

An Experimental Study on Earing and Planar Anisotropy of Low Carbon Steel Sheets

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Abstract: The deep drawing process is used in the modern industry extensively to produce specific parts with desirable shape. Material properties of the blank have a significant effect not only on the quality of formed part but also on the determination of process parameters. Earing is the well-known phenomena in this process that decreases the product yield. That is affected by material anisotropy and it is important to investigate the influence of material parameters on this material behavior. In this study, the deep draw ability of thin sheet of low carbon steel has been experimentally investigated. Based on deep drawing test, the earing phenomenon due to planar anisotropy in low carbon steel sheet was observed and the different height of cups at any direction with respect to rolling direction was measured in order to determine the r-value of sheet. Earing tendency during drawing is increased at higher planar anisotropy. By difference in height of drawn cup, the r-value was measured successfully. It was found that maximum cup height take place in 0° and 90° relation to rolling direction and in this area thickness of cup wall is less than other direction.

Key words: Planar anisotropy • Low Carbon Steel • Earing • R-Value

INTRODUCTION

Deep drawing involves conversion of flat thin sheet metal blanks into different parts with desired final shape. This process is a complex forming process which involves tension (at cup wall), bending (at punch and die corners) and compression (at flange). For the successful deep drawing, both high tensile strength at formed wall region and better ductility of material at flange area are expected from initial material [1]. Nowadays, the deep drawing process is used in the modern industry extensively for forming automotive inner and outer panels. This process usually has several interrelated variables include the sheet blank (geometry and material), the tools (geometry and material), the conditions at the tool-material interface, the mechanics of plastic deformation, the characteristics of the final product, and the plant environment in which the process is being conducted [2, 3]. Among these variables, the material properties of the blank have a significant effect not only on the quality of formed part but also on the determination of process parameters [4].

Material properties play an important role in metal forming process. The formability is dependent upon the material properties such as strain hardening exponent (n), strain rate sensitivity parameter (m), anisotropy parameter (r), and grain size as demonstrated in [5-8]. Anisotropy

behavior of materials has most significant effect on deep draw ability of sheet. Metals have undergone extensive plastic deformation, show anisotropy behavior in mechanical properties and plastic deformation on different directions due to preferred grain orientation at structure. Even in the case of untextured metals showing isotropic or almost isotropic yielding behavior, ductility can be very anisotropic [9]. Earing in drawn cups comes from different plastic strain ratio at different directions. After drawing, this irregularity on top of cup should be cut which decrease the yield of process. More anisotropic properties lead to greater ear and then decrease efficiency of deep drawing process.

Low carbon steel with high demand on deep drawing process, unfortunately, shows serious earing in production. In the present study, based on observed earing on drawn cup from cold rolled and annealed sheet of low carbon steel, the r-value of experimented material was measured and compared with those reported in references.

Materials and Experimental Procedures

Research Material: The as-received material was cold rolled low carbon steel sheet with a thickness of 1.1 mm. The chemical composition of the material is given in Table 1.

Table 1: Chemical composition (% wt) of the investigated alloy

C	Si	Mn	P	S	N	Fe
0.16	0.20	0.35	0.050	0.05	0.009	Balance

Metallographic Practice: Metallographic samples were prepared by sectioning from the initial sheet to carry out metallography on the rolling plane. The metallographic specimens were prepared by mounting, grinding and then polishing by using alumina powder.

Deep Drawing: The formability may be expressed as a limiting drawing ratio (LDR) in deep drawing experiment. LDR is defined as the ratio of the largest diameter of the blank that can be drawn without failure to the smallest diameter of the cup or punch. Different blank diameters from 60 to 70 mm of steel sheet with a thickness of 1.1 mm were employed in deep drawing process for determining LDR value of material...

For study the planar anisotropy of this plate, the height of cup at different direction was measured to reveal earing phenomena in drawn cup. Based on the variation of height of cup versus the angle of position with respect to rolling direction (θ), the r-value of sample was calculated by using following Eqs.(1,2) [10].

$$h_{\theta} = 2h_0 \left[1 + (d^1/d_0) \frac{1}{1 + R_{\theta+90}} \right]^{-1} \quad (\text{Eq.1})$$

$$h_{\theta} = 2h_{90} \left[1 + (d^1/d_0) \frac{1}{1 + R_{\theta}} \right]^{-1} \quad (\text{Eq.2})$$

Where h_0 and h_{90} are the height in rolling direction ($\theta=0$) and transverse direction ($\theta=90$), respectively. In addition d_0 is the initial diameter of circle and d_1 is punch diameter. Drawn cup from blank diameter of $D_1=60\text{mm}$, $D_2=64\text{mm}$ and $D_3=66\text{mm}$ were chosen for this measurement. The normal anisotropy or mean plastic strain ratio (\bar{r}) and the planer anisotropy (Δr) were calculated from the variation of r-values versus angle of θ .

RESULTS AND DISCUSSION

Microstructure: The microstructure of as-received material is shown in Fig 1.

Deep Draw Ability: The results of deep drawing test on different blank diameter are shown in Fig. 2. The blank diameter of up to 66 mm is drawn without defect,

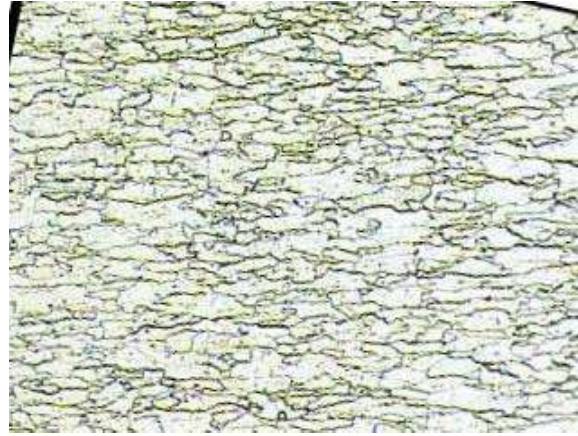


Fig. 1: Microstructure of low carbon steel used in this investigation (x100, Etchant: Nital).

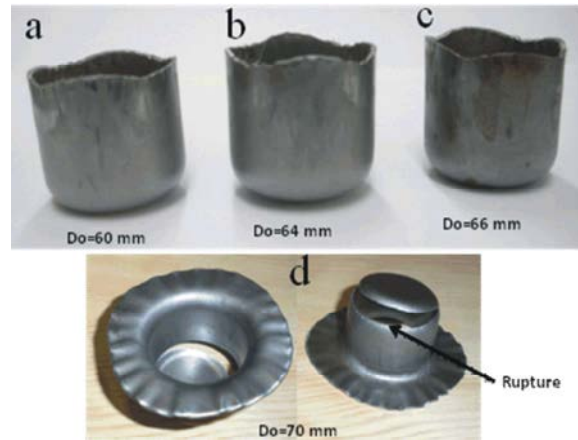


Fig. 2: Cups formed with different diameter; 60mm (a); 64mm(b); 66mm(c) and 70mm (d).

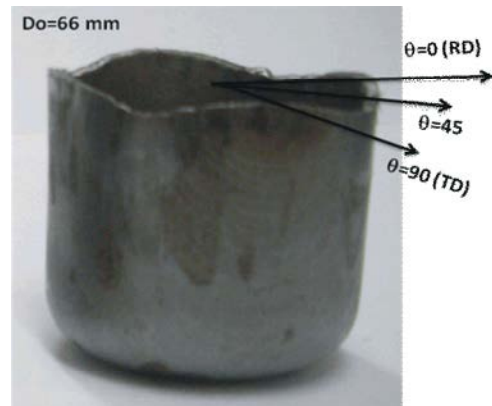


Fig. 3: Occurrence of earing phenomenon in drawn cup with $d_0=66$ mm.

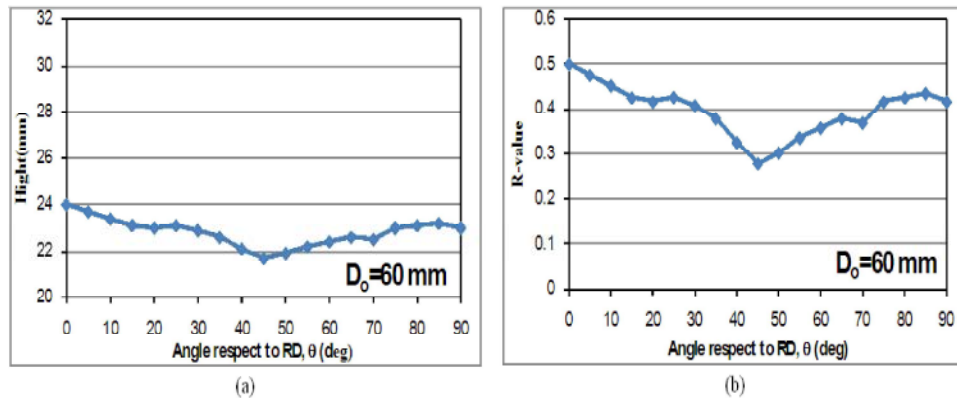


Fig. 4: Variation of height of cup (a) and R-value (b) for sample with blank diameter of 60 mm

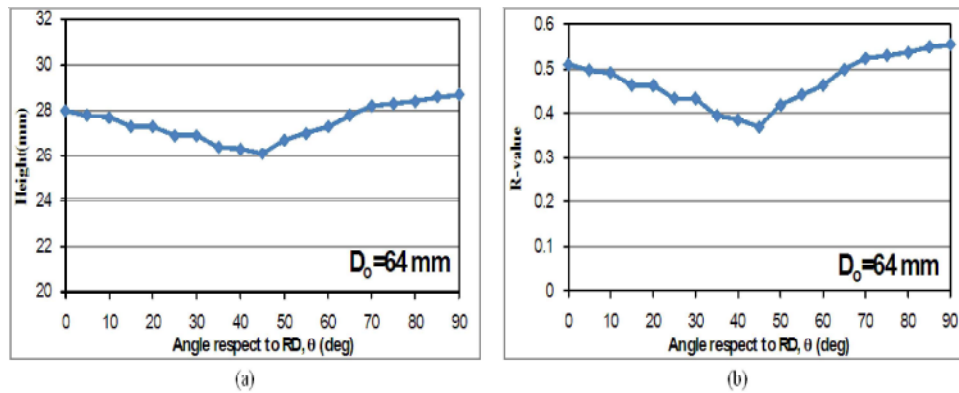


Fig. 5: Variation of height of cup (a) and R-value (b) for sample with blank diameter of 64 mm

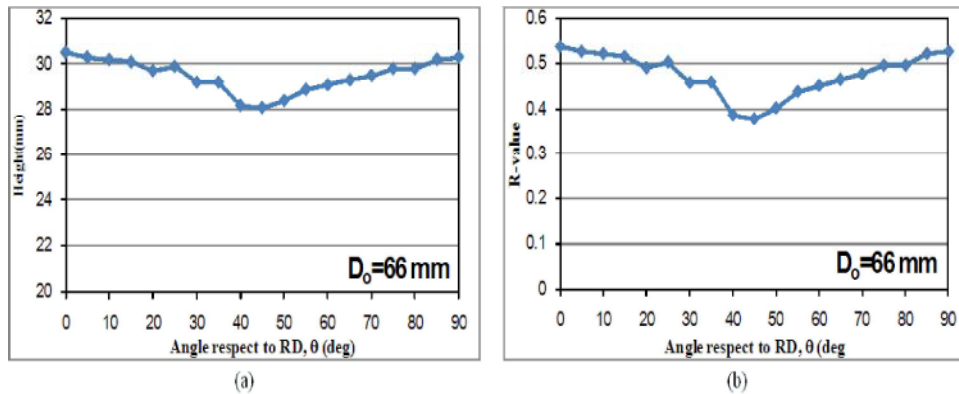


Fig. 6: Variation of height of cup (a) and R-value (b) for sample with blank diameter of 66 mm

successfully. It is clearly indicated that sample with the initial diameter of circle (D_0) equal to 70 mm has broken under test. Based on the definition of LDR, computed by using equation $LDR = D_0/D_1$ where D_0 is the initial diameter of circle and D_1 is punch diameter. The diameter of punch in deep drawing was 30 mm. The maximum diameter of blank, which can be drawn for tested material, is 66 mm and the LDR value is at least 2.2. This value of LDR can be comparison with LDR value of 2.2-2.5, which has been reported for low carbon steel [11].

Earing (Planar Anisotropy): The results of deep drawing samples show that the more deformation takes place at angle of 0 and 90-degree respect to rolling direction, Fig 3. This phenomenon and the inhomogeneity of deformation is observed in same directions on drawn cup from all blanks, even for blank of 70 mm which is ruptured before completion of drawing process, Fig. 2. Indeed, in these regions ($\theta=0$ and 90) resistance to thinning is more than other regions like $\theta=45$. This is given rise from plastic strain ratio of material

in different angle, which can be evaluated by r-value parameter.

R-Value Parameter: The results of calculated r-values from measured height of cup at different position and by using Eqs.1-2 are summarized in Fig. 4-6.

The results of calculated r-values indicate that three samples with different initial blank diameter, achieve equal amount of r-value at same angle position. Furthermore, amount of earing altitude (difference between maximum and minimum height in a sample) show small increase with increasing diameter of blank.

In addition, the mean of r-value (\bar{r}) by using calculation the area under curves in Figures4-b; 5-b and 6-b were measured to be 0.39, 0.47 and 0.47 for $D_0=60\text{mm}$, $D_0=64\text{mm}$ and $D_0=66\text{mm}$, respectively. The amount of Δr by using analytical calculation on above curves was estimated to be 0.062, 0.061 and 0.057, respectively.

Summary: The formability and anisotropic behavior of a low carbon steel sheet via the limit-drawing ratio (LDR) and R-value were conducted. Based on the results and discussions presented in the foregoing sections, the following conclusions can be drawn:

- The LDR value was observed at least 2.2 for tested material.
- High amount of deformation take place in 0 and 90-degree respect to rolling direction and in this area thickness of cup wall is less than bottom of cup. Minimum cup height observed at $\theta=45^\circ$.
- On other hand, the result indicated that r-values were calculated for three samples are equal in same angle relation to rolling direction. Furthermore, amount of earing with increasing diameter of samples show small increase.
- The mean of r-value of low carbon steel was measured 0.45 whereas the amount of Δr was estimated to be 0.06.

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