International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 12, December - 2013

Experimental Study on Strain Variation and Thickness Distribution in Deep Drawing of Axisymmetric Components

Prof. A C Sekhara Reddy[1], Dr. S. Rajesham[2], Dr. P. Ravinder Reddy[3]

[1]Dept of Mech. Engg, HolyMary Institute of Technology, Hyderabad,India
[2] Director, TKR College of Engineering, Hyderabad
[3] Professor and HOD, Dept of Mechanical Engineering, CBIT, Hyerabad, India

---

Abstract

Deep drawing process is an important sheet metal forming in which flat sheet metal had been forced through the die in association with the forward punch force and opposing blankholder force. As the blank passes through the tool set converts 2D bank into 3D cup form. The process of achieving the required diameter of the cup can be produced in single stage or multistage operation. In this study, experimental study had been conducted on single stage deep drawing process for assessment of radial strain, circumferential strain and thickness variation in aluminum alloyAA6061. Cylindrical cup deep drawing experimental tests were performed with blank of 350 mm diameter of 0.953mm thickness sheet. It has been found that deeper cups were produced by selecting the optimum design parameters and the results are in good agreement with simulation results found form literature.

***Key words**: Deep drawing, electro chemical etching, FLD, Normal anisotropy, Planar anisotropy plastic strain ratio. Wrinkling, Necking, Tearing*

---

1. Introduction

The wide range of components produced in deep drawing process had been extensively used in automobile, beverage, aerospace, kitchen utensils and its applications include containers of all shapes, cartridge bases, zinc dry cells, metal cans, steel pressure vessels and also in testing of formability of sheet metals like Swift cupping test.

Deep drawing is a sheet metal forming process that still requires a careful and effective research further necessitated for production of defect free products. J Hematian and P M Wild studied the problem of wrinkling on annular blanks by finite element modeling [1]. The process parameters and its analytic applications for non-axisymmetric rectangular cup of multistage deep drawing process using low carbon thin sheet metal had been studied by Beom-Soo Kang, Woo Song and Tae-Wan Ku [2] found that a small change in die entrance angle gives a large variation in the performance of the drawn product. H. Iseki and R.sowerby presented the influence of punch and blank shape, coefficient of friction, blank holder force, die radius on limiting drawing ratio in their numerical analysis [3]. Meharan Mahaboubkhah evaluated forming limit diagram by experimental as well as numerical study and found a difference of 8% between experimental and numerical results [4]. S.Thuillier [5] had conducted experimental and numerical study of reverse re-drawing of anisotropic sheet metals and the experimental results are in good agreement with numerical results for first stage drawing and the results in second stage especially wrinkle formation and punch force estimation were not in good agreement with numerical results when used FEM software(Pam-stamp dynamic explicit shell elements) for simulation. J.Cao and M.C.Boyce studied extensively to delay wrinkling and tearing failures on axisymmetric and square cup deep drawing and had been accurately predicted limiting cup forming height diagrams under constant binder force[6]. Increasing of the drawing depth using tailor rolled blanks were studied by A. Meyer [7] and others by numerical and experimental analysis and concluded that tailor rolled blanks produced cups of increased cup height. The connection between formability and inverse analysis (IA) had been studied by Thaweepat Buranathiti and Jian Cao [8] in triangular cup deep drawing with the use of different blank shapes such as triangular blank, circular blank as well as square blank and found that the blank configuration has highest influence in the forming process of deep drawn triangular cup.

In Deep drawing operation, the desired geometry of the component to be produced is stored in the tool and die assembly and the same has been imparted onto the sheet by inducing resistance to the work piece while passing through the die. The process consists of punch, die, blank holder and work material in the form of thin sheet. The blank is forced by means of the punch to pass through the gap between punch and die in production of hollow cup. The sheet metal can be drawn into simple cylindrical or conic or box-shaped parts and also the complicated parts which normally require redrawing processes using progressive dies. The deep drawing process had been acquired its popularity due to rapid press cycle times, low technical labors requirement and its simplicity. The most important parameters influencing the formability are material properties, tool parameters and friction parameters. Proper selection of these variables is of utmost important in deep drawing to optimize the formability of the sheet blank while producing defect free components that are free from ears, wrinkling, necking, tears, galling and cracks.

2. Basic Theory

Deep drawing process is one of the important sheet metal forming process used to produce cup shaped containers by means of deep drawing tool setup. The tool set up consists of punch that is used to force the sheet blank to flow through the gap between the punch and the die. As a result of this, circular plane blank be formed into cylindrical or conical or box-shaped part in the die according to the tool setup with minimal material wastage. The typical layout of the deep drawing process is as shown in fig 1. There are two types of processes in deep drawing: Pure drawing and ironing. Pure drawing is a deep drawing process without reduction of thickness of blank, whereas ironing is a deep drawing process where in blank thickness reduced during the wall generation. Unlike bulk metal forming, in sheet metal forming bending and stretching in plane stress conditions are the dominant mechanisms, and elongation, anisotropy, residual stress, and springback are considered to be significant factors. As deep drawing of aluminum materials are easily formable and their strengths are lower in comparison to steel. In contrast to that these are widely used due to increased strength due to favorable strain hardening index under forming process. After forming the strength of the material had considerably increased and ductility decreased when the tests were conducted after first draw.

2.1. Drawability

In an idealized forming operation in which drawing is the only deformation process, that occurs by easy flow of blank material under the balanced forces of blank holder and punch that takes place to permit the work material to flow radially into the die cavity without wrinkling and tearing. Deformation takes place in the flange while passing over the lip of the die. It is desirable in drawing operations to maximize material flow in the plane of the sheet and to minimize the material flow in a direction perpendicular to the plane of the sheet. Low flow strength in the plane of the sheet is preferred in comparison to thickness direction. Low flow strength in plane of the sheet is of no use unless higher flow strength even in thickness direction. The flow strength of sheet metal in the thickness direction is difficult to measure and hence the plastic strain ratio *r* is used to compare strengths in the plane and thickness directions by determining true strains in these directions under tension test. For a given metal strained in a particular direction, *r* is a constant expressed as

$$r = \frac{\varepsilon_w}{\varepsilon_t} \qquad (1)$$

where ε_w is the true strain in the width direction and ε_t is the true strain in the thickness direction. Sheet metal in general is anisotropic in nature due to rolling process. That is the properties of the sheet are different in different directions. It is therefore necessary to use the average of the strain ratios measured at 0^0, 45^0 and 90^0 to the rolling direction of the sheet to obtain an average strain ratio called as normal anisotropy and is expressed as in equation 2.

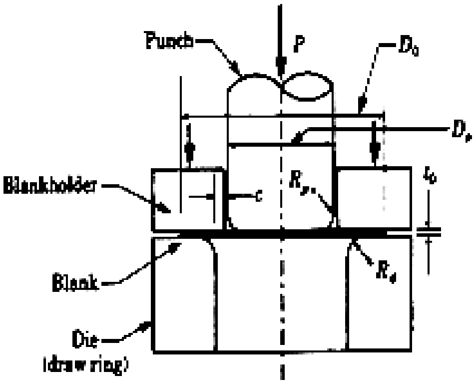

Fig 1: Deep drawing tool setup

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

where r_0 is the strain ratio in the longitudinal direction, r_{45} is the strain ratio measured at 45° to the rolling direction, and

r_{90} the strain ratio in the transverse direction. If flow strength is equal in the plane and thickness directions of the sheet, then $\bar{r} = 1$. For $\bar{r} > 1$, is the case where the strength of the sheet along normal to plane greater that of average strength of along the plane. When, $\bar{r} > 1$, the material resists for uniform thinning and hence the material is of superior in drawing process. In general higher the $\bar{r}$ value, deeper is cup formed in deep drawing process. Variations of flow strength in the plane of the sheet is termed as planar anisotropy represented by Δr and is expresses as

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

where Δr is the variation in strain ratio. Planer anisotropy is the cause for ears formation in the cup top and leads to uneven height of the cup that needs to perform do trimming process after drawing operation. A perfectly isotropic `material would have $\bar{r} = 1$ and $\Delta r = 0$. These two parameters are convenient measures of plastic anisotropy in sheet metals. The drawability is also a measure of formability and it can be expressed in terms of a limiting drawing ratio or percentage of reduction based on results of Swift cup testing. The limiting drawing ratio is the ratio of the diameter D of the largest blank that can be successfully drawn to the diameter of the punch d. Mathematically it can expressed as

$$\mathrm{LDR} = \frac{D}{d} \quad (4)$$

and the Percentage of reduction would then equal to 100(D-d)/D.

3. Mechanical Testing

The material testing had been performed under tensile testing machine. Tensile testing had been performed to determine yielding as well as anisotropic properties of the material. The composition of aluminum alloy AA6061 is as follows.

Aluminum	97.8%
Magnesium	1.0%
Silica	0.6%
Copper	0.8%
Chromium	0.2%

3.1 Evaluation of material properties

The material used in this study is the aluminum alloy AA6061 having Silicon and Magnesium as an alloying elements is an important aluminum that is more versatile for heat treatment. It is having excellent formability and corrosion resistance and having wide applications such as rivets, bolts, nuts as well as deep drawn product. Testing samples specimen were prepared as shown in fig 2 from a rolled sheet of 0.953 mm thickness had already heat treated for reliving residual stresses induced while rolling process. The tensile tests were carried out according to ASTM standard. To omit the edge effects associated with shearing processes, uni-axial testing specimens were cut by wire EDM, to eliminate errors resulted from misalignment of tensile testing. The tests were carried out along different rolling directions of the sheet. The specimens were tested along the three directions at room temperature, with the tensile axis being parallel (0^0), diagonal (45^0), and perpendicular (90^0) to the rolling direction of the material used, and the tensile test apparatus was INSTRON 8516 with the capacity of 100KN. The various mechanical properties of sheet metal that were evaluated from tensile testing of sheet metal is as follows.

Poisson's ratio	0.33
Elastic modulus (GPa)	75
Tensile strength (Mpa)	115
Yield strength (Mpa)	48
Elongation (%)	25
Hardness (HB500)	60
Strain hardening exponent n	0.27
Anisotropy factor r_0	0.935
Anisotropy factor r_{45}	0.388
Anisotropy factor r_{90}	0.640

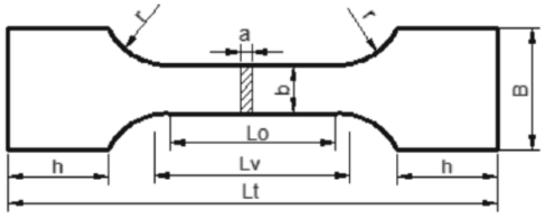

Fig 2: specimen for tensile test

Table 1: parameters for specimen preparation

All dimensions are in mm							
a	b	B	Lo	Lv	r	h	Lt
0.953	8	20	28	33	4	12	65
0.953	5	15	21	24	3	10	50

4. Experimental procedure

The experimental setup consists of 200T double acting press as show infig.3 had been provided with deep drawing tool setup. The drawing force, die fillet radius, clearance between punch and die are the most important considerations in efficient forming of the cup. The drawing force can be calculated from theoretical equations based on plasticity theory or from empirical equations. The maximum drawing force $F_{d,max}$ required to form a round cup can be expressed by the following empirical relation

$$F_{d,max} = n\pi d t \sigma_u \tag{5}$$

where σ_u is the tensile strength of the blank material *d* is the punch diameter, *t* is the sheet thickness and *n* is the ratio of drawing stress to tensile strength of the work material (i.e., σ_d/σ_u). The length of stroke and the force required at the beginning of the working portion of the stroke are both important considerations. Parts that have straight walls can often be drawn through the die cavity and then stripped from the punch and ejected from the bottom of the press.

Fig.3: Mechanical press used in deep drawing process

4.1 Deep drawing tests

The experiment had been performed so as to investigate the deformation pattern, radial and circumferential strain and thickness distribution. Appropriate specifications had been selected for punch diameter, nose radius of the punch, diameter of the die, fillet radius of the die; blank holder force and other parameters are selected as follows.

Punch diameter	150mm
Punch nose diameter	5mm
Die opening diameter	152.5mm
Die corner radius	8mm
Lubrication	Teflon film
Friction coefficient on punch	0.24
Friction coefficient on die	0.12
Blank holder force	2000kgf

An Aluminum alloy sheet AA6061 of 0.953mm thick was carried out on 200T double acting mechanical press as shown in fig 3. During the drawing process the ram of the tester moved at the rate of 1mm/s. The blank of 350 mm diameter and thickness of 0.953 mm (20 gauge) had been selected and electro chemically etched on one side with 2.5mm diameter circular grids were etched as shown specimen fig 4. While deep drawing the blank is influenced to bending, unbending, stretching and compression and finally obtained the shape of cup as shown in fig 5.

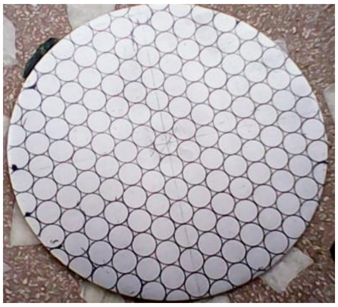

Fig 4: Electro chemical etched sample

Circle grid analysis is a best practical method used in measurement of strains at different locations of the sheet and to assess the formability in comparison with FLD. Indeed, it is a practically viable method and while forming, the grid circles had been deformed into ellipses of different major and minor diameters. The major diameter and minor diameter of ellipses can be measured experimentally in finding of both major and minor strains. The major strain and minor strain values measured from centre of the cup bottom to the top edge of the rim had been plotted as shown in fig 6. The drawn cup had also been cut into two halves and measured for thickness variation form bottom of the cup to the top most point of the wall and the values are plotted in fig 7. The goal of using circle grid strain analysis is to predict potential problems before they become severe problems. Strain analysis is also useful during tool development that helps to predict and limit the problems during production stage itself. Strain analysis can also helps in assessing the process parameters to be adopted while going for use of higher grade materials or even in use of increased thickness of the material.

Fig 5: Deep drawn cups

5. Results & Conclusions

In this study, forming of aluminum alloys has been studied and the strain distribution and thickness variations were measured in the laboratory with the use of microscope for accurate measurement of readings of major and minor diameter. The obtained results are in good agreement results presented else ware in the literature. The circumferential as well as radial strains are as plotted in the fig.6. The fig 6 shows the plot of radial tensile strains as well as circumferential compressive strains measured from centre of the cup bottom to the extreme height of the cup formed. It has been observed from the results that there is no variation in the grid circle diameter in the bottom of the cup as this area is not subjected to stresses and hence no strain inducement. The change in the shape of the grid circle had been observed from the bottom of the wall only and major diameter is gradually increased from bottom to the top of the cup wall. Similarly minor diameter which is the indicator of minor stress responsible for compressive strain gradually decreased from wall bottom to top of the cup, and the results are as shown in fig 6. These results are in good agreement with the results found from previous literature.

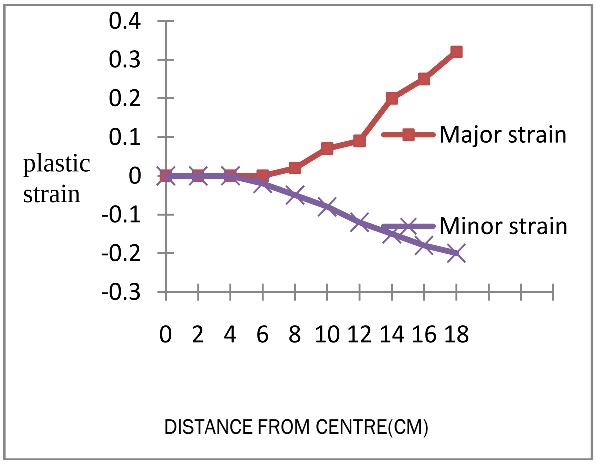

Fig.6: measured radial and circumferential strains

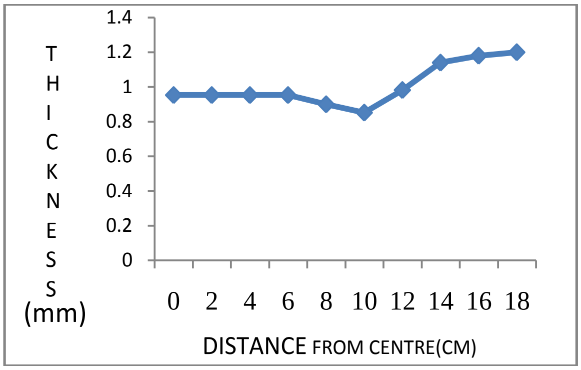

Fig 7: Distribution of sheet thickness

5.1 Conclusions

The drawing mechanism and inflow of material and variation in major strain, minor strain while under going deep drawing process and also thickness variation were investigated. It had been found that the bottom of the cup is not subjected to any strains as well as no variation in thickness. But the thickness variation as well as strain inducement started at the bottom corner of the cup wall and all the values such as major strain, minor strain and thickness variation increased while moving towards the top end of the cup.

References

1. J. Hematian, P M Wild, (2000) , Initial imperfections and the initiation of wrinkling in the finite element modeling of deep drawing, *Proceedings of the institution of Mechanical Engineers, Part E: journal of process Mechanical Engineering 214:63. DOI:10.1243 0954408001530227* pp 63-73.

2. Beom-Soo Kang, Woo Song and Tae-Wan Ku , (2010) , Study on process parameters and its analytic applications for non-axisymmetric rectangular cup of multistage deep drawing process using low carbon thin sheet, *International Journal of Manufacturing* , Techno49, pp 925-940.
3. H.Iseki and R.Sowerby. (1993), A method of evaluating limiting drawing ratio, *Journal of Material Engineering and Performance*,Volume2(1), pp107-112
4. Meharan Mahaboubkhah, (2013), Determination of the forming limit diagrams by using the FEM and experimental method, *Journal of Mechanical Science and Technology* 27(5), pp 1437-1442
5. S.Thuillier,P.Y.Manach, L.F.Menezes, M,C, Oliverira, (2002), Experimental and numerical study of reverse re-

drawing of anisotropic sheet metals, *Journal of Material Processing Technology* 125-126, pp 764-771

6. J.Cao, M.C.Boyce, A Predictive Tool for Delaying Wrinkling and Tearing Failures in sheet metal forming(1997), Journal of Engineerin materials and Technology, Transactions of ASME, vol119, pp 354-365
7. A.Meyer, B.Wietbrock, G.Hirt,(2008), Increasing of the drawing depth using tailor rolled blanks – Numerical and experimental analysis, International Journal of Machine Tools & Manufacture, 48, pp 522-531.
8. Thaweepat Buranathiti and Jian Cao (2007) Inverse Analysis to Formability Design in a Deep Drawing process, *Journal of Solid Mechanics and Materials Engineering* Vol.1, No.6, pp796-804