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The experimental investigation of drawing parameters on the deep drawing of Al1050 sheets in angular deep-drawing dies

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The deep drawing process of sheet plate takes an important place in metal forming. The drawing ratios with traditional deep-drawing dies used in industry are limited. In order to obtain optimal process parameters, the geometries of die/blank holder and punch radiuses are particularly important factors. In this study, we investigated the effects of blank holder and die shapes for Al1050 sheet metal. We measured the distribution of blank holder force (BHF), forming load at different drawing depths as well as thickness reduction of cup wall thickness for each set of matrix and blank holder geometries. The experimental implementation has shown that the angular dies are effective way to promote deep drawability of Al1050. Deep drawing ratios with matrix / blank holder angle designed have been increased about 10 % larger than those that usually can be obtained by a conventional die.

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Keywords: Limit drawing ratio (LDR), Deep drawing, Al1050, Angular deep drawing die

1. Introduction

Deep drawing is a sheet metal forming process that is commonly used in industry due to its efficiency. In deep drawing a sheet metal blank is drawn over a die cavity using a shaped punch. As the blank is drawn radially inwards the flange undergoes radial tension and circumferential compression [1]. The latter may cause wrinkling of the flange if the draw ratio is large, or if the cup diameter-to-thickness ratio is high. A blank-holder usually applies sufficient pressure on the blank to prevent wrinkling [2]. The radial tensile stress of the flange is entirely governed by the punch. Hence, when drawing cups at larger draw ratios, increased radial tension requires higher tensile stress of the material. Bending and unbending over the die radius are also provided by this tensile stress on the cup wall. In addition, the tension on the cup wall should help to overcome frictional resistance at the die interfaces. However, in Aluminum alloy sheets are inferior in press formability compared to the mild steel sheets. Most of the aluminum alloys have an R-value (plastic anisotropy value) between 0.7 and 1.0. Nonetheless, even though the R-values for the aluminum alloys are only about half of steel, they show, under the right circumstances, quite satisfactory drawing behavior [3, 4]. Among the aluminum alloys some noticeable differences in forming behavior on the stamping shop floor have been observed, like the relationship between the materials, die design and test parameters, etc., and the deep drawability may change with alloy systems. While many of the general metallurgical and die design principles that promote enhanced deep drawing are understood, the researches to improve the formability of aluminum sheet are still insufficient. Moon et al. showed, due to plastic anisotropy value of material AL1050, the maximum draw ratio is about 1.86 [5]. In order to draw deeper cups, alternative processes are used, e.g. hydro-forming, hydro-mechanical forming, counter-pressure deep drawing, hydraulic-pressure augmented deep drawing, air-pressure augmented deep drawing etc. [6, 7]. These processes are relatively slow, and the maximum draw is limited to 1.9 or 2.27 for Al1050 [8]. However, Savas V. et al. developed a new conventional deep drawing die design called as angular deep-drawing die [9-12]. They investigated the change of side wall thickness with the effect to the drawing ratios of the blank holder and matrix angular for low carbon steel. Their studies showed that the limit drawing ratios (LDR) obtained from these angular deep drawing die are close to hydro-mechanical and etc. In this study, we aim to increase deep drawing ratio (β) and decrease blank holder forces (BHF) at the deep drawing of Al1050 sheet metal by using the die and blank holder with an angle (α). In order to increase deep drawing ratio, a new type deep drawing die was designed and the validity of the developed design was demonstrated experimentally [9]. This novel die design enabling higher drawing height than that achieved in the conventional deep drawing process, and the principle of the process is explained in this paper. Results of experiments conducted using aluminum alloyed (Al1050) blanks of thickness of 0.8 mm to draw cylindrical cups are reported here. Using deep drawing dies provided with the aforementioned angles, blank thickness change was investigated, the changes in deep drawing ratio and blank holder force were determined. Measured drawing load, drawing height and thickness distributions were compared with those obtained from the conventional deep drawing die.

2. Material and methods

In this study, Al1050 aluminum blank with high formability and at a thickness of 0.8 mm was used (Table 1).

Table 1. Chemical properties of aluminum sheet metal.

Al	Fe	Si	Mn	Cr	Others
99.5	0.278	0.102	0.0042	0.0034	0.1124

Tensile tests were carried out in rolling directions of 0^0, 45^0, and 90^0 and with 4 mm/min of tension speed using a tensile test machine (Shimadzu-100 kN) and the results are given in Table 2.

Table 2. Mechanical properties in the tensile direction.

Specimen angle to rolling direction	**Yield strength (MPa)**	**Tensile strength (MPa)**
0^0	114	125
45^0	123	132
90^0	126	135

The extensive experiments have been carried out with strips and circular blanks to investigate the effect of different matrix/blank geometry. The experimental setup used for deep drawing is schematically shown in Fig. 1, containing of die, blank holder and punch, and spring and piston. The experiments have been carried out using a 60 kN hydraulic press with a die cushion to control the BHF and limit the switch to determine a stroke of upper ram at a fixed punch velocity of 4 mm/s.

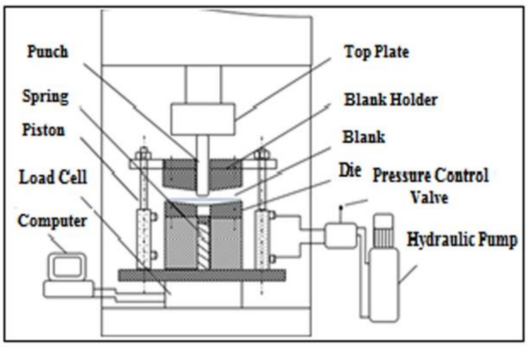

Fig. 1. The experimental setup used for deep drawing.

The die is placed in the die holding device precisely to maintain a uniform clearance and precise alignment with the punch. The blank holder is mounted on three hydraulic cylinders that exert a preset blank holder force during the drawing process. A Constant clamping force to the blank holder was used throughout experiments for all three hydraulic pistons to ensure the formation of a complete nondefective cup and to prevent wrinkling of the blank. The blank holder force is measured by means of hydraulic pressure.

The punch speed was fixed at 4 mm/min, considering literature [5]. In order to punch force, a load-cell (Pan Cake load cell, 20 tons) was placed under the bottom die. Precision of the load-cell is ±2 N. The load-cell was connected to a computer using a RS232 special cable and punch force values was recorded on a PC.

Die sets having seven different angles (blank holder and matrix) and a punch were designed and manufactured. The punch profile radius (Rp) and the die corner radius (Rm) were kept constant at 6 mm considering the literature [5] for comparison of the results. A punch with a diameter of 30 mm and a die diameter of 31.9 mm is used with 0.95 mm of clearance as shown Fig. 2.

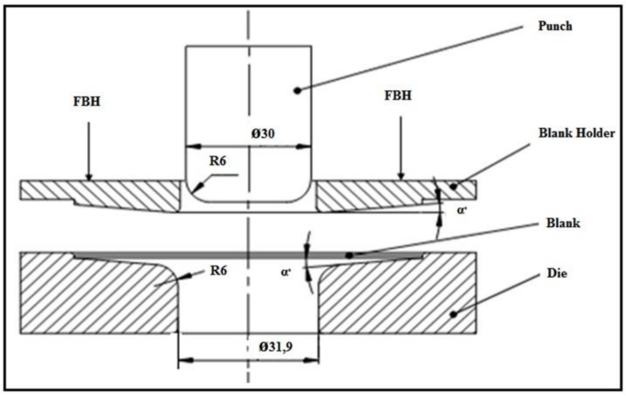

Fig. 2. A new type deep drawing die.

The BHF was applied to the blank, and then the punch was moved into the die hole. The deep drawn cup was then removed using the spring-back force. The punch force and stroke have been measured with devices attached to the press counter.

Proper tool steel with appropriate mechanical properties and hardening treatment is used for the materials of the punches and dies. The tools are ground to an appropriate surface finish and a final hardness of 60HRC.

The deep drawn cup has been cut vertically starting from the top to the bottom; the wall thicknesses were measured using a calibrated micrometer (QLR digit) having an accuracy of 1/1000.

3. Results and discussion

To investigate the effect of angle (α) on the deep drawability, the LDR is obtained at each process condition. For the calculation of LDR, the maximum blank diameter, this diameter being that below which the blanks will be drawn successfully and above which tearing will occur in the cup wall is determined [13].

Fig. 3 shows the variation of LDR with changing angle (α) for AI-1050. It shows that LDR resulted the most successful for α =12.5^0. β value at this degree is close to hydro-mechanical deep drawing.

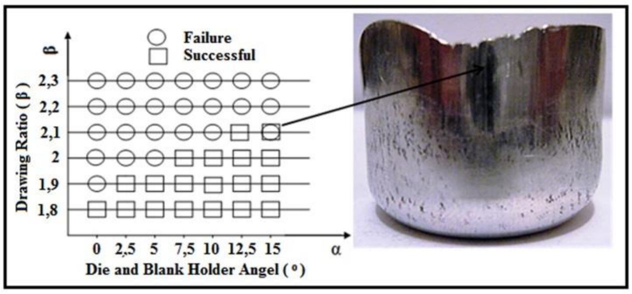

Fig. 3. Relationship between β value and α angle.

However, LDR at the = 15° is successful too, the wrinkles has been partially occurred and this has been accepted as failure (Fig. 3). The results show that the drawing ratio increases with α. For example, β is 1.75 when α=0° and 2.1 when α=12.5°as shown Fig. 4.

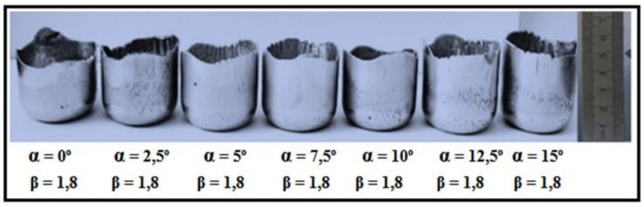

Fig. 4. Relation between β and α and formation of wrinkles

Fig. 4 shows photograph of deep drawn cups at given process conditions. Above figures show that higher LDR is obtained at α=12.5^0. Fig. 3 and 4 show that the wrinkles are occurs for drawing ratios (β) for 2.1 and larger. If α is increased further, the radial force continues to decrease and the favorable effect LDR at α = 15^0 of α is cancelled out due to formation of wrinkles. The reason for the increased 12.5^0 can be explained by thickness profile of cross sectioned cup shown in Fig. 5.

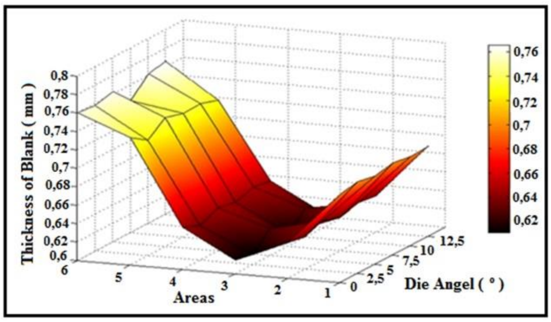

Fig. 5. Changes in thickness vs. position along sectional cut.

Fig. 5 shows that the overall thickness of deep drawn cup and the degree of thickness variation at rounding part are changed in accordance over all angles. The relatively steep decrease in thickness at rounding part that had touched with punch nose radius reflects the local strain has been concentrated on this part. Therefore, the decrease in the degree of thickness variation at the rounding part confirms that the local strain concentration has been relaxed by changing of angle α.

Fig. 5 and 6 shows that the wall thickness varies depending on angle of α along a sectional cut of the cup. It is believed that this is caused by the angle α, which provides improved conditions for the sheet to flow into the die cavity.

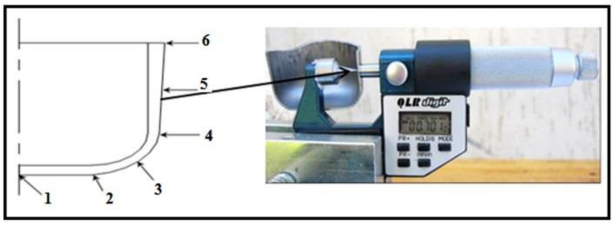

Fig. 6. Changes in thickness vs. position along sectional cut.

Fig. 7 shows the effect of the angle α on the drawing force-displacement curves. In general, an increase in the drawing force is observed for larger blank diameters due to the enlargement of fictional interfaces such as the die-blank and blank holder- blank interfaces. While the figure indicates that the maximum drawing forces are not increased significantly even with increasing maximum blank diameters depending angle α. It means that the angle contributes to the reduction of drawing load possibly by reducing friction between interface of die and blank.

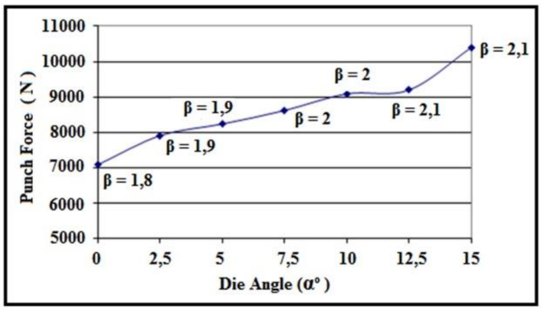

Fig. 7. Influence on punch forces of α angle at the optimal deep drawing.

Angle α created on the interface of die elements does not alter the deformation resistance of deforming sheet blanks. In other words, the angle α provides easier making into the die cavity of sheet blanks and increases LDR of blank. The effectiveness of angle α for aluminum alloy sheets similar to mild steel sheets [7], but, due to plastic anisotropy of aluminum alloy, LDR is less than mild steel sheets. It can be clearly from the figure that when α is increased, punch force required for longer punch strokes decreases giving an optimum at α = 12.5°. Finally, the major principal strain increases up to its critical value and the cup fractures. Fig. 8 shows changing of the blank holder force for optimal LDR. For constant blank diameter, since increasing α angle raises axial force enhancing flow of blank in side die, blank driving force recesses. For example, while the blank holder force is 2.072 kN at α = 0°, it decreases to 1.537 kN at α =5° and 1.036 kN at α =12.5°.

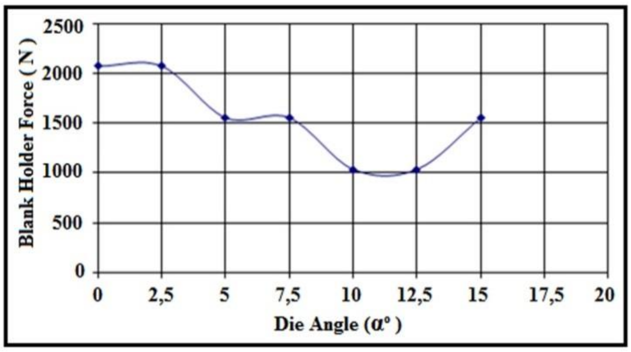

Fig. 8. Influence of α angle on drawing ratio and blank holder force.

The blank holder force gives an optimal value at α=10° and 12.5°. So at the production, these forces are taken at the large values. However, α set over at the die and blank holder decreases. Because of this, If α is further increased, the axial forces (F_1) increases (Fig. 9), causing the flank to flow more easily into the die cavity. In this way, to impede used wrinkle in a value smaller than blank holder force (F_2). Finally, blank holder force decreases from 2.072 kN to 1.036 kN.

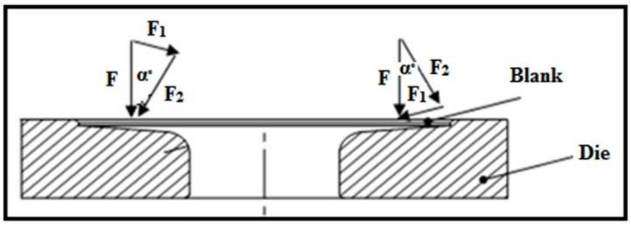

Fig. 9. Radial and axial forces over the blank.

4. Conclusions

In this study, we carried out experiments on a deep-drawing die by setting seven different angles over the die/blank holder. Limit drawing ratio (β) by depending on α has increased without failure from 1.8 up to 2.1. Both energy consumption and cost of dies decreased with the type of dies used in this work. Especially in die manufacturing it can be used at the first-stage drawing instead of twice or three times deep drawing. The following main conclusions can be drawn from this study:

Limit drawing ratio (β) increases with increasing die/blank holder. The highest limit drawing ratio was obtained as β =2.1 at angles of α =12.5°. However, Punch force increased with increasing die/blank holder angle α. According to limit drawing ratio results, the optimal blank holder angle was obtained at angle of α = 12.5° in applied punch forces.

Limit drawing ratio (β) increased with changing of die/blank holder angle because of increasing radial stress and longitudinal circumferential direction stress. This is due to the easy flow of the sheet metal into the die cavity. Increasing α value tend to decrease minimum wall thickness. As a result, the maximum thinning is observed to be less than 11%wt., depending upon the angle α value (α = 12.5°). This results show that limit drawing ratios obtained at angle of α = 12.5° for aluminum sheets are similar to the previous literature studies examined by using matrix angular deep drawing die[9-11].

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