on the numerical simulation of mild (DC06) and dual phase (DP600) steels submitted to several bending/unbending strain-path changes, during which a high level of equivalent plastic strain attained. 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 aluminium sheets with different thicknesses and explored a relation between the amount of springback and total equivalent plastic strain and also equivalent 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 characteristic strain.

The forming limit in conventional deep drawing of sheet metals with a metal punch and die is qualified mainly by the fracture of a cup at the punch profile portion. The limiting drawing ratio achieved by the first stage drawing seldom exceeds about 2.2. Thus if a cup of final proportion exceeding this limiting value is required, redrawing or ironing in one or more stages is necessary as subsequent operations. Since a pair of punch and die is needed for each stage, the cost and time for making tools increases particularly in small-lot production of deep cups. Many novel processes [5] have been developed to overcome this problem in the small-lot production of deep cups. Among these deep drawing processes the so-called Maslennikov process [6] is a unique method in which a rubber ring put in a container is utilized as a pressure medium to generate drawing deformation of a blank. Unlike the conventional method, the frictional force between the blank sheet and the rubber ring is used to achieve deep drawing. Since the drawing of the blank is carried out by the radial compressive force, the fracture at the punch profile portion can be avoided. However, for thin sheets, circumferential fracture was observed at the flange portion. As another defect of the Maslennikov process, blanks of high deformation resistance cannot be drawn because the induced frictional force is not sufficient.

To overcome these deficiencies, Hassan et al. [7] proposed using a blank holder divided into four segments instead of the rubber ring used in the Maslennikov process. The possibility of the deep drawing with such technique has been confirmed. However, there was one limitation during the application of such proposed device which was the occurrence of wrinkles due to flowing of the flange material into the gaps between the blank holder segments. Such a problem was overcome by fitting four small wedges in these gaps between the four drawing segments [8]. Using this new blank holder divided into eight segments (four small wedges and four drawing segments) good results were obtained. But, in the case of using thin sheets a crack was observed due to the localized intensive shear deformation at the boundaries between the drawing segments and the four small wedges.

Therefore, a two-layered tapered blank holder divided into four segments was proposed to eliminate the defects of localized wrinkling and intensive shear deformation

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regions [9]. But, there was a non-uniform flow of material in the flange portion of cup in this method. Hence, a novel process on friction aided deep drawing using eight tapered segments blank holder has been proposed to defeat this deficiency. The deformation mechanism and the effects of drawing conditions have already been investigated by ABAQUS/Explicit by authors.

The finite element analysis (FEA) of springback is shown to be very sensitive to many numerical parameters, including the number of through-thickness integration points, type of element, mesh size, angle of contact per element on die shoulder, possible inertia effects and contact algorithm. Moreover, springback is also sensitive to many physical parameters including material properties, hardening laws, friction coefficient, blank holder force (BHF) and punch profile radius. All those make springback simulation very cumbersome [10].

In this paper the springback occurred in the cup produced by friction aided deep drawing process using eight tapered segments blank holder is numerically studied. Influence of initial sheet thickness, punch profile radius, blank holder force, friction coefficient and hardening model on springback is investigated by means of the FE software, ABAQUS.

Numerical simulation

Explicit models are nowadays widely utilized to analyze sheet metal forming processes since they allow fully 3-D geometry and complex contact conditions to be taken into account with relevant CPU savings with respect to the implicit algorithms (Li et al. [11], Li et al. [12], Onate et al. [13], Rebelo et al. [14]). At each time increment such models solve a set of independent dynamic equilibrium equations in order to upgrade the geometry of the meshed structure. No inversion of the stiffness matrix is needed; no numerical iterative procedure to get a satisfactory solution is required. In this way CPU time is saved and the incidence of plastic instabilities can be described well since the analysis continues even if diagonal terms of stiffness matrix approach to zero. However, as far as evaluation of the springback phenomenon is concerned, when the contact between the stamped part and the rigid dies is lost, the deformed sheet starts to oscillate around the new equilibrium position, until the accumulated kinetic energy is dissipated. As a consequence, the prediction of the elastic springback is a very time consuming step in explicit FEM analysis of sheet stamping processes. Actually a suitable amount of damping should be artificially introduced in order to accelerate the kinetic energy dissipation, but unfortunately, it is very difficult to evaluate the correct amount of applied damping. The commercial ABAQUS code used here provides such combined approach, incorporating a procedure by which the stress state at the end of the loading phase is supplied to the implicit numerical code (ABAQUS/Standard) which performs a simple elastic step. This stress state was obtained through a dynamic explicit FEM simulation carried out with ABAQUS/Explicit. The FE model of blank is shown in Figure 1. Because of the symmetry, only one quarter of blank is modelled. The blank is modelled using 4-node, shell element (S4R). In the simulation, 1859 elements are used in one quarter of blank.

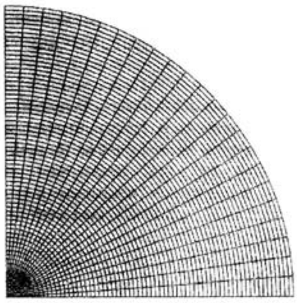


Figure 1: FE model of blank.

Figure 2 shows schematically friction aided deep drawing process using eight tapered segments blank holder. Tapered blank holder consists of eight drawing segments that have similar planes of slightly tapered angle of 5 degree, the drawing segments can slide in radial direction under a constant speed over the tapered surfaces of the stationary base. The main function of this developed blank holding device is adopting the frictional force between the blank and the blank holder to work in the useful drawing direction. Drawing mechanism and compound motion of the blank holder segments has already been investigated.

In order to measure the springback of the cup two parameters are considered, mean radius of the cup edge and the bottom angel of the cup (theta), as shown in Figure 3. Since this process has not been done by experimental method until now, the results cannot be compared with any data.

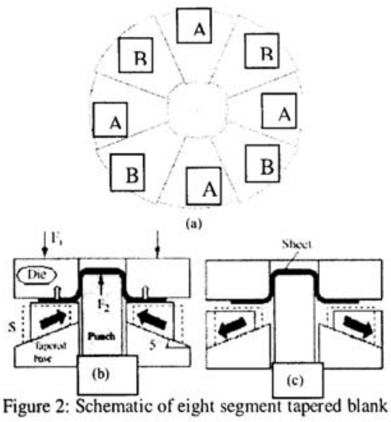


Figure 2: Schematic of eight segment tapered blank

holder.

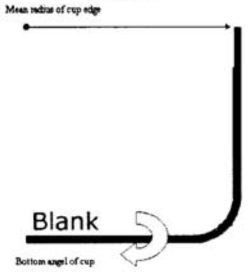


Figure 3: Springback definition parameters.

Test material and numerical conditions

Soft aluminium (Al-O) blank is used as a testing material. Tool dimensions are listed in Table 1. The material constants *F*, *n* and *r* determined from the uniaxial tension test are listed in Table 2.

Table1: Tool dimensions

Die	Outer diameter(mm)	120
	Inner diameter(mm)	32
	Profile radius(mm)	3
Tapered blank holder	Outer diameter(mm)	116
	Inner diameter(mm)	35
	Blank holding force(kN)	60-100
Assistant punch	Diameter(mm)	30
	Profile radius(mm)	3-5
	Punch force(kN)	4

Table 2: Mechanical properties and dimensions of aluminium blank.

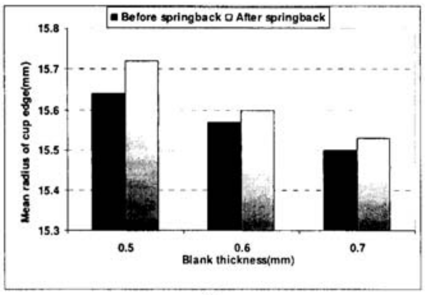
n-value	0.27
r-value	0.76
F-value(MPa)	220
Young modules(GPa)	70
Poisson ratio	0.35
Thickness(mm)	0.5, 0.6, 0.7
Blank diameter(mm)	100
Yield stress(MPa)	3

Results and Discussions

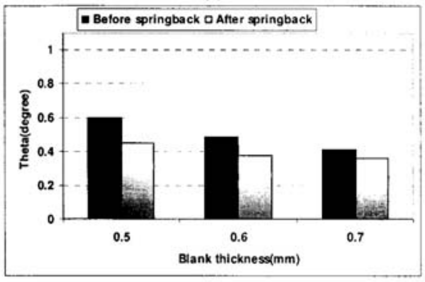
Effect of initial sheet thickness

Initial sheet thickness is one of the parameters that clearly affects on springback in sheet metal forming which in fact may be utilized to control it. On the other hand, increasing the initial sheet thickness causes increasing of required punch load and weight of the blank that are undesirable factors in design parameters. Therefore, finding the optimum value for initial sheet thickness is vital for the purpose of using suitable values in the design stage. Simulations are performed for aluminium alloy. Three different values of sheet thickness are considered for this purpose, i.e. 0.5mm, 0.6mm and 0.7mm.

In Figure 4(a), the relation between the value of initial blank thickness and the springback of mean radius of cup edge and in Figure 4(b), the relation between the value of initial blank thickness and the springback of bottom of cup are displayed. It is found that with increasing the initial blank thickness, springback amount is decreased. Since, with increasing the initial blank thickness, amount of equivalent plastic strain is increased; as a result, springback amount will be decreased. In other words, springback phenomenon is due to elastic portions of available strains in work piece. So, the amount of springback reduction with increasing of initial sheet thickness depends on formation of larger plastic region in a definite deformation. This fact demonstrates the sensitivity of springback to value of initial blank thickness in sheet metal forming.



(a)



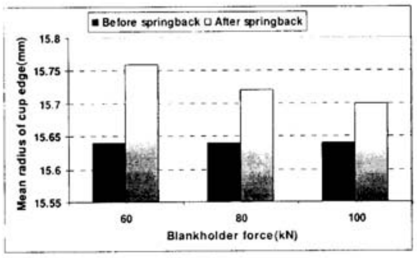
(b)

Figure 4: Influence of initial sheet thickness on springback: (a) mean radius of the cup edge, (b) theta

Effect of blank holder force

The influence of blank holder force on springback is studied in this part. Three different values of blank holder force are considered for this purpose. The relation between the value of blank holder force and springback is shown in Figure 5. It is observed that the springback amount decreases as the blank holder force increases. This phenomenon can be explained by the fact that under sufficiently large value of blank holder force more plastic deformation will happen, hence, the amount of

... decreased. On the other hand, excessive ... blank holder force may cause tearing of the sheet. As a result, an optimum amount of blank holder force has to be found in order to reduce the springback and avoid the sheet tearing.



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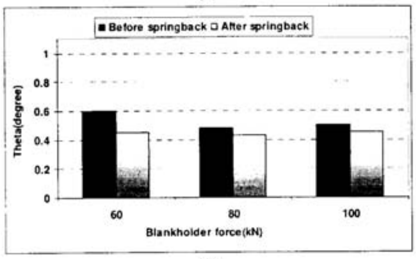


(b)

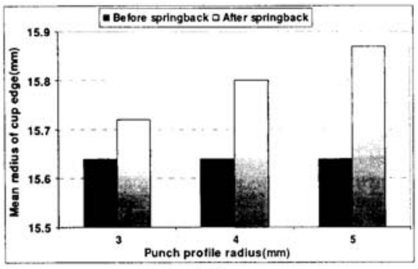
Figure 5: Influence of blank holder force on springback: (a) mean radius of the cup edge, (b) theta

Effect of punch profile radius

Simulation performed under different punch profile radii (Rp: 3, 4 and 5 mm). From Figure 6, it may be observed that the springback increases as the punch profile radius increases which can be justified by the amount of plastic deformation. It is to be noted that the stress over the punch corner (punch profile radius) is the most significant factor governing the magnitude of springback.

Effect of friction coefficient

In order to investigate the effect of friction coefficient between the blank and blank holder on springback prediction, this process is simulated with different friction coefficient, i.e. 0.25, 0.3, 0.4. In Figure 7 effect of friction coefficient on springback is displayed. As it is seen, with increasing friction coefficient the springback is decreased. In fact, increasing the friction coefficient can increase sheet drawing during forming process. It means that the plastic deformation region is increased under definite deformation in sheet and as a result, springback amount is decreased with increasing plastic region.



(a)

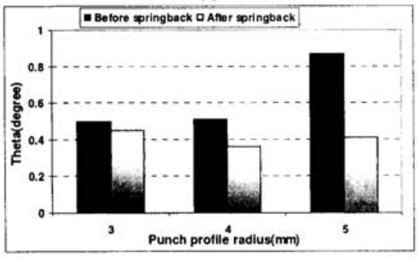


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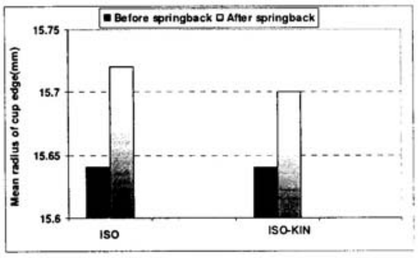
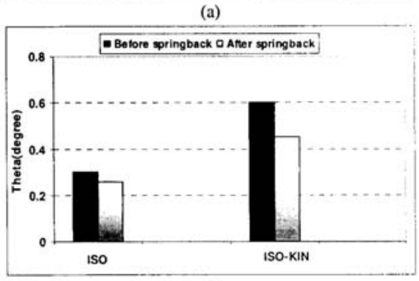
Figure 6: Influence of punch profile radius on springback: (a) mean radius of the cup edge, (b) theta



(a)

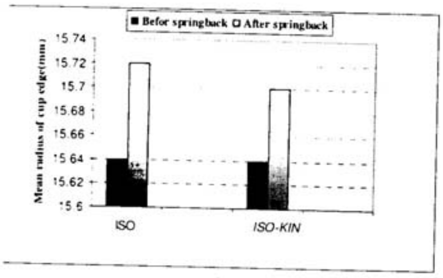


(b)

Figure 7: Influence of friction coefficient on springback: (a) mean radius of the cup edge, (b) theta

Effect of hardening model

One of the remarkable factors in FE simulation of the sheet metal forming is the hardening model type utilized in finite element code. In other words, accurate prediction of springback in finite element method depends on hardening model type of the material. Isotropic hardening rule, linear kinematic hardening, non-linear kinematic hardening and combined isotropic/ kinematic hardening (ISO-KIN) models can be used in modelling of material behaviour. The classic isotropic hardening model does not consider the Bauschinger effect. The linear kinematic hardening proposed by Prager [16] and Ziegler [17] can only be applied into materials with linear stress-strain curve and it usually under-predicts the springback. A non-linear kinematic hardening rule was first used by Armstrong and Frederick [18]. The non-linear kinematic hardening rule presented by Lemaitre and Chaboche [19] introduced a recall term to realize the smooth elastic-plastic transition upon the change of loading path. Many researches have already been done on the effect of using hardening model types on springback. It has been shown that a combination of non-linear kinematic hardening rule and isotropic hardening can well predict material behaviour.



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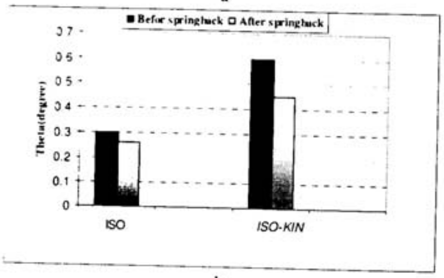

b

Figure 8: Influence of hardening model type on springback: (a) mean radius of the cup edge, (b) theta

In this research, two hardening models are utilized in simulations: isotropic hardening model (ISO) and combined isotropic/ kinematic hardening (ISO-KIN). In Figure 8 springback of the cup is shown for two hardening models. It is observed that isotropic model has predicted springback of mean radius of cup edge more than the combined model. But, the amount of bottom angle has been predicted less than the combined model. In overall, the combined hardening model has predicted the larger springback than the isotropic model.

Conclusion

Springback of friction aided deep drawing process was studied numerically by means of ABAQUS software. The influence of some important factors such as initial sheet thickness, blank holder force, punch profile radius, friction coefficient and type of hardening model on springback of the cup produced by means of friction aided deep drawing process was investigated. The obtained numerical results showed that increasing the value of the initial sheet thickness reduces the springback of the deformed sheet. Also, with increasing blank holder force, the springback will be decreased. On the other hand, excessive increasing of blank holder force may cause tearing of sheet. As a result, an optimum amount of blank holder force should be selected to reduce the springback and avoid the sheet tearing. The same result obtained for the effect of friction coefficient, i.e. with increasing friction coefficient between the sheet and blank holder, springback of the deformed sheet was decreased. Furthermore, with the rising of punch profile radius, the springback increases. Finally, comparing different hardening models revealed that the combined hardening model predicted the larger springback than the isotropic model.

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