

Finite Element Simulation of Deep Drawing Process to Minimize Earing

Pawan S. Nagda, Purnank S. Bhatt, Mit K. Shah

Abstract—Earing defect in drawing process is highly undesirable not only because it adds on an additional trimming operation but also because the uneven material flow demands extra care. The objective of this work is to study the earing problem in the Deep Drawing of circular cup and to optimize the blank shape to reduce the earing. A finite element model is developed for 3-D numerical simulation of cup forming process in ABAQUS. Extra-deep-drawing (EDD) steel sheet has been used for simulation. Properties and tool design parameters were used as input for simulation. Earing was observed in the simulated cup and it was measured at various angles with respect to rolling direction. To reduce the earing defect initial blank shape was modified with the help of anisotropy coefficient. Modified blanks showed notable reduction in earing.

Keywords—Finite element simulation, deep drawing, earing, anisotropy.

I. INTRODUCTION

DEEP drawing is a sheet metal forming process which is used in packaging, automotive and household appliances industries for mass production of cup shaped component. Everyday countless objects are manufactured with sheet metal from mild steel, stainless steel, EDD steel, copper, aluminium, brass and titanium. In the deep drawing process, a blank or sheet is forced by the punch into a die to form the final product. The objective of this work is to model and simulate the deep drawing process and modify the initial blank to reduce earing. The simulation of the deep drawing process was done in ABAQUS 6.13.

Ears are formed at the ream of cup when a cup is drawn from blank. It is undesirable because it requires additional processing. In spite of earing, there are other defects also like wrinkling, tearing, thinning, cracking, drawing grooves etc. These defects can be reduced by varying blank holder force or improving surface of drawing die. Earing is dependent upon the anisotropic property of material which is generated due to preferred crystallographic texture developed during rolling of sheet [1].

The draw ratio is an important factor for deep drawing in determining the required number of drawing steps and drawing force [8]. The draw ratio is the ratio of the diameter of the initial blank to the diameter of the drawn part. It has

been found that the limit draw ratio (LDR) increases with normal anisotropy [5]. A new, simple and practically applicable equation, including the normal anisotropy value R and the strain hardening exponent n , for estimating the limiting drawing ratio LDR in cup-drawing of a cylindrical cup was investigated [5]. Demirci et al. presented the effects of fixed blank holder forces on the wall thickness distribution and wrinkles [9].

Han et al. investigated optimum drawing process by changing circumferentially the blank holder forces, to draw earless circular cups from anisotropic blank sheet [10]. Padmanabhan et al. presented the significance of three important process parameters namely, die profile radius, blank holder force and friction coefficient on the deep-drawing characteristics of a stainless steel axis-symmetric cup [3]. Kishor and Kumar [4] presented a method to optimize the initial blank shape to minimize earing for determination of initial blank and accordingly blank shape was modified. Oluwole et al. investigated the effect of blank/punch diameter ratio (draw ratio) in deep drawing on earing for different gauges of Al 1200 sheet [2]. Das et al. [1] studied the earing problem in deep drawing of cylindrical cups by finite element modeling using HYPERWORKS-6.10. Zein et al. presented a Finite Element (FE) model for the 3-D numerical simulation of deep drawing process to predict the thickness distribution and thinning of the blank with the die design parameters (geometrical and physical parameters) [7]. Agarwal predicted the minimum blank holding pressure required to avoid wrinkling in the flange region during axisymmetric deep drawing process [6].

The orientation of grains produced by the metal forming process is the primary cause of anisotropy in material. The anisotropy coefficient r is defined by

$$r = \frac{\epsilon_w}{\epsilon_t} \quad (1)$$

where ϵ_w and ϵ_t are the strains in the width and thickness directions. This equation can be written in as

$$r = \frac{\ln \frac{w}{w_0}}{\ln \frac{t}{t_0}} \quad (2)$$

where w_0 and w are the initial and final width, while t_0 and t are the initial and final thickness of the specimen, respectively.

The average of the r -values obtained for different directions in the plane of the sheet metal represents the so-called coefficient of normal anisotropy. The coefficient of normal anisotropy is determined by:

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$$\bar{r} = \frac{r_0 + 2r_{45} + r_{90}}{4} \quad (3)$$

A measure of the variation of normal anisotropy with the angle to the rolling direction is given by the quantity known as planar anisotropy. This quantity is related to the earring amplitude of the deep-drawn cups.

$$\Delta r = \frac{r_0 + r_{90} - 2r_{45}}{2} \quad (4)$$

where r_0 , r_{45} and r_{90} are anisotropic coefficients along 0° , 45° and 90° direction from rolling direction.

II. MODELING AND SIMULATION

A. FE Simulation

In current work, the ABAQUS version 6.13 was used to model and simulate the deep drawing process of cylindrical cup. The important dimensions of die, punch and blank are shown in Table I.

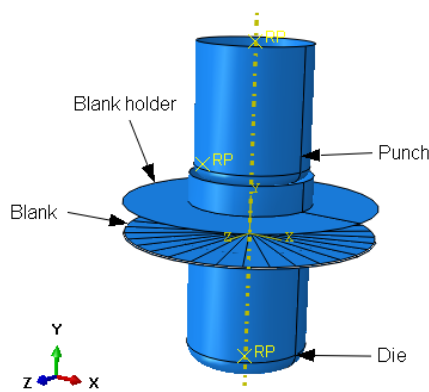


Fig. 1 FE model for Cup Forming

TABLE I
TOOL DIMENSIONS FOR DEEP DRAWING

Die radius	20.7 mm
Die profile radius	6 mm
Punch radius	19.5 mm
Punch profile radius	4 mm
Sheet thickness	1 mm
Blank Dia	84.52 mm

Fig. 1 shows the FE model for the deep drawing process. The blank was modelled using shell element (S4R) with five integration points and rigid surface element (R3D4) was used to model the die and punch. The die was fixed in all directions while the punch could move in the vertical direction. The friction behaviour of blank-supported die/blank-forming tool was modelled using the Coulomb friction law.

B. Material Properties

The blank was made of EDD steel. In the simulation, elastic/plastic material obeying Hill'48 yield criterion was

used. R_{11} , R_{22} , R_{33} , R_{12} , R_{13} and R_{23} are anisotropic yield stress ratios. They are defined as:

$$R_{11} = R_{13} = R_{23} = 1$$

$$R_{22} = \sqrt{\frac{r_{90}(r_0+1)}{r_0(r_{90}+1)}} \quad (5)$$

$$R_{33} = \sqrt{\frac{r_{90}(r_0+1)}{(r_0+r_{90})}} \quad (6)$$

$$R_{12} = \sqrt{\frac{3(r_0+1)r_{90}}{(2r_{45}+1)(r_0+r_{90})}} \quad (7)$$

These equations are imported into material modelling to investigate the earring phenomenon in FEM simulation [11]. Table II shows the material properties.

TABLE II
PROCESS PARAMETER & MATERIAL PROPERTY [4]

Material	EDD Steel
Young's Modulus (E) (Gpa)	210
Yield stress Mpa	155
Strength of coeff. (K) Mpa	431
Strain hardening exp. (n)	0.237
Blank holder force (kN)	20
Coeff. of friction (μ)	0.15
Punch velocity mm/sec	200
r_0	1.67
r_{45}	1.16
r_{90}	1.76

C. Earing Height Measurements

Earing height was measured by following procedure:

1. Circular blank was divided into 24 equal parts by drawing lines at 15° intervals from center to the circumference of the blank with respect to rolling direction.
2. At every node on the circumference of the blank the displacements (z-axis) were measured. Those displacements were subtracted from the displacement of centre node. These differences show the heights of the cup for those particular node.
3. The cup height was measured at every 15° interval from rolling direction of blank. Hence earring profile is generated between the 0° and 360° .

D. Simulation and Result

The material used in deep drawing process is EDD steel. Kishor and Kumar [4] performed an experimental analysis of the process and therefore a comparison between the present works against the values which have been recorded for the cup height of the deep drawn cup has been used to validate the model.

Fig. 2 shows the variation of cup height with rolling angle. It also shows the comparison of the present simulated earring height profile with experimental result of the literature [4]. There is a good agreement observed between the simulated cup earring profile and experimental results.

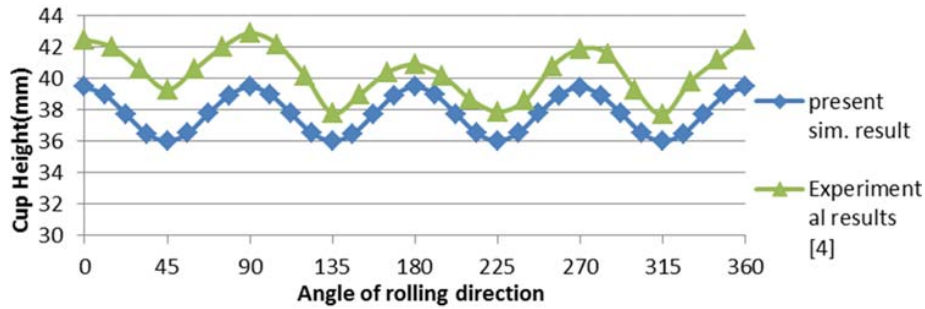
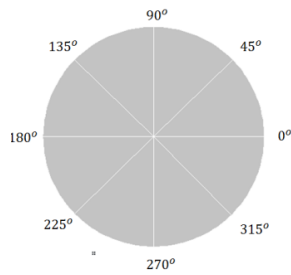
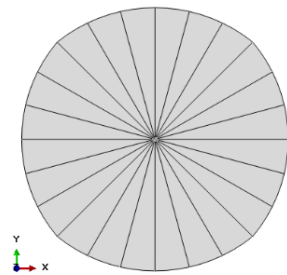


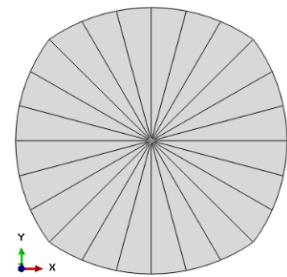
Fig. 2 Comparison of cup height of present simulated and experimental results



(a) Initial blank



(b) Modified blank I



(c) Modified blank II

Fig. 3 Blank shapes before and after modification

E. Modification of Initial Blank to Minimize Earing

In this work, material used was EDD which has high value of planar anisotropy. As its Δr is positive, ears were formed at 0° and 90° to the rolling direction. Hence according to the flow of material it is necessary to remove extra material from initial blank at 0° and 90° angle to reduce earing. Initial blank was modified by following procedure:

1. The initial blank was modified by determining new coordinates on X axis (0°) and Y axis (90°). Points at 45° ,

135° , 225° , 315° on the circumference of initial blank were not changed. Those points were joined by three point arc taking point at 45° , modified Y axis (90°) and 135° . Similarly other four arcs were generated. The new X- and Y- coordinates of four points were determined as:

$$\text{Modified X-coordinate} = R - \beta \delta r_1 \tag{8}$$

$$\text{Modified Y-coordinate} = R - \beta \delta r_2 \tag{9}$$

where, R is the radius of circular blank

$$\delta r_1 = r_{0^\circ} - r_{45^\circ}$$

$$\delta r_2 = r_{90^\circ} - r_{45^\circ}$$

2. Initial blank was modified two times taking two value of β .

- (a) Modified blank 1 for $\beta=3$
- (b) Modified blank 2 for $\beta=5$

III. RESULTS AND DISCUSSIONS

The use of modified blank has significantly reduced the variation in cup height. The cup heights were measured at different points with respect to rolling direction and plotted as shown in Fig. 4 for different blank shape. The cup height was more uniform using the 2nd modification with $\beta=5$ where the variation of cup height is less.

The minimum cup height is the height of the cup that will be obtained after trimming the uneven top edge of the cup. % ear height is calculated as:

$$\% \text{ ear height} = \frac{(\text{cup height} - \text{min.cup height})}{\text{min.cup height}} \times 100 \tag{10}$$

Fig. 5 compares the % ear height before and after the first and second stage of modification for the drawn cup by simulation. It can be observed that % ear height above the minimum cup height before modification 9-10%, which reduces to 5-6.4% after first modification and 3-4% after second modification. Hence, second modification of initial blank gives the least % earing height or more uniform earing profile than other blank, it is considered to be an optimal blank. The earing is reduced by using the modified blank due to material is removed where the metal flow is low to modify

the blank further.

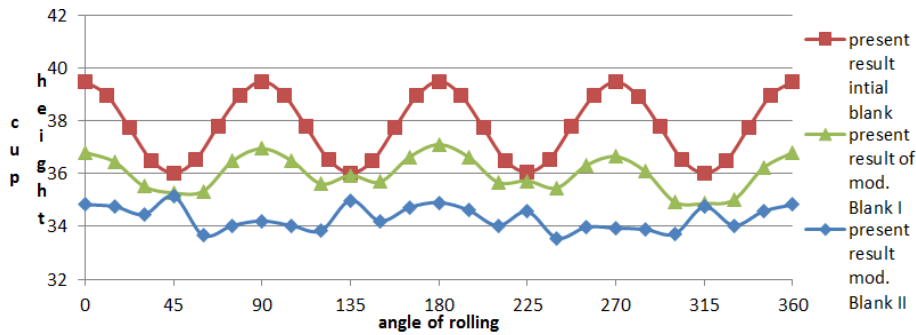


Fig. 4 Comparison of cup height of initial and modified blank

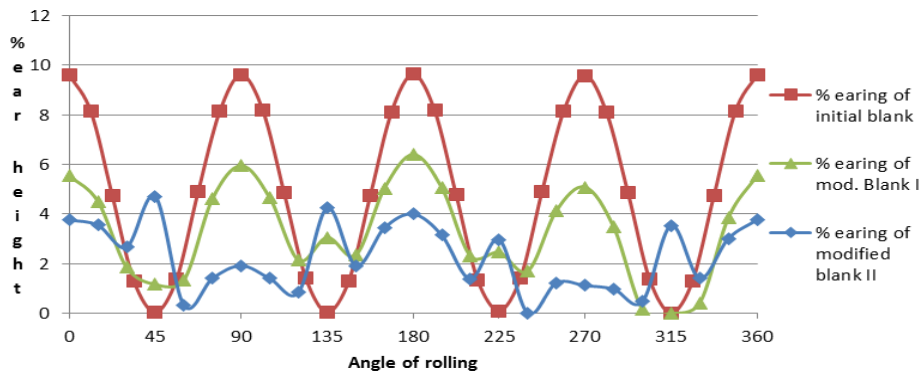


Fig. 5 Comparison of % earing before and after modification

IV. CONCLUSION

In the present work, deep drawing process has been simulated with the help of software (ABAQUS) to study cup forming process using EDD steel as blank material. The FEM simulation is a very powerful tool in sheet metal for analysis of deep drawing process. Based on the results and discussion, it can be concluded that minimization in the earing defect of deep drawing is possible by modification of initial blank shape. Simulated results showed the initial blank as circular blank produced more % earing height because of planar anisotropy and modified blank showed reduction in the % earing height. The use of modified blank i.e. non circular blank produced considerable reduction in % earing height.

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