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Numerical and Experimental Investigation on Die and Blank Holder Shape in Deep Drawing Process

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Abstract: In the present investigation, deep-drawing process of a cylindrical cup is simulated using non-linear implicit finite elements method to study the blank holder and die shapes. Punching and blank holder forces, drawing ratio, material flow and stress distribution are measured. Experimental and numerical results show that blank holder and die shapes influence punching and blank holder forces, drawing ratio, material flow.

Key words: Cylindrical deep-drawing process, finite element method, blank holder shape, die shape, low carbon steel

INTRODUCTION

An important objective of the deformation processing of metals is the production of defect-free parts, with the desired properties. This goal can be achieved through better design and by better control of the parameters of the deformation processes.

Nowadays, in the industry, the deep drawing process is used extensively. Design costs are usually between 5 and 15% of the total production costs (Thomas and Altan, 1998). The decisions made in this early stage significantly determine the overall manufacturing costs. So this stage of production is very important. In recent years, the Finite Element Method (FEM) has been widely used to simulate sheet metal forming operations.

In the deep drawing process, several factors effect on the product quality as well as formability such as tool design, blank material selection and shape, binding force, forming speed, etc. Punching and blank holder force control has been regarded as an effective technique for improving the formability and product quality. Excessive metal flow will cause wrinkles in the part, while insufficient metal flow will result in tears or splits. The blank holder controls metal flow by exerting a predefined Blank Holder Force (BHF) profile (Demirci *et al*., 2007; Sheng *et al*., 2004). On the other hand decreasing in BHF and Punching force cause a decreasing in blank holder and punch costs and increasing in the efficient life of them. Many studies on the optimization of such forces have been carried out (Savas and Secgin, 2007; Wang *et al*., 2007). Savas and Secgin (2007) investigated the effects of blank holder and die shapes, using five kinds of blank holder and die shapes. The distribution at blank holder force is measured according to the ratio of sheet metal drawing and it is clarified that the angle of blank and die at deep drawing process influence blank holder force distribution and ratio of drawing (Savas and Secgin, 2007). Wang *et al*. (2007) conducted an experimental study on the Process modeling of controlled forming with time variant blank holder force using Response Surface Methodology (RSM). The forming processes with several types of time variant BHF were simulated and compared to find a suitable one to achieve our desired product shape. The comparison implied that the staircase-shaped time variant BHF can direct the strain path to the desired place to acquire a targeted product (Wang *et al*., 2007). Koyama *et al*. (2004) obtained a high quality product with higher strength through the implementation of the simulator with the variable blank holding path obtained by the virtual database and FEM-assisted intelligent press control system. Using the database and FEM-assisted intelligent press control system, the process control path was determined without assistance from an engineering expert and high efficiency of our process control system was confirmed (Koyama *et al*., 2004). Yagami *et al*. (2004) described an experimental and numerical attempt to control the blank holder motion by a newly proposed algorithm and investigate on the effect of this parameter on deep-drawability for a circular-cup deep drawing process of a thin sheet metal, from the perspective of wrinkle behavior as well as the fracture limit (Yagami *et al*., 2004).

In the present study, deep-drawing process of a circular cup is simulated using non-linear implicit finite elements method (ANSYS Software), with the aim of investigating the Punching and blank holder forces,

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drawing ratio and material flow. The optimum value for slope of die and blank holder is predicted by numerical solution. Accuracy and reliability of results are examined by experiment. We have tried to decrease amounts of Punching Force (PF) and Blank Holder Force (BHF) and increase draw ratio.

MATERIALS AND METHODS

Material properties: ISO 1624 low carbon steel with the thickness of 1.5 mm is used in this study. This material is selected because of good formability specification and widespread usage in the industry especially in automotive industry. Mechanical properties of material are given in Table 1.

Table 1: Mechanical Properties of used material

E (MPa)	ν	Y (MPa)	ε_0	K (MPa)	n
125000	0.29	185	0.0015	480	0.225

E is the young's modulus, ν is Poisson's ratio and Y is the yield stress of the material. The work-hardening behavior is considered isotropic and described by the Swift power law of Eq. 1:

$$\sigma = K\,(\varepsilon_o + \varepsilon_p)^n \qquad (1)$$

σ is the flow stress, K is the strength coefficient, ε_o is the elastic strain, ε_p is the equivalent plastic strain and n is the strain hardening exponent. To simulate the plastic deformation of the blank, isotropic hardening and Von-Mises/Hill yield criterion are employed.

Experiments and numerical model of deep drawing process: Experiments have been performed using the numerical analysis results that had been obtained previously. Dimensions and parameters of Analytical model of deep drawing process are presented in Table 2 and deep drawing tools are shown in Fig. 1. The values used for parameters have been investigated to reach to the optimum results. Lubricant for operation of deep drawing was used nylon and soluble oil.

Table 2: Tool and process parameters used in the simulation of deep drawing

Part name	Structural specification		Model description
Punch	R_p = 15 mm	R_1 = 6 mm	2D 4-node structural solid
Die	R_{id} = 16 mm	R_2 = 10 mm	2D 4-node structural solid
Blank holder	R_{ibh} = 15.5 mm	B = 3.15°, 6.28°, 9.38°	2D 4-node structural solid
Blank	H = 1.5 mm	Diameter = 35 mm	2-D 8-Node viscoplastic solid
Contact	Static friction coefficient = 0.1	Dynamic friction coefficient = 0.07	2-D 3-Node surface to surface contact

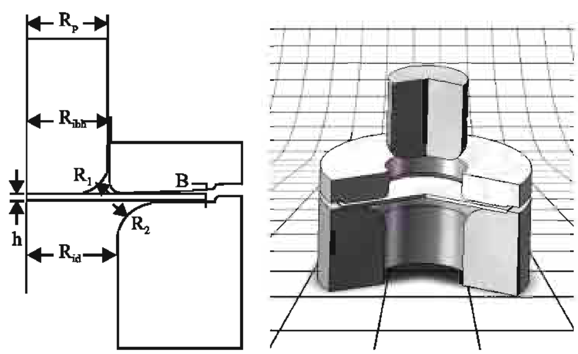

Fig. 1: Geometry of deep drawing tools

Because of the low anisotropy, the sheet is considered to be isotropic. So, the problem can be analyzed as an axisymmetric one. Blank is deformable, while Die, punch and blank-holder are assumed to be rigid. The configuration including the finite element meshing of the model before and after drawing is shown in Fig. 2. The mesh of the blank consists of VISCO 108 elements while the die, punch and blank holder are composed of PLANE42 elements. PLANE42 is 2-D element defined by four nodes having two degrees of freedom at each node. VISCO 108 is 2-D element capable of modeling the plastic and viscoplastic behavior of the material. Eight nodes having up to three degrees of freedom at each node define this element. Element sizes are controlled by controlling the division specification of lines and a free network is netted for the blank and the tools. Mesh density of the blank and tools affect the accuracy of the results. So the meshes in the blank are fine. The most important portion of the tool whose mesh density affects the accuracy and reliability of the results is its arc segment and the meshes of this portion are finer than other portions. The mesh of the blank consists of 315 elements. Up to 2623 nodes are included in the finite element models. The contacts between the blank and the tools surfaces are modeled with the aid of the pair of CONTA172-2D and TARGE169-2D elements (ANSYS, Inc., 2007). The contact issue is solved using the classic Coulomb model. In the mechanical formulation an augmented Lagrange multiplier is applied to associate the equilibrium equations with the contact problem. A Newton-Rapshon scheme is used to solve this problem in a single iterative loop algorithm. The solutions and viewing the solutions were made in the ANSYS/Structural. Displacement of the punch is selected automatically in each load-step. Totally 250 substep is selected for process in numerical analysis. The static yield data are used as the inputs for multilinear stress-strain curve in ANSYS software. Because the deformation of the die is much less than that of the blank, it is assumed to have elastic behavior. Young's modulus (E) and Poisson's ratio (υ) of the blank and the die are 204 GPa, 0.3 and 210 GPa,

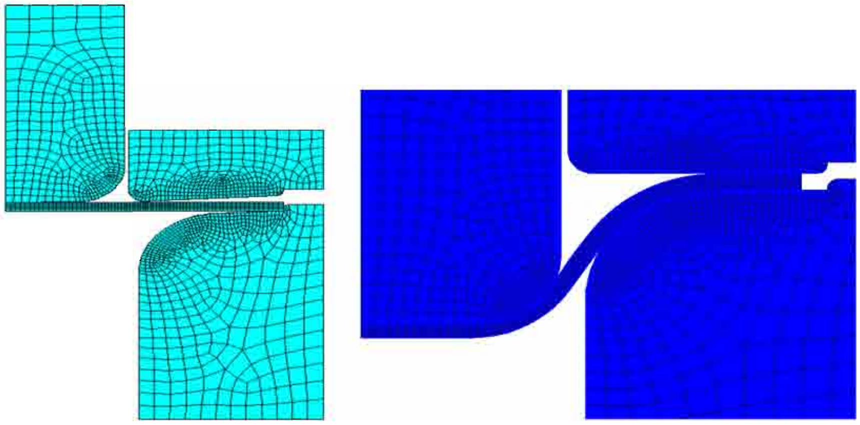

Fig. 2: Finite element meshing of deep drawing model before and after drawing

0.29, respectively. The deep-drawing process is performed up to a drawing depth of 18 mm making an incompletely drawn cup.

RESULTS AND DISCUSSION

Multiple simulations were performed in order to investigate the effect of tools slope in the quality of process. Figure 3 shows a comparison of typical punch load versus displacement traces from deep drawing tests on the blank. Peak point of the curves does not vary vastly for higher slopes. On the other hand, it is seen that increasing in slopes of die and blank holder widens the curves, which shows better condition of drawing and improvement in process and part quality. Peak points in the curves show the maximum depth of drawings. As shown in Fig. 3 and 4 increasing in slopes of die and blank holder cause an increasing in maximum depth of drawing. This amount is approximately 14% for optimum amount of slope that is 6.4 degree in the present study. Curves are the similar to this curve for slopes greater than the optimum amount.

In deep drawing process, flange and other elements of blank begin to draw-in after punch contact. Shelvy tools have greater contact areas than flat ones and resist more against displacement. However, as shown in Fig. 5, improvement in the other conditions makes the displacement of blank elements easier than flat tools. When the slope of die and blank holder is 6.4 degree, displacement of flange is around 51% more than the flat ones. This amount is around 27% for materials at punch shoulder zone. As represented in this Fig. 5, flow of materials decreases for the tools with more than optimum slopes in die and blank holder.

Wrinkling and tearing are two major issues that induce irregularities in the formed part. Wrinkling is

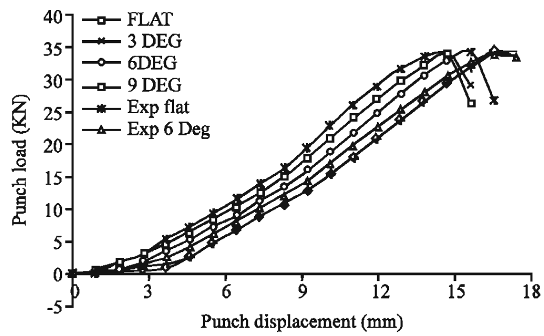

Fig. 3: Punch load versus punch displacement traces

Fig. 4: Experimental results of deep drawing

mainly caused by inadequate blank holder force and tearing is caused by excessive blank holder force. The effect of die and blank holder slope on the optimum blank holder load scheme is shown in Fig. 6. Variable blank holder force is used for tests. It can be observed from this figure that increasing in tools slope lower the BHF for similar Hoop Stress distribution. Hoop stress distribution of flange is represented in Fig. 7.

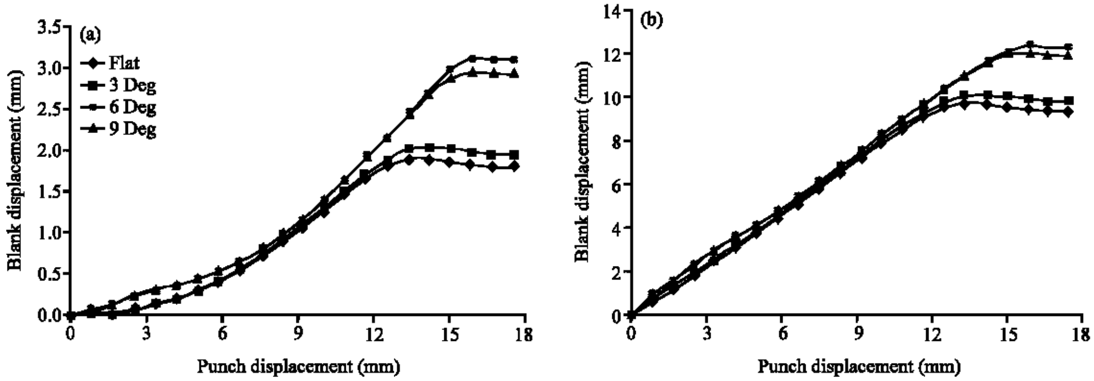

Fig. 5: Blank displacement versus punch displacement traces. Material in (a) Flange and (b) Punch shoulder

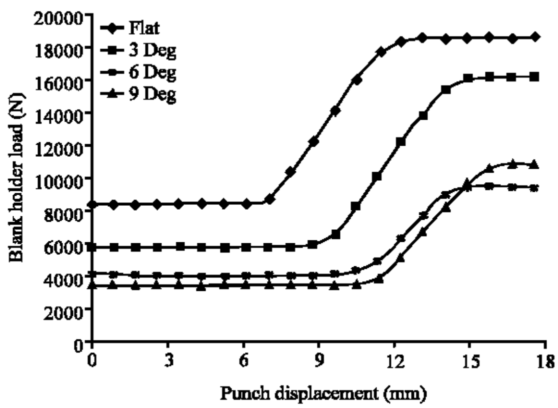

Fig. 6: Blank holder load versus punch displacement traces

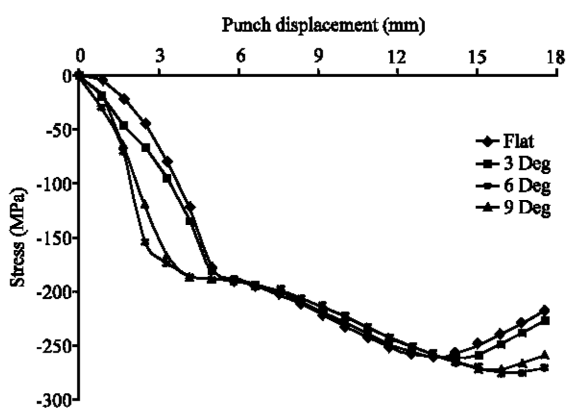

Fig. 7: Hoop stress distribution of blank in the flange for different die and blank holder distribution

CONCLUSION

In this study, the effect of die and blank holder shape on the punch and blank holder load, max depth of drawing and material flow is investigated. As represented by numerical and experimental results, increasing in slopes has not visible effect on the magnitude of punch load and lowers the blank holder force. So the wrinkling will be eliminated by increasing the slopes of die and blank holder up to an optimum amount. The optimum amount for tools slope is 6.38 degree in our investigation. Increasing the slope of die and blank holder facilitate material flow and then increase LDR.

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