Optimization of Blank Shape in Square Cup Deep Drawing Process

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Abstract

Deep drawing is an important sheet metal forming process used in the production of cup-shaped components. It is having applications in various industrial as well as domestic fields such as automobile, aerospace, beverage, and household kitchen utensils in large quantities. The deep drawing processes have been affected by many factors such as blank shape, punch and die radii, operating speed, lubricating conditions, forming characteristics of the material, and many more. Maximizing drawability in the deep drawing process minimizes the manufacturing cost as well as the time associated with production. In order to obtain the optimal drawability of the deep drawing process, the shape of the blank places a vital role and it is necessary to study the blank shape for optimum design. The finite element method has been used in this paper for investigating the initial blank shape. The main superiority of the drawn cup with a modified blank is that the drawn cup is not only uniform height and shape but also of reduced punch load during the deep drawing process.

Key words: *Deep drawing, Numerical simulation, Finite element methods, Formability, Blank*

1 Introduction

Drawability in deep drawing process is directly influencing the manufacturing cost and time. The prior knowledge on drawability and its limitations certainly enhances the optimum design of the process. Various process failures such as draw in failure as well as fracture limits the drawability in deep drawing process [1, 2]. The drawability in deep drawing process can be increased by delaying the occurrence of initiations for these failures. Various parameters that influences the deep drawing process are thickness, size, shape, anisotropic properties, strength co-efficient, strain hardening coefficient, strain rate sensitivity index of the material; process parameters such as punch nose radius, punch corner radius, die radius, clearance and blank holder pressure; process parameters such as lubrication and friction conditions, operating speed [3]. Among the material parameters, blank shape strongly influences the drawability in sheet metal forming particularly in the deep drawing process.

Blank design is a difficult problem to handle. For the past many years various methods were used in industry for optimization of blank size [4, 5, 6, 7, 4, 8, 9]. Trial and error methods or empirical rules were used for blank design in industry. The experimental cut and trial technique of finding the best blank size is not only time consuming but is confuses due to variations in the mechanical properties of individual blanks and hence produces different results with same material. So numerical methods have been used to investigate blank shape[10]. Many numerical analysis methods have been proposed by various researchers. For general cup drawing operations, the optimal blank profile as, that profile which can be formed into a cup with uniform final flange profile or a uniform rim height.

Kim and Kobayashi [11] were proposed a geometrical scheme to determine the contour shape of the blank for rectangular cup drawing. Toshihiko [12] was used an innovative scheme; starting with a cup having the desired geometry and obtaining the blank shape by the use of slip line field theory. Liu and Sowerby [13] proposed a method based on potential flow to establish the optimum blank shape for prismatic cup drawing. They assumed that the flow of material in cup drawing is comparable to irrotational flow of an inviscoid fluid. Chung and Richmond [14] were optimized the initial blank shape for minimization of earings by the use of ideal forming theories.

Many numerical analyses have been proposed to predict the optimum blank shape. Chung et al. [15] developed a sequential design procedure to optimize sheet-forming processes based on the ideal design theory, FEM analysis as well as experimental trials. Iseki and Murota [15] were proposed the numerical modeling of non-circular cup drawing process to determine the shape of the blank that can be formed into a cup of uniform height. Zaky et al [16] were determined the optimum shape of blank for deep drawing process of cylindrical cup without ears. Kishor and Kumar [17] were used the software LS-DYNA to observe the earings and compared with the experimental data with reasonably good accuracy. Shim et al [18] proposed a method of blank shape design based on the sensitivity analysis for non-circular deep drawing process. Son and Shim [19] were proposed a new method of optimal blank shape design using the initial nodal velocity (INOV) for the drawings of arbitrary shaped cups. With the given information of tool shape and the final product shape, corresponding initial blank shape has been found from the motion of boundary nodes. The deformed shape with predicted optimal blank almost coincides with the shape at every case. In this paper, a numerical scheme for blank design optimization in the context of square cup drawing has been proposed. Numerical techniques for predicting the onset of fracture failure and draw-in failure are presented and optimum blank shape has been deduced for square cup drawing. These results are compared with experimental results of earlier authors and found acceptable [20].

2 Basic Theory

FEM has been applied to simulate the plastic flow of materials during forming process. The governing equations for the solution of deep drawing process in which plastic deformation of blank takes place depends on equilibrium equations, yield criteria, constitutive equations, and compatibility conditions. The useful form of governing equations are:

$$\pi \;=\; \int \overline{\sigma}\;\dot{\overline{\epsilon}} dv \;-\; \int F_i u_i ds \tag{1}$$

Where is the effective stress, ($\dot{\overline{\epsilon}}$) is the effective strain rate, Fi the surface tractions.
The variational form of finite element discretization is given by

$$\delta\pi \;=\; \int \overline{\sigma}\;\delta\;\dot{\epsilon}\;dv \;+\; k \int \dot{\epsilon}_v\;dv \;-\; \int \;F_i\;\delta\;u_i\;ds \;=\; 0 \tag{2}$$

where $\dot{\epsilon}_v \;=\; \dot{\epsilon}_i i$ is the volumetric strain rate,
π is the function of the total energy and work and
k is the penalty constant of large positive quantity.
$\dot{\overline{\epsilon}}$ and $\delta\;\dot{\epsilon}$ are the variations in the effective strain rate and the volumetric strain rate.
Equations 1 and 2 are the basic equations for the finite element formulation.

Table 1: Material properties

S.No	Item	Quantity
1	Material	DD Quality cold rolled steel
2	Thickness,mm	1
3	Youngs Modulus(E), GPa	210
4	Poisson's ratio	0.3
5	Power law σ	514.734(0.006309+ϵ_p)0.227
6	Anisotropy	$R_0 = 2.04$ $R_{45} = 1.3$ $R_{90} = 2.16$
7	Punch velocity, mm/sec	1.2

3 Experimental procedure of deep drawing process

The drawing process, which presented in this work has been achieved with a forming of deep drawing quality (DDQ) cold-rolled steel sheet of 1 mm thickness. The mechanical properties of the sheet metal have been determined through tensile tests, along three directions with respect to the rolling direction. The mechanical properties are determined by preparing sheet samples and conducting tensile tests on UTM. The samples were prepared by cutting along three different direction, namely 0^o, 45^o, and 90^o to the rolling direction of the sheet. During the tensile test, the variations in length, width, and thickness corresponding to each load were measured, and the length strain, width strain, and thickness strain are calculated. The true stress – true strain graph has been plotted and found strain hardening exponent 'n' and strength coefficient 'K'. The plastic strain ratio 'r' (i.e. the ratio of the width strain to the thickness strain) along the three directions, namely parallel (0^o), diagonal (45^o), and perpendicular(90^o) to the rolling direction has found. The normal anisotropy values are determined using the expression

$$R = \frac{r_o + r_{45} + r_{90}}{4} \tag{3}$$

where r_o, r_{45}, r_{90} represent the plastic strain ratios along 0^o, 45^o, and 90^o orientations respectively to the rolling direction.

The mechanical properties used in the deep drawing test which determined in tensile test are specified in Table 1. A schematic diagram of the square cup deep drawing process is shown in Fig. 1. A flat circular sheet has been drawn by pressing through the die by applying force on the punch and a suitable blank holder pressure for smooth flow of blank through the die. The cup produced has been examined for rim height and found that the rim height is not uniform along all the sides and corners of the square cup.

It has been found that the cup at flat ends are having less height than the height at corners. This is due to more stretching of the blank at corners than at flat ends. The bank design has been changed by trial and error methods and performed experiments till production of uniform cup height. The blank shape is very near to circular shape even in forming of square cups. The cup produced is as shown in Fig. 1(b). The modified blank has been drawn and the cup height has been investigated for uniform height and found the cup with equal height at all sides as well as at all corners. The maximum radius of the circular blank is almost equal to the radius

(a) Deep drawing process

(b) Deep drawn square cup

Figure 1: Square cup deep drawing with drawn cup

of circular blank. The process parameter used in deep drawing are as shown in the Table 2.

It has been found that the limits of sheet metal formability have been received considerable attention and subsequent extensive experimental investigations led to the introduction of Forming Limit Diagram (FLD).

Table 2: process parameters of square cup deep drawing

S.No	Item	Quantity
1	Punch size, mm	60x 60
2	Punch nose radius, mm	8
3	Punch corner radius, mm	8
4	Die size, mm	62.5X62.5
5	Blank holder force, N	5000
6	Diameter of the blank, mm	125
7	Thickness of blank, mm	0.95

The abscissa of the plot is the minor strain ϵ_2 while the ordinate represents the major strain ϵ_1 as shown in Fig.2. Above the curve is unacceptable deformation state and below the curve is the safe deformation zone. It is necessary to provide an adequate width for the flange upon completion of drawing as it may be necessary to rivet the flange while assembly operation. If the minimum width of the final flange is found to be smaller than the required minimum flange width, draw-in failure is deemed to have occurred.

4 Deep drawing simulation

Finite element method has been used to simulate the square cup deep drawing process. The simulated cup has uneven heights. For obtaining uniform height reverse forming method has been adopted such that the excess material measured above the demarcation line in the formed cup is measured and same amount has been removed from the blank

In this paper, a finite element method software LS-DYNA, a commercially available software has been used for square cup deep drawing process. The punch, die, blank-holder are discretized

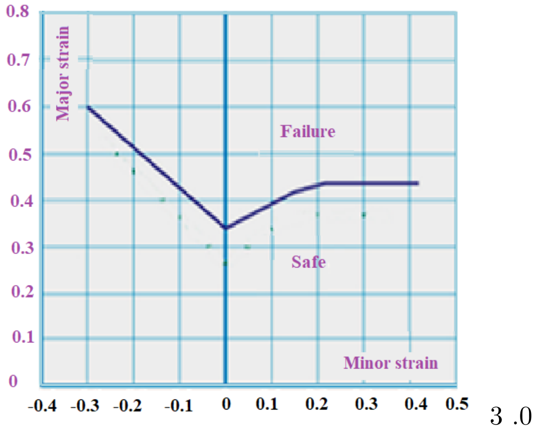

Figure 2: FLD diagram

and tool properties such as punch nose radius, die radius, blank holding pressure; material properties such as punch speed , friction conditions are provided as inputs for the simulation. Fig.3 shoes the simulation of deep drawing process. The strain and displacement undergone by the sheet has obtained as outputs. With the use of this data, it is possible to predict the onset of fracture failure and draw-in failure.

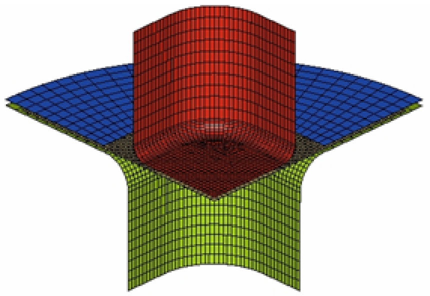

Figure 3: Wire mesh modelling of square cup deep drawing

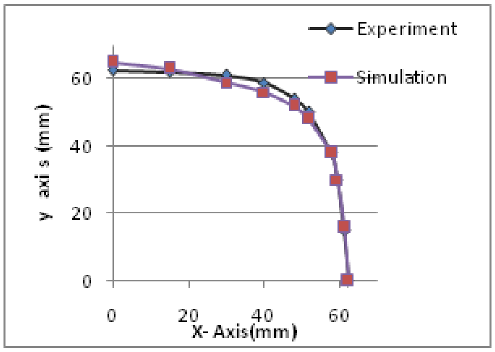

Figure 4: Blank design (one quarter of the blank)

The fracture failure has been recognized as the most undesirable form of failure. The shape of the square cup by the simulation is similar to that of the experimental results as shown in Fig. 4. The drawn cup height with the modified blank is more uniform than that of the circular blank.

5 Results and conclusion

The blank design optimization problem for square cups has been studied. The main objective of this study is to maximize the drawing depth while the constraints are, no fracture and draw in failures. The blank design for optimum LDR was defined. The optimum shape of blank profile was found to be very nearly circular shape of the initial blank. Thus it has been concluded that the circular shape can be considered to be an overall blank shape for square cup drawing.

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