NEWS LETTER

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3. Paper presented in International conferance at Osmania University By the Faculty form Mechanical Department

Experimental and Simulation Study in Deep Drawing of Circular Cups for Determination of LDR

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Abstract. Still today, the analysis and design of deep drawing is an art than science. In this paper, an attempt was made to study the deep drawing process for experimental determination of Limiting Drawing Ratio (LDR) and justify the results with simulations. The FE simulation software can predict sheet metal forming process such as deep drawing and also enhances the efficiency, by reducing development time and cost. The deep drawing experimental tests were carried out, using the tool setup ingeniously developed in the lab and mounted on universal testing machine. The AA611 aluminum alloy sheet blanks of different sizes were drawn using optimum forming conditions established through Taguchi design of experiments. The drawn cups were tested for wrinkling and cracks, if any and determined the LDR by considering the maximum size of the blank successfully drawn without these defects. The LDR found in this study for AA6111 was 1.8325. The simulation tests were conducted using the FE code Pam-Stamp and are in good agreement with the experimentally drawn cups when inspected for wrinkles and cracks. The forming limit diagram in each test shows that the strains were within safe limit for the successfully drawn cups and exceeded the limit in case of fractured and or wrinkled cups.

Keywords: Deep drawing, LDR, FE simulation, PAM-STAMP

1 Introduction

Variety of problems of sheet metal forming can be solved better with the use of advanced numerical simulation methods [1,2]. These methods readily provide a practical knowledge and gives feedback to the researchers and/or manufacturers about the forming characteristics of manufacturing process in advance of the actual production. The use of Finite Element Methods (FEM) in sheet metal forming had become an efficient concept of virtual tool design, testing and it eliminates the physical try-out method that consume a lot of time and cost. By the use of Finite Element software such as PAM-STAMP, ANSYS, LS-DYNA, it is possible to better understand the deformation phenomenon in

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sheet metal forming process. The different parameters and their influence on sheet metal parts deformation can be studied thoroughly using numerical simulations for taking intelligent decisions based on optimal forming conditions [3]. The deep-drawing process is used extensively in various industrial applications such as beverages, automobile and household. Any advanced research in this area can directly improve the productivity of sheet metal forming industries.

The stress state in deep drawing process is a complex phenomenon and varies from compression in the circumferential direction at flange to a biaxial tensile stress state at the bottom of cup. The movement of the punch ends with the ejection of cup formed from the blank and it experiences a complex series of stresses and strains continuously, during transformation of flat blank into complete cup. The downward movement of the punch pushes the bent metal over the die into the gap between the punch and die and straightens the side wall of the final cup. The bottom of the initial cup and the metal that was bent over the punch nose moves downwards. In order to avoid stretching of the metal in the die corner region, an additional material can be received from the flange region. Hence, the flange portion of the sheet blank is drawn continuously towards the die cavity and compensates for the metal used in cup sidewall forming and it results in reduction in circumference (perimeter) of the blank [4].

Pourboghrat et al. [5] were conducted a research study on the deep drawing ofAA5754 aluminum sheets. The various parameters such as displacement, punch force, hydro-forming pressure, temperature and the maximum draw depth prior to wrinkling/tearing were recorded for comparing with simulation readings. The parameter optimization methods were applied for different applications by various researchers [6-13] using Taguchi techniques. It was concluded that Sheet Hydro-Forming (SHF) and Thermo Hydro-Forming (THF) processes can achieve more than 100% deep drawing with the AA5754 aluminum sheet. Lazarescu et al. [14] were conducted experiments and finite element simulations for investigating the influence of constant and time variable blank holder force on punch force. The thickness distribution of cylindrical and square cups produced in the deep drawing was investigated. The experimental and numerical results show that the use of variable BHF, instead of a constant BHF reduces the punch force considerably. In analyzing the sheet forming operation, the local strains that are very near to the failure zone were treated as critical points. K S Prasad et al. [15] measured the critical strains and compared with the standard FLD. As the blank is deformed during stamping process, the strains occur both on the surface of the sheet (major and minor strain) as well as in thickness (thinning strain) direction. In deep drawing process it was essentially assumed that the thickness variation in through-thickness direction was negligible in comparison to planar directions [16].

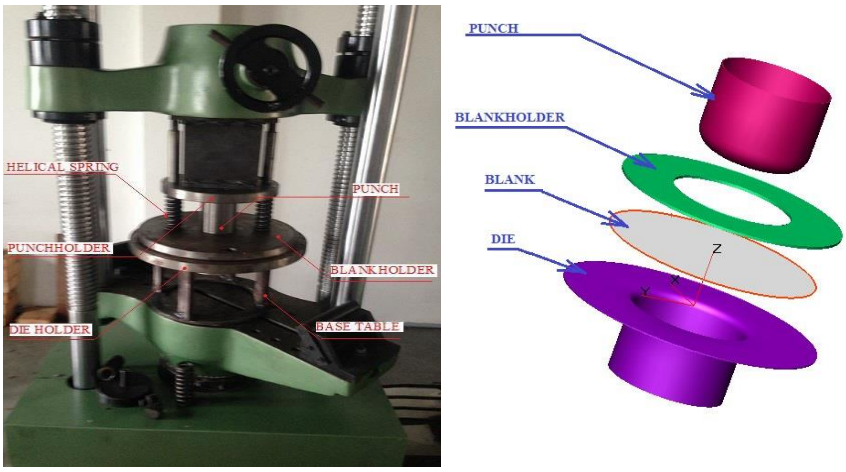
2 Experimental and FE simulation works

The design and fabrication of deep drawing tool setup requires a background knowledge of blank size used, size of the cup produced and process / tool parameter selected. The tool setup shown in Fig. 1 consists of various components such as die, punch and blank holder. The blank holding was done by means of spring loaded mechanism. The setting of correct blankholder force was applied by proper tightening of the nut to compresses the helical spring with the use of digital torque wrench . The blankholder force was calculated using the equation 1.

$$F_b = S_i \, . \, dl \, . \, n \tag{1}$$

where
F_b = Blankholder force,
S_i = Spring index,
dl = Change in length of the spring,
n = no. of springs used

The different sizes of blanks from AA6111 aluminum alloy were prepared by laser cutting. The different sizes of the blanks prepared from 100 mm to 160 mm with 10 mm increment in diameter [8] are 100 mm, 110 mm, 120 mm, 130 mm, 140 mm, 150 mm and 160 mm. The maximum size of the blank prepared is about 15-20 % more than the critical size of the blank.



(a) (b)

Fig. 1. Deep Drawing tool setup (a) Physical model, (b) CAD model

Table 1. Tool parameters used for CAD, simulation and experimentation

Punch	Diameter	80 mm
	Nose Radius	5.5 mm
Die	Inner diameter	81.5 mm
	Shoulder radius	5.5 mm
Blankholder	Inner diameter	85 mm
	Outer Diameter	250 mm
	Thickness	30 mm
Blank	Diameter(s)	120 – 140 mm
	Thickness	0.9 mm

The deep draw tests were conducted to check the quality of each cup produced. It was observed that the cups were drawn successfully for the blank sizes of 100 mm, 110 mm, 120 mm, 130 mm and 140 mm diameter and shown in Fig. 2 to Fig. 8. The punch load vs. punch displacement recordings were shown in Fig. 9 and it confirms that the punch load was minimum at the beginning of the draw and gradually increases to a maximum and then again falls to a minimum at the end of the process as shown in Fig. 9. The simulation tests were also conducted for the same experimental tests. A 3D modeling software CATIA was used for the design of deep drawing model and PAM-STAMP finite element simulation software package was used for analysis. The blanks of 100 mm, 110 mm, 120 mm, 130 mm, 140 mm, 150 mm and 160 mm were tested and the simulated results are shown in Fig. 2 to Fig. 8. In both experimental and simulation tests, the blank diameters of 100 mm, 110 mm, 120 mm, 130 mm and 140 mm were drawn successfully and from 150 mm onwards the cups drawn were failed due to wrinkling and / or fracture.

3 Experimental Comparison

When experimental results were compared with the simulation results, in terms of deformation and stress distribution, they are very well matching. It was observed from the FLD diagram that the induced strains in the cups produced using 100 mm, 110 mm, 120 mm, 130 mm and 140 mm blanks were well below the critical limit. But in the case of cups drawn using 150 mm, and 160 mm blanks were found that the induced strains are above the critical limit strains and the produced cups were failed due to wrinkles and/ or cracks.

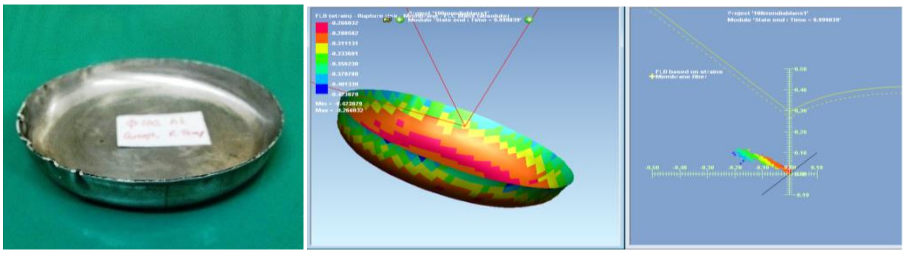


Fig. 2. FLD diagram and experimentally drawn cup with 100 mm diameter AA6111 alloy blank

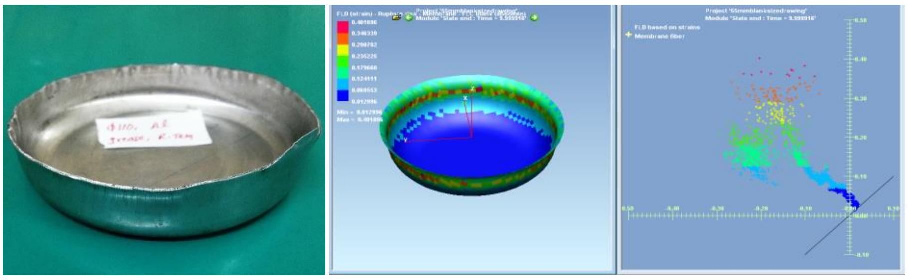


Fig. 3. FLD diagram and experimentally drawn cup with 110 mm diameter AA6111 alloy blank

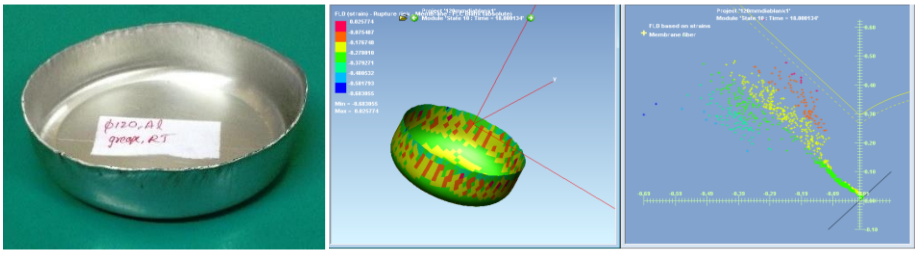


Fig. 4. FLD diagram and experimentally drawn cup with 120 mm diameter AA6111 alloy blank

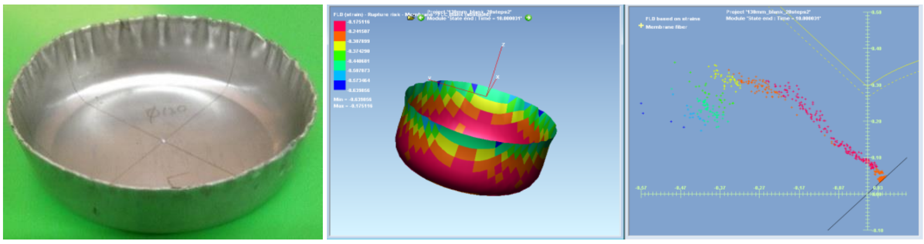


Fig. 5. FLD diagram and experimentally drawn cup with 130 mm diameter AA6111 alloy blank

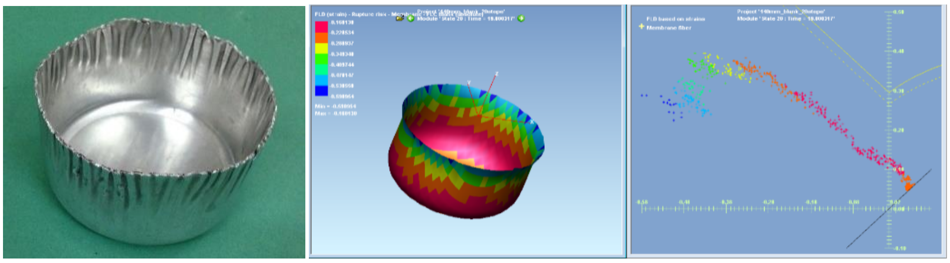


Fig. 6. FLD diagram and experimentally drawn cup with 140 mm diameter AA6111 alloy blank

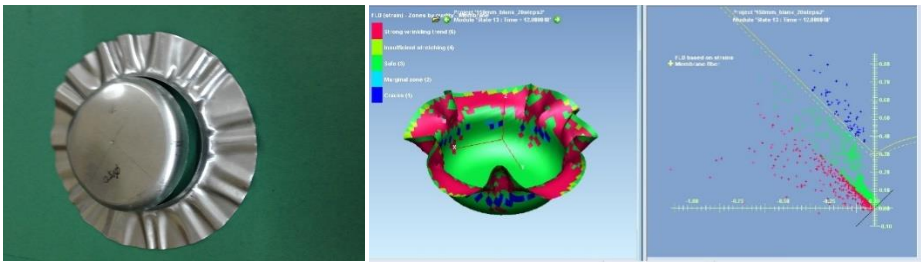


Fig. 7. FLD diagram and experimentally drawn cup with 150 mm diameter AA6111 alloy blank

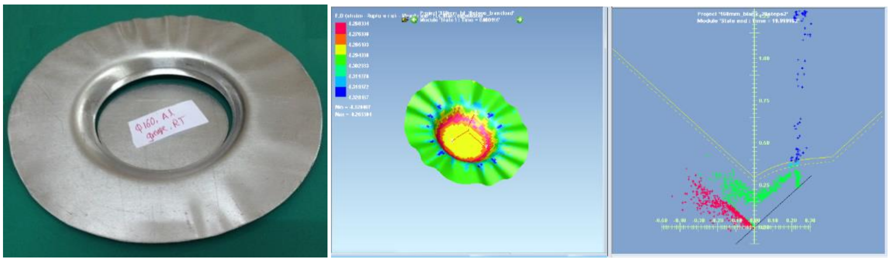


Fig. 8. FLD diagram and experimentally drawn cup with 160 mm diameter AA6111 alloy blank

4 Results

The Fig. 2 shows the cup experimentally drawn and the simulation results for 100 mm blank. The maximum punch load is 9.08 kN. Similarly from Fig. 3 to Fig. 8 shows that the maximum punch load for 120 mm, 130 mm, 140 mm, 150 mm, 160 mm and 170 mm are 12.04 kN, 13.91 kN, 15.57 kN, 18.5 kN, 19.78 kN, 19.78 kN and 19,78 kN respectively. The formed cups along with the FLD diagram were also shown. The Fig. 9 shows the relation between punch load vs. punch depth. It can be readily inferred from the Fig. 10 that, the maximum punch load is linearly proportional to blank size for all drawn cups without failure and remains constant with all cups failed by fracture.

It can be observed in Fig.10 that the critical size of the blank is the intersection of the fracture limit load line and the successfully drawn load line and found to be 146.6 mm. The Limiting Drawing Ratio (LDR) is the ratio of the highest value of blank diameter to the punch diameter which can be drawn without failure. The LDR was calculated as 146.6 mm/80 mm = 1.8325, where 146.6 mm is the highest drawn blank diameter obtained from the graph while using punch size of 80 mm.

5. Conclusions

The experimental deep drawing process was studied with different black diameters and also FEM analysis for comparison. The following conclusions were drawn from the current study.

1. FEM results are very close match to the experimental results.
2. The maximum punch load drawn is linearly proportional to blank diameter up to critical diameters and remains constant thereafter.
3. The critical diameter found through this study for AA6111 alloy was 146.6mm.
4. The Limiting Drawing Ratio (LDR) of 1.8325 was obtained.

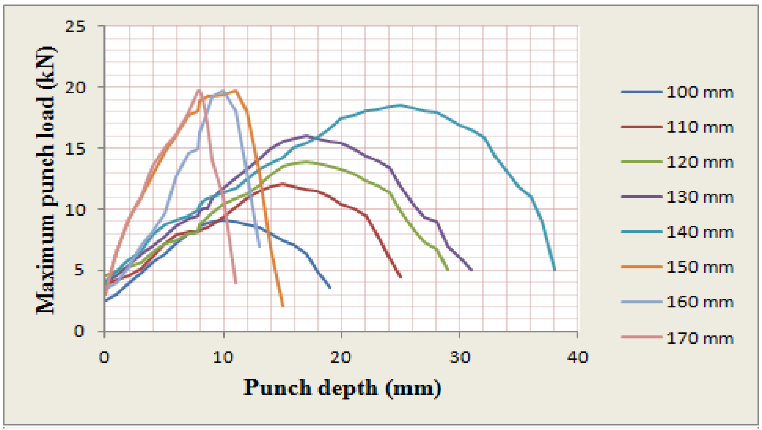


Fig. 9. Punch load vs. punch displacement diagram for different blank sizes

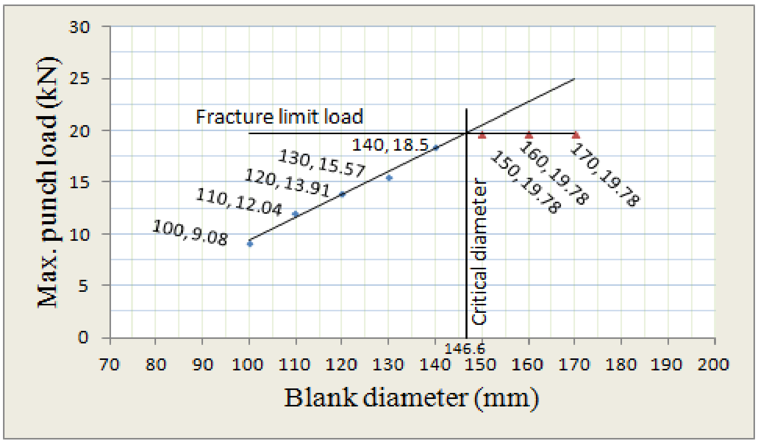


Fig. 10. Graphical determination of critical diameter of the blank

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4. EDITORIAL BOARD