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ARTICLE

Effect of Anisotropy, Temperature, Strain Rate on Deep Drawing Using Conical Die

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ABSTRACT

This paper covers the role of anisotropy, temperature, and strain rate on the flow behavior of the material when a conical die is used instead of conventional blank holder. The effect of anisotropy was investigated using Lankford's coefficient (r) in three directions (0°, 45°, and 90°). The effect of working temperatures (Room temperature, 100°C - 300°C) on drawing stress and strain rate sensitivity on punch pressure were also investigated in detail. ANSYS APDL was used to investigate the effects of temperature, strain rate and anisotropy. The simulation results have confirmed that the strain variation in the direction of r_0 and r_{45} are more than the variation of r_{90}.

1. Introduction

Conical type die raises the limiting drawing ratio of deep drawing cups. It can manufacture various cross sections at die cylindrical throat to permit best metal flow from the conical section to desired shape at the die end.

Mihael Volk et al. [1] presented few aspects of blank-holder pressure patterns in conventional deep drawing based on finite element assessment. In all models, ABAQUS software was used with full 3-D model to investigate anisotropy and wrinkling of the parts. The blank is made of aluminum 5182 alloy, this is an elastic-plastic analysis. Friction based on Coulomb friction model with 0.1 coefficients between the blank and the various tool. Lihui Lang et al. [2] observed influences of many parameters that start wrinkling on a cylindrical cup. The goal of this study is to show the influence of different factors such as BHF, punch and die radius, and friction on the wrinkling of cylindrical parts. Marisa P. Henriques et al. [3] describes the initiation of wrinkles during sheet metal forming. ABAQUS software was used for FEA. The results showed that, correct prediction of wrinkling defects.

In this present study, effects of strain rate, anisotropy and temperature on plastic deformation characteristics of AISI 304 grade steel blanks analyze using ANSYS APDL simulation software.

2. Methodology of Present Work

In this present study, the methodology, consists of a number of steps and sub-steps (Figure1). Starting from the creation of a 3-Dimensional axisymmetric model and then defining input parameters such as material properties, parameters, boundary conditions, meshing, and iterations.

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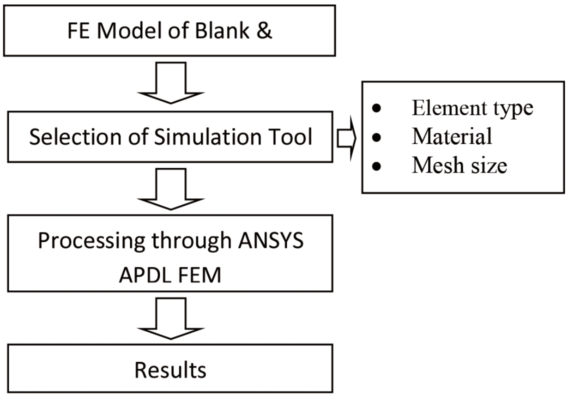

Figure 1. Flow chart of methodology

3. Creation of Tool and Work Piece Geometry

In this investigation, a finite element model is created using ANSYS APDL pre-processor. The axisymmetric 3-Dimensional model developed for analysis is shown in the below figure 2.

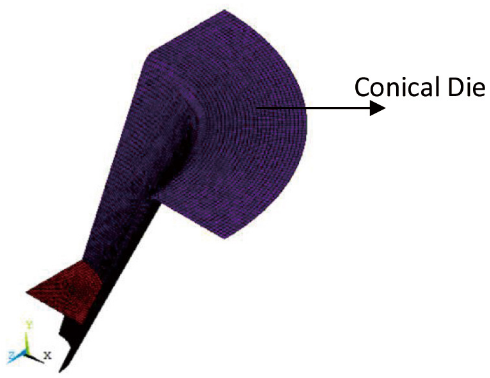

Figure 2. FE model for conical die without blank holder

4. Investigation of Anisotropy Problems in Deep Drawing using FEM

This section discusses the results of the numerical simulations by considering plastic anisotropy of stainless steel sheets. A 3-D parametric FE model was built using the ANSYS APDL. The material used in this work was sampled from a rolled sheet of 1.5 mm thickness AISI 304 stainless steel.

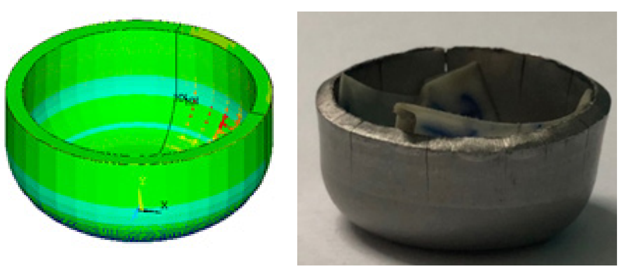

Figure 3. Experimental and simulated cylindrical cup

In general, the anisotropic behavior of sheet metals is evaluated using Lankford's coefficient, (r) commonly known as plastic anisotropy parameter [4-6]. A uniaxial tensile test is used to determine the r-value by using two extensometers, one in the longitudinal direction and the other one in the transverse direction. The ratio between two major strains are determined using constancy of volume i.e $\varepsilon_l + \varepsilon_w + \varepsilon_t = 0$ and expressed as below –

$$r = \frac{\varepsilon_w}{\varepsilon_t} \tag{1}$$

Where, r is Lankford's plastic anisotropy ratio, ε_w and ε_t are the strain values in width and the thickness directions respectively. The true strain values are also be expressed as –

$$\varepsilon_l = \ln\left(\frac{l_0}{l_f}\right) \tag{2}$$

and

$$\varepsilon_w = \ln\left(\frac{w_0}{w_f}\right) \tag{3}$$

Where Lo is the original length of the tensile specimen, Lf is the final length of the specimen; W_o and W_f are the initial and final width of the tensile specimens respectively. Thus, the equation (4) may be rewritten as –

$$r = \frac{\ln\left(\frac{w_0}{w_f}\right)}{\ln\left(\frac{l_f w_f}{l_0 . w_0}\right)} \tag{4}$$

Often, the r-values are determined at different directions of the sheet metal i.e. at 0, 45 and 90 degrees from the rolling direction, as shown in the inset of Figure4.The average value is called normal anisotropy, which is expressed as ($\bar{r}$) -

$$\bar{r} = \frac{(r_0 + 2r_{45} + r_{90})}{4} \tag{5}$$

The experimental results of tensile specimen obtained from a stainless steel sheet at different directions are shown in Figure4 and values of Lankford's coefficient, strain hardening exponent and other mechanical properties are presented in table 1.

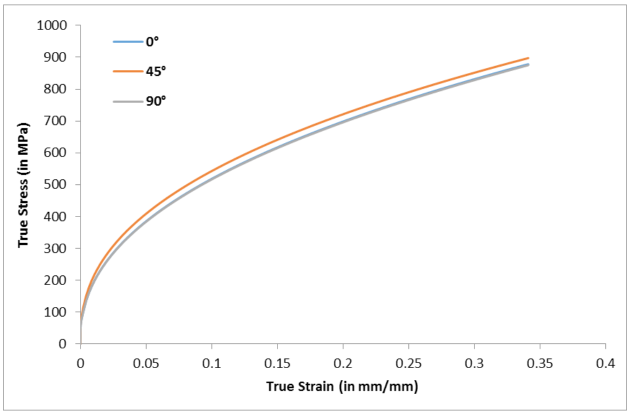

Figure 4. True stress-strain curve for AISI 304 Stainless steel at r_0, r_{45} and r_{90} degrees from the rolling direction

Table 1. Plastic Anisotropy parameter of AISI 304

Orientation	Ultimate tensile strength (in MPa)	Hardening exponent (n)	Lankford's coefficient (r)
0°	528	0.43	0.76
45°	524	0.41	1.38
90°	530	0.43	0.83

As determined through the experimental measurements the AISI 304 sheet metals shows higher normal anisotropy ($\bar{r}$). This suggests that the cup wall of this material can withstand higher load without excessive thinning and fracturing [7-10]. The values of planar isotropy (Δr), suggests that ear formation will occur ± 45°.

5. Simulation Results by Considering Plastic Anisotropy

The variation in the deep drawing behavior of AISI 304 sheet metal with respect to plastic anisotropy is investigated through simulation studies. The possibilities of wall thinning, fracturing and earring were investigated by considering plastic anisotropy i.e. by using Lankford coefficients.

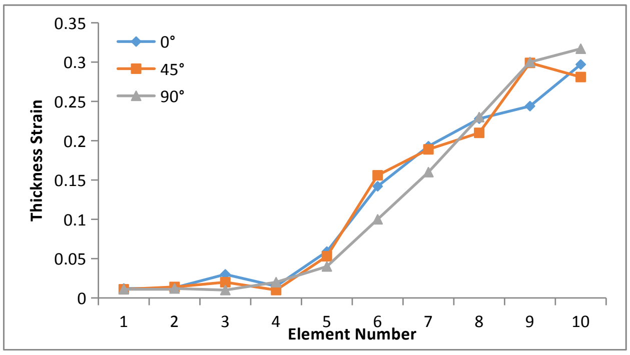

Figure 5. Effect of plastic anisotropy on thickness strain of cylindrical cup simulated using FEM

A cylindrical cup drawn using a conical die instead of a conventional blank holder is considered for simulations studies. The variation in the thickness strain at different regions of the cup drawn by considering plastic anisotropy is shown in Figure 5.

6. Effect of Temperature on Deep Drawing of Cylindrical Cup Using Conical Die

Warm working is the plastic deformation of metal at temperatures below the temperature range for recrystallization and above the room temperature. In this investigation, 1.5 mm thick circular blank of stainless steel AISI 304 were warm deep drawn and the influence of temperature on the deformation behavior of material and the drawing stress which is required to draw the component was studied by FEM software ANSYS APDL.

Influences of temperature on drawing stress

Temperatures ranging from 25°C (room temperature) to 300°C in various temperatures of 100°C, 200°C, and 300°C were applied during forming and the effect on the required drawing stress was studied. It is observed from figure 6 that increase in temperature decreases the drawing stress approximately by 33%. Figure 6 is showing that, stress is continuously decreased with increasing temperature.

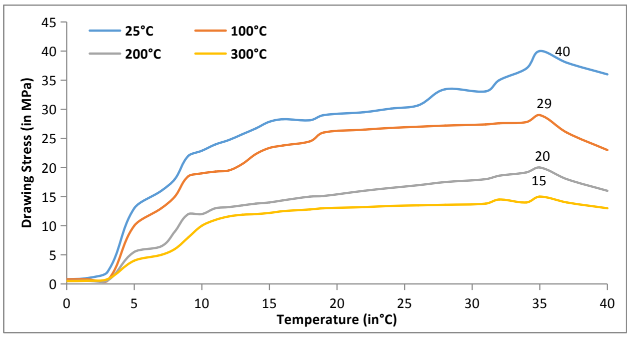

Figure 6. Effect of temperature on drawing stress

Figure 7 (a-c) is shows effects of temperature on principal stress on cylindrical cup. Result shows that the principal stress is observed to decrease with increasing temperatures, this is because the flow stress is better on high temperatures. Figure 7 (a) shows at room temperature the principal stress is 60 MPa but after increment of temperature the stress decreases upto 54 MPa. This shows that the temperature affect the formation of deep drawing process.

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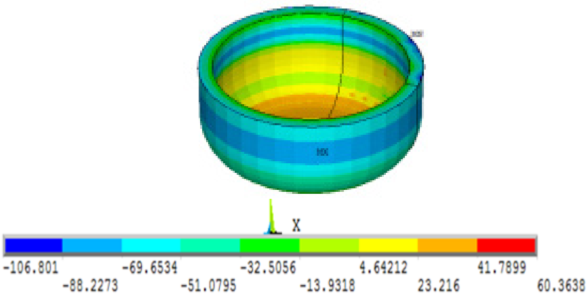
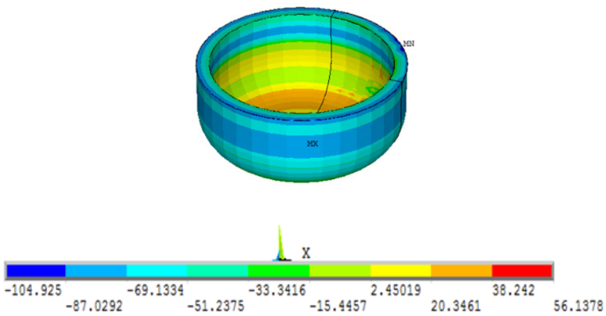
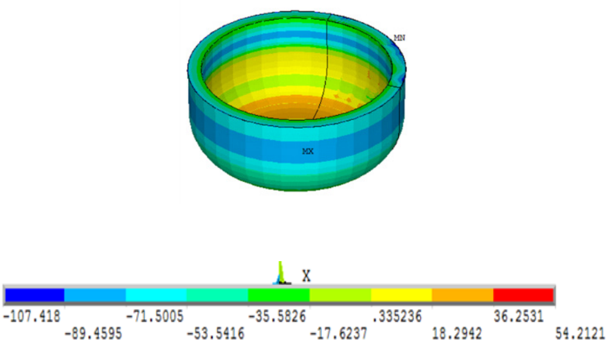


(a) Maximum Stress = 60 MPa



(b) Maximum Stress = 56MPa



(c) Maximum Stress = 54MPa

Figure 7. Effect of temperature on stress (a) Room temperature (b) 100° temperature (c) 200° temperature

Figure 7 is shows effects of temperature on principal stress on cylindrical cup. Result shows that the principal stress is observed to decrease with increasing temperatures, this is because the flow stress is better on high temperatures. Figure 7 (a) shows at room temperature the principal stress is 60 MPa but after increment of temperature the stress decreases upto 54 MPa. This shows that the temperature affect the formation of deep drawing process.

7. Effect of Strain Rate on Deep Drawing Using Conical Die

The strain rates can be determined if the velocities are known. The stresses and strains are computed by using the strain rates. For stainless steel metal, a better description of the strain-rate sensitivity of flow stress is given by–

$$\sigma_f = K.\varepsilon^n.\left(1+\frac{\varepsilon_1}{\varepsilon_2}\right)^m \quad (6)$$

Where, σ_f is flow stress (in MPa), K is strength coefficient (in MPa), ε is the flow strain, $\varepsilon_1/\varepsilon_2$ is the ratio of strain rate and m is the strain rate sensitivity.

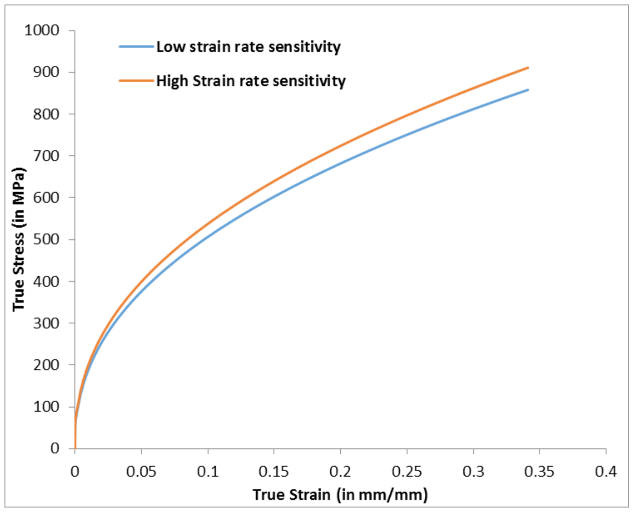


Figure 8. Two possible effects of strain rate sensitivity on stress–strain curves

Figure 8 shows the strain rate sensitivity. The tensile test was conducted for different strain rates (high as well as low strain rates). Both the values of stress-strain used as input data in FE simulation.

8. Conclusions

The significant credentials of the present study are listed below:

The values of planar isotropy (Δr), suggests that ear formation will occur ± 45°. The maximum thickness strain is observed at to the cup wall region in comparison to the cup bottom. The simulation results have demonstrated that the strain variation in the direction of r_0 and $r_{45}$are more than the variation of r_{90}, an increase in temperature decreases the drawing stress approximately by 33% but temperature does not affect the formation of tearing in the thinning section, and at low strain-rate punch pressure decreases and punch pressure rise in high strain rate.

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