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# INFLUENCE OF DRAWING RATIO ON THICKNESS VARIATION ALONG THE WALLS OF DEEP DRAWN CUPS

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## ABSTRACT

Deep drawing is the process of converting a flat blank into cup shaped articles. In this process a punch forces the blank to take the shape of die cavity. In the deep drawn cups the thickness of the sheet metal varies throughout the walls of cup. This is undesirable as non uniform thickness leads to defects like cracks or failures. As thickness variation depends upon several parameters like limit drawing ratio, drawing force, sheet material, geometry of blank etc. it can be minimized by selecting optimum process parameters. In this work the effect of drawing ratio on the thickness distribution along the walls of deep drawn cup is performed. An experimental study is carried out using various drawing ratios, and materials which give small difference between maximum and minimum thickness distribution along the cup. It is found that the thickness variation (thinning) is maximum at the bottom corner radius of the cup which is a source of initial fracture.

**Keywords:** *Thickness variation, deep drawing, sidewalls of cup, thinning.*

## 1. Introduction

Deep drawing is one of the extensively used sheet metal forming processes in the industries to have mass production of cup shaped components in a very short time. In deep drawing, a flat blank of sheet metal is shaped by the action of a punch forcing the metal into a die cavity. Deep drawing products in modern industries usually have a complicated shape, so these have to undergo several successive operations to obtain a final desired shape. It is used to manufacture complicated parts from sheet metal and in many industries such as automobile, aerospace, appliance, cooking pans, containers, sinks, automobile parts such as panels and gas tanks and so on. Fig.1 shows schematic diagram of deep drawing process.

The equipment for deep drawing processes involves a double action press, one for the blank holder and one for the punch. Both mechanical and hydraulic presses are used in manufacturing industry. Typically the hydraulic press is slow but can control the blank holder and punch separately, but a mechanical press is faster. Punch and die materials, for the deep drawing of sheet metal, are usually tool steels and cast steel. The shape of a deep drawn part is not limited to a circle or square, more complex contours are possible. However, as the complexity goes up, the manufacturing difficulties increase rapidly.

In deep drawing process there are several defects which occur like wrinkling, earning, excessive thinning of cup and rupture of the blank. These defects usually occur due to unsuitable or non optimal variables in deep drawing process. By controlling these parameters it is possible to get defect free components. In deep drawing for many calculations the sheet metal thickness is assumed to be constant. In the deep drawn cups the thickness of the sheet metal varies throughout the walls of cup. This is undesirable as non uniform thickness leads to defects like cracks or failures. As thickness variation depends upon several parameters like limit drawing ratio, drawing force, sheet material, geometry of blank etc. It can be minimized by selecting optimum process parameters. In this work the effect of drawing ratio on the thickness distribution along the walls of deep drawn cup is performed.

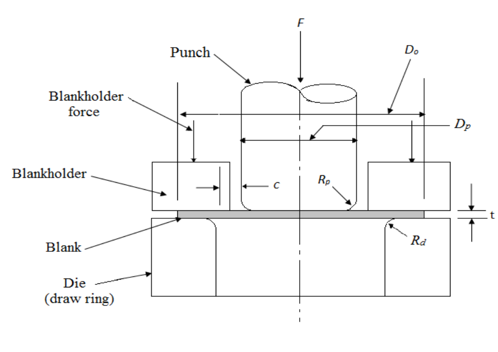


**Fig.1 schematic diagram of deep drawing process**

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The objective of this work is to vary the drawing ratio, blank size and blank material and investigate variation in side wall thickness .This will further enable us to predict and prevent formation of crack. In addition to this the minimum clearance required to be maintained between the punch and die during ironing operation can be determined using this information. Hence it can be said that prediction of thickness variation is as important as the forming severity prediction.

($D_p$ = Punch diameter, $D_o$ = Blank diameter, $R_p$ = Punch corner radius, $R_d$ = Die corner radius, t = Sheet thickness, C = Clearance)

## 2. Literature review on Thickness variation

In deep drawing the sheet metal thickness varies throughout the process. The thickness variation depends on process parameters. Several research works have been reported to evaluate thickness variation. Claudio et.al. [1] has simulated deep drawing process for steel sheets to predict values of maximum punch force, in-plane principle deformation and thickness distribution in the sheet. The performance of model has been assessed by Erichsen test and the deep drawing of a cylindrical cup. The model then has been applied to simulate industrial sheet metal forming process consisting of the deep drawing of a component of a commercial washing machine. Brabie et.al. [2] has investigated the thickness variation in the case of micro/milli- cylindrical drawn cups made from foils, having thickness from 0.05 to 0.20 mm. A mathematical model has been proposed based on experimental and numerical simulation results to control and minimize the thickness variation in the part wall where the variations of part diameter, wall inclination and wall curvature can generate negative effects. Natarajan et.al. [3] has simulated deep drawing of circular blanks considering the axis-symmetric component using finite element techniques. A rigid plastic material model with the variation approaches are used in the finite element analysis. Amount of draw and flange thickness variation have been determined numerically and verified experimentally, for this the circumferential and radial strains have been calculated. Aluminium 1100-O grade material has been taken to analyse hemispherical cup drawing. Signorelli et.al. [4] has investigated effect of process parameters on product surface finish and thickness variation in hydro-mechanical deep drawing process. In this research the effect of process parameters like pre- bulge pressure, cut off pressure and oil gap in hydro forming process are investigated. The results have shown that pre-bulging pressure affected the cup quality in terms of thickness distribution and surface finish. It has been observed that there is a region where uniform thickness distribution and better quality surface is obtained during drawing process. Also it has been observed that in hydro-mechanical deep drawing more uniform thickness is obtained along the cup wall as compared to conventional deep drawing. Peled et. al. [5] has used Cosserat theory of a generalized membrance to evaluate thickening of the blank including strain rate and strain hardening. The proposed analytical approach has the capability to calculate rate of thickening of the blank, the current radius, the current stress applied at blank holder and the current punch load. Thiruvarudchelvan et. al. [6] has carried out theoretical analysis, finite element analysis and experimental work to determine correlation between the forming parameters of the process and to determine the mechanics of the process. The process has been simulated using the commercial FEM code MARC considering elastic-plastic behavior. The Experimental work has been conducted using the tooling assembled on a 200 ton press. This investigation has suggested that the wall thickness is quite uniform except for the area near the punch nose radius when drawing cups at the three draw ratios 3.0, 3.3 and 3.5. This research suggests as drawing ratio increases thinning increases. Tahir et.al.[7] made an attempt to obtain fem solution of sheet thickness variation on verified it experimentally. The material considered was DIN EN 101-30-99 steel and the software used was Autoform. 3 different values of BHF were used in the study to obtain thickness values at various locations of the drawn cup. S M Magar et.al. [8] conducted study to understand the effect of yield strength, drawing ratio and blank holding force on thickness distribution for cup shaped components without flange. Both numerical and Experimental studies were carried out. The materials considered were EDD quality steel and DD quality steel. Three different drawing ratios with blank diameters (Φ360, 370 and 314) and (220,170) were considered. It was concluded that thickning of cup wall took place by 3-10% for increase in yield strength and drawing ratio. Further with higher values of yield strength and drawing the phenomenon of thinning of cup bottom and thickning of cup walls declined. Najimeddin et.al.[9] made an attempt to study theoretically and experimentally the flange thickness variation by taking into account work hardening. The sheet metal used in this research was 2 mm thick with 148.5 mm diameter carbon steel sheet according to German Standard DIN-EN10130-FePO4-(st14). Through their study an analytical model was developed to calculate the radial, circumference, thickness, and equivalent strains of drawn cup by taking into account work hardening effect. Prof A C Sekhara Reddy et.al. [10] conducted studies on single stage deep drawing process for assessment of radial strain, circumferential strain and thickness variation in aluminium alloy AA6061. Cylindrical cup deep drawing experimental tests were performed with blank of 350 mm diameter of 0.953mm thickness sheet. It has 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. Mrs Ketaki N. Joshi et.al. [11] investigated the effect of die draw radius, sheet thickness and blank holder force on the variation in wall thickness of a deep drawn cup using finite element simulations. The variation in wall thickness is minimized by carrying out analysis of variance (ANOVA) for individual factors and their interactions.

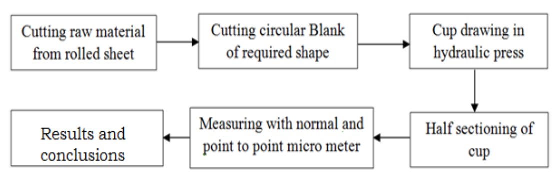
Swadesh singh et al.[12] have performed studies on hydro mechanical deep drawing in which LDR has been determined by using blanks of various diameters. Simulations were performed using LSDYNA software. The material used was carbon steel (deep drawing grade) with sheet thickness 0.96mm. It was concluded that by using this process more uniform thickness distribution could be obtained. Dr. A.D.Younis et al.[13] studied the effect of drawing ratio in deep drawing process on the thickness distribution along the cup. Both experimental and numerical analysis were carried out on various drawing ratios (1.484, 1.589, 1.739, 1.908, 2.12 and 2.332). The diameter of the cup drawn was 82 mm, height 22mm and sheet thickness 1mm. The material used was mild steel. In this work the commercial FEM code (ANSYS 9) has been used to simulate the process of deep drawing operation. The simulation results showed that the best drawing ratio was 1.484 which gave small difference between maximum and minimum thickness distribution along the cup. C. Ozek et al. [14] made an attempt to determine the effect of various radi of die and punch, limit in drawing ratio and die/blank holder angles on the wall thickness using DIN EN10130-91 sheet material. The diameter of cup used for analysis was 30 mm. The die/blank holder profile with angles of $\alpha = 2.5^0$, $7.5^0$, $12.5^0$, $15^0$ and die/punch profile with radi of R=10, 8, 6, 4mm were used. The experiments showed that the wall thickness decreased with increasing limit drawing ratio, die/blank holder angles and die-punch radius. M.A. Hasan et al. [15] developed a new process for increasing the deep drawbility of drawn clover, rose, star and triangular cross-section cups. It was shown that deeper cups can be successfully drawn by pushing a circular blank metal through a conical die having one of the previous sections of the end of the die cavity. The material used consisted of aluminum and brass. The parameters studied were liming drawing ratio, cup height, strain distributions at die orifice and cup thickness distribution.

These studies suggest that the thickness variation for large diameter cups for Brass, GI, and Steel is not completely investigated yet. Hence this has become a potential area for further studies which has been taken up in this work.

## 3. Methodology

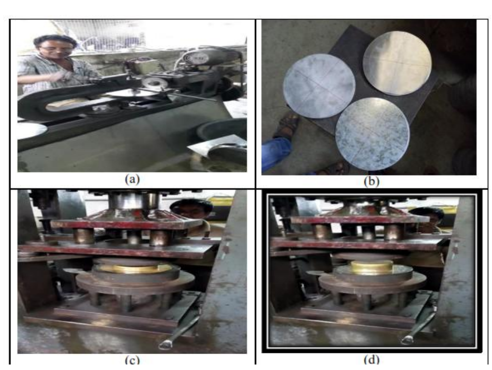
This work is carried out in Metal Industries, Sanathnagar, Hyderabad. The flow charts of methodology is shown in Fig.2. The materials choosen for this work are Brass, Galvenised iron and Stainless steel.

**Fig.2 Methodology of present work**




Initially circular blanks of 4 different sizes for each of the material stated above were cut. The sizes of the blanks cut were based on different drawing ratios viz 1.67, 1.70, 1.72 and 1.81. in all the cases the cup diameter was 140mm. After the blanks were cut, it was followed by cup drawing in hydraulic press. After deep drawing of cups the cups were cut using a fine grinding wheel. Then the thickness along the walls was measured at various points using point to point and normal micrometers. The images of circular blanks cut are shown in figures 3(a) and 3(b). The experimental setup consisting of press and dies used for the present work are shown in figures 3(c) and 3(d). The deep drawn cups made up of brass and G.I are shown in figure 3(e).

Figure 4 indicates sectioning of drawn cups and its measurement along the walls. Fig 4(a) and 4(b) shows cups being cut using fine grinding operation.



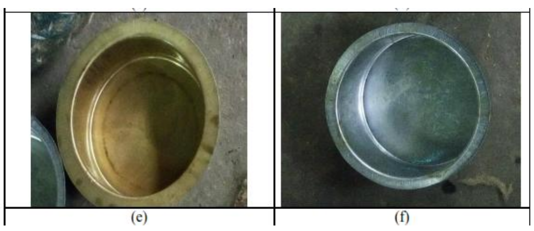



**Fig.3. Circular blanks and cups drawn using Hydraulic press. (a) Blank cutting operation (b) Circular blanks use for making cups (c) Hydraulic press use for deep drawing operation (d) Closer view of dies use for deep drawing operation (e) Circular cups made up of Brass and GI (f) Circular cup made up of GI.**


**Fig. 4 Setup for cutting circular cups using surface grinding machine and measurement of wall thickness (a) Cups sectioned in the middle using surface grinding machine (b) Cup sectioning operation in progress (c) Cup sectioned in the middle (d) point to point micrometer use for measurements of wall thickness**

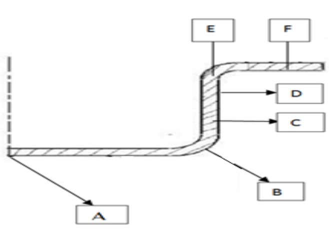



**Fig.5 Thickness Measurement locations**

The half section cups are shown in fig 4(c). The measuring instrument(point to point micrometer) use to measure wall thickness is shown in fig 4(d). The various points at which wall thickness of cup is measured is shown in Fig 5. Distance of measuring point from the centre of cup in mm: A=0, B=65, C=90, D=111, E=128, F=143.

## 4. Results and Discussions

Table 1 to Table 4 show thickness distribution along the walls of deep draw cup for brass material with sheet thickness 0.71mm, cup diameter Φ = 140mm, blank die corner radius is 5mm, punch corner radius 5mm, and cup height 63.5mm.

**Table 1. Thickness distribution along the Brass cup with Drawing ratio (DR) =1.67**

**Sheet thickness : 0.71mm Blank diameter : 234mm**

| Sl. No. | Distance of the measuring point from the centre of cup (mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
|---|---|---|---|---|---|
| 1 | A | 0.71 | 0.71 | 0 | 0 |
| 2 | B | 0.71 | 0.52 | 0.19 | 26.70 |
| 3 | C | 0.71 | 0.63 | 0.08 | 11.26 |
| 4 | D | 0.71 | 0.64 | 0.07 | 9.85 |
| 5 | E | 0.71 | 0.67 | 0.04 | 5.63 |
| 6 | F | 0.71 | 0.69 | 0.02 | 2.81 |

From table 1 it can be seen that the maximum thickness variation (range) = 0.71-0.52 = 0.19mm.

**Table 2. Thickness distribution along the Brass cup with Drawing ratio (DR) =1.70.**

**Sheet thickness : 0.71mm Blank diameter : 239mm**

| Sl. No. | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
|---|---|---|---|---|---|
| 1 | A | 0.71 | 0.71 | 0 | 0 |
| 2 | B | 0.71 | 0.54 | 0.17 | 23.9 |
| 3 | C | 0.71 | 0.64 | 0.07 | 9.85 |
| 4 | D | 0.71 | 0.66 | 0.05 | 7.1 |
| 5 | E | 0.71 | 0.69 | 0.02 | 2.81 |
| 6 | F | 0.71 | 0.70 | 0.01 | 1.4 |

From table 2 it can be seen that the maximum thickness variation (range) = 0.71-0.54 = 0.17mm

**Table 3. Thickness distribution along the Brass cup with Drawing ratio (DR) =1.72**

**Sheet thickness : 0.71mm Blank diameter : 242mm**

| Sl. No. | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$(mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
|---|---|---|---|---|---|
| 1 | A | 0.71 | 0.71 | 0 | 0 |
| 2 | B | 0.71 | 0.51 | 0.20 | 28.16 |
| 3 | C | 0.71 | 0.60 | 0.11 | 15.49 |
| 4 | D | 0.71 | 0.64 | 0.07 | 9.85 |
| 5 | E | 0.71 | 0.53 | 0.18 | 25.35 |
| 6 | F | 0.71 | 0.67 | 0.04 | 5.63 |

From table 3 it can be seen that the maximum thickness variation (range) = 0.71-0.51 = 0.2mm, From table 4 it can be seen that the maximum thickness variation (range) = 0.71-0.53 = 0.18mm .Fig 6(a) to 6(d) shows variation in thickness of walls of brass cup with distance from the centre of the cup for different DR values. Table 5 to Table 8 show thickness distribution along the walls of deep draw cup for GI material with sheet thickness 0.46mm, cup diameter Φ = 140mm, die corner radius 5mm, punch corner radius 5mm, and cup height 63.5mm.

**Table 4. Thickness distribution along the Brass cup with Drawing ratio (DR) =1.81**

**Sheet thickness : 0.71mm Blank diameter : 254mm**

| Sl. No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$(mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
|---|---|---|---|---|---|
| 1 | A | 0.71 | 0.71 | 0 | 0 |
| 2 | B | 0.71 | 0.53 | 0.18 | 25.3 |
| 3 | C | 0.71 | 0.65 | 0.06 | 8.4 |
| 4 | D | 0.71 | 0.67 | 0.04 | 5.63 |
| 5 | E | 0.71 | 0.68 | 0.03 | 4 |
| 6 | F | 0.71 | 0.72 | 0.01 | 1.4 |

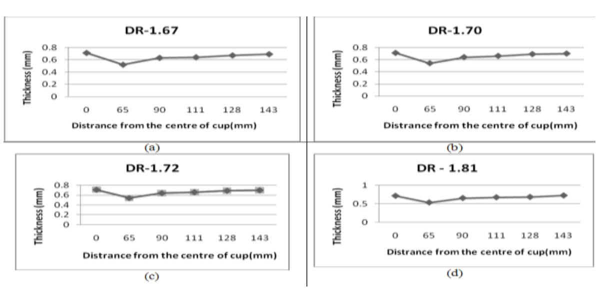



**Fig.6 Thickness distribution at various DRs along the walls of the cup from its centre for Brass Cups (a) DR = 1.67, (b) DR = 1.70, (c) DR = 1.72, (d) DR = 1.81**

For Table 5: Thickness variation range = Thickness maximum value - Thickness minimum value
Thickness variation range = 0.46-0.38 = 0.08 mm

For Table 6: Thickness variation range = Thickness maximum value - Thickness minimum value
Thickness variation range = 0.46-0.36 = 0.1 mm

**Table 5.Thickness distribution along the Galvenised Iron(GI) cup with Drawing ratio (DR) =1.67**

**Sheet thickness : 0.46mm Blank diameter : 234mm**

| S.No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
|---|---|---|---|---|---|
| 1 | A | 0.46 | 0.46 | 0 | 0 |
| 2 | B | 0.46 | 0.38 | 0.08 | 17 |
| 3 | C | 0.46 | 0.42 | 0.04 | 8 |
| 4 | D | 0.46 | 0.43 | 0.03 | 6.52 |
| 5 | E | 0.46 | 0.44 | 0.02 | 4.52 |
| 6 | F | 0.46 | 0.45 | 0.01 | 2.17 |

**Table 6: Thickness distribution along the Galvenised Iron(GI) cup with Drawing ratio (DR) =1.70**

**Sheet thickness : 0.46mm Blank diameter : 239mm**

| S.No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
|---|---|---|---|---|---|
| 1 | A | 0.46 | 0.46 | 0 | 0 |
| 2 | B | 0.46 | 0.36 | 0.1 | 21 |
| 3 | C | 0.46 | 0.41 | 0.05 | 10 |
| 4 | D | 0.46 | 0.43 | 0.03 | 6.52 |
| 5 | E | 0.46 | 0.42 | 0.04 | 8.6 |
| 6 | F | 0.46 | 0.44 | 0.02 | 4.34 |

For Table 7: Thickness variation range = Thickness maximum value - Thickness minimum value
Thickness variation range = 0.46-0.39 = 0.07 mm

For table 8: Thickness variation range = Thickness maximum value - Thickness minimum value
Thickness variation range = 0.46-0.36 = 0.1 mm

Fig.7(a) to Fig.7(d) show variation in thickness of walls of GI cup with distance from the centre of the cup for different Drawing Ratios (DR).

**Table 7. Thickness distribution along the Galvenised Iron(GI) cup with Drawing ratio (DR) =1.72**

| Sheet thickness : 0.46mm | | | Blank diameter : 242mm | | |
|---|---|---|---|---|---|
| Sl. No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference = $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
| 1 | A | 0.46 | 0.46 | 0 | 0 |
| 2 | B | 0.46 | 0.39 | 0.07 | 15.21 |
| 3 | C | 0.46 | 0.43 | 0.03 | 6.52 |
| 4 | D | 0.46 | 0.45 | 0.01 | 2.17 |
| 5 | E | 0.46 | 0.40 | 0.06 | 13.04 |
| 6 | F | 0.46 | 0.46 | 0 | 0 |

**Table 8. Thickness distribution along the Galvenised Iron(GI) cup with Drawing ratio (DR)=1.81**

| Sheet thickness : 0.46mm | | | Blank diameter : 254mm | | |
|---|---|---|---|---|---|
| Sl. No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
| 1 | A | 0.46 | 0.46 | 0 | 0 |
| 2 | B | 0.46 | 0.34 | 0.12 | 26 |
| 3 | C | 0.46 | 0.42 | 0.04 | 8.6 |
| 4 | D | 0.46 | 0.44 | 0.02 | 4.34 |
| 5 | E | 0.46 | 0.45 | 0.01 | 2.37 |
| 6 | F | 0.46 | 0.46 | 0 | 0 |

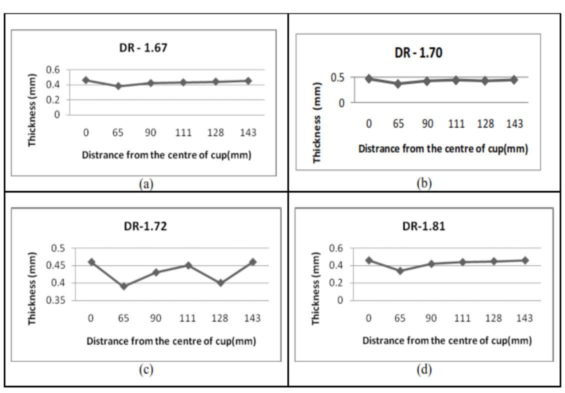



**Fig.7 Thickness distribution at various DRs along the walls of the cup from its centre for GI (a) DR = 1.67, (b) DR = 1.70, (c) DR = 1.72, (d) DR = 1.81**

Table 9 to Table 12 show thickness distribution along the walls of deep draw cup for stainless steel material with sheet thickness 0.42mm, cup diameter Φ = 140mm, die corner radius 5mm, punch corner radius 5mm, and cup height 63.5mm.

**Table 9. Thickness variation along the Stainless steel (SS) cup with DR =1.67**

| Sheet thickness:0.42 mm | | | Blank diameter: 234 mm | | |
|---|---|---|---|---|---|
| Sl. No. | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
| 1 | A | 0.42 | 0.42 | 0 | 0 |
| 2 | B | 0.42 | 0.37 | 0.05 | 11.9 |
| 3 | C | 0.42 | 0.39 | 0.03 | 7.14 |
| 4 | D | 0.42 | 0.40 | 0.02 | 4.76 |
| 5 | E | 0.42 | 0.39 | 0.03 | 7.14 |
| 6 | F | 0.42 | 0.45 | -0.03 | -7.14 |

Thickness variation range = Thickness maximum value - Thickness minimum value Thickness variation rang e= 0.45-0.0.37 = 0.08mm

**Table 10. Thickness variation along the Stainless steel (SS) cup with DR =1.70**

| Sheet thickness : 0.42mm | | | Blank diameter : 239mm | | |
|---|---|---|---|---|---|
| Sl. No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
| 1 | A | 0.42 | 0.42 | 0 | 0 |
| 2 | B | 0.42 | 0.36 | 0.06 | 14.28 |
| 3 | C | 0.42 | 0.38 | 0.04 | 9.52 |
| 4 | D | 0.42 | 0.39 | 0.03 | 7.14 |
| 5 | E | 0.42 | 0.37 | 0.05 | 11.9 |
| 6 | F | 0.42 | 0.42 | 0 | 0 |

Thickness variation range = Thickness maximum value - Thickness minimum value Thickness variation range = 0.42 - 0.36 = 0.06mm

**Table 11. Thickness variation along the Stainless steel (SS) cup with DR =1.72**

| Sheet thickness:0.42mm | | | Blank diameter: 242mm | | |
|---|---|---|---|---|---|
| Sl. No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Diffe.= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
| 1 | A | 0.42 | 0.42 | 0 | 0 |
| 2 | B | 0.42 | 0.37 | 0.05 | 11.9 |
| 3 | C | 0.42 | 0.40 | 0.02 | 4.76 |
| 4 | D | 0.42 | 0.38 | 0.04 | 9.52 |
| 5 | E | 0.42 | 0.39 | 0.03 | 7.14 |
| 6 | F | 0.42 | 0.42 | 0 | 0 |

Thickness variation range = Thickness maximum value - Thickness minimum value Thickness variation range = 0.42-0.37 = 0.05mm.

**Table 12. Thickness variation along the Stainless steel (SS) cup with DR =1.81**

**Sheet thickness: 0.42mm** **Blank diameter: 254mm**

| Sl. No | Distance of the measuring point from the centre of cup in(mm) | $t_0$ (mm) | $t_i$ (mm) | Difference= $t_0$-$t_i$ (mm) | Percentage variation ($t_0$-$t_i$ /$t_0$ x 100) |
|---|---|---|---|---|---|
| 1 | A | 0.42 | 0.42 | 0 | 0 |
| 2 | B | 0.42 | 0.35 | 0.07 | 16.67 |
| 3 | C | 0.42 | 0.40 | 0.02 | 4.76 |
| 4 | D | 0.42 | 0.39 | 0.03 | 7.14 |
| 5 | E | 0.42 | 0.36 | 0.06 | 14.28 |
| 6 | F | 0.42 | 0.43 | -0.01 | -23.8 |

Thickness variation range = Thickness maximum value - Thickness minimum value Thickness variation range = 0.43-0.35 = 0.08mm

Fig 8(a) to Fig 8(d) show variation in thickness of walls of stainless steel (SS) cup with distance from the centre of the cup for different DR values.

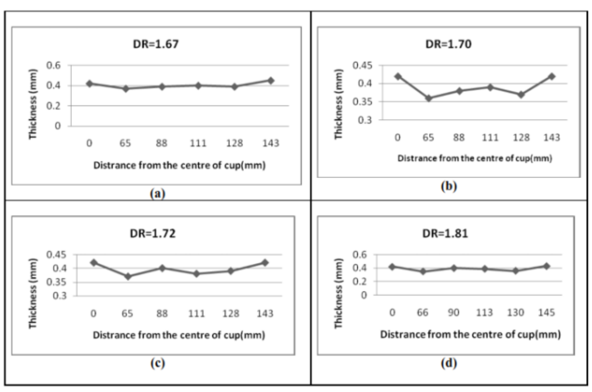



**Fig.8 Thickness distribution at various DRs along the walls of the cup from its centre for Stainless Steel (a) DR = 1.67, (b) DR = 1.70, (c) DR = 1.72, (d) DR = 1.81**

The Table 13 shows minimum thickness variation range for different materials and for different Drawing Ratios. It is seen that in all the three cases Drawing Ratio of 1.72 has minimum thickness variation (Range).

**Table 13. Thickness variation Range for different values of Drawing Ratio (DR)**

| MATERIAL BRASS: | | MATERIAL GI: | | MATERIAL SS: | |
|---|---|---|---|---|---|
| DR | Min. thickness variation (Range mm) | DR | Max. thickness variation (Range mm) | DR | Max. thickness variation (Range mm) |
| 1.67 | 0.19 | 1.67 | 0.08 | 1.67 | 0.08 |
| 1.70 | 0.17 | 1.70 | 0.10 | 1.70 | 0.06 |
| 1.72 | 0.20 | 1.72 | 0.07 | 1.72 | 0.05 |
| | | 1.81 | 0.1 | 1.81 | 0.08 |

Figure 9 shows bar graph of minimum thickness variation (range) for different sheet thickness values. It is seen that with increase in sheet thickness the minimum thickness variation (range) also increases.

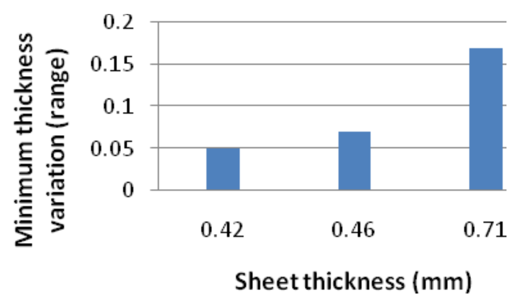



**Fig. 9 Bar Graph showing minimum thickness variation range for different sheet thickness**

After analyzing the variation in wall thickness it is further required to develop an equation or an empirical model which will readily gives us the required value of thickness from the centre of cup. This is achieved by carrying out regression analysis using minitab17. The equation obtained by carrying out regression analysis is given below :

Regression Equation for brass with DR=1.7: ti = 0.6191 + 0.000355 dis --------- (1)

Regression Equation for GI with DR=1.67: ti = 0.4377- 0.000041 dis ------------ (2)

Regression Equation for SS with DR=1.72: ti = 0.4068 - 0.000097 dis ------------ (3)

Here dis=distance from centre of cup, ti = wall thickness and DR= drawing ratio. On calculating percentage error for every measured value it is found that the error is within the acceptable limits (6%) for most of the observations. Hence the developed empirical models may be treated as fairly accurate and can be used to predict wall thickness from centre of cup. Table 14 shows percentage error between actual value and value obtained using empirical model for brass cup with DR= 1.7. Similarly %error for GI and SS were calculated and checked for accuracy.

**Table 14. Percentage error between actual value and calculated value using model.**

| Measuring Distance from center of cup | Actual wall thickness (mm) | Calculated values of thickness using empirical model (mm) | % error |
|---|---|---|---|
| 0 | 0.71 | 0.61 | 14% |
| 30 | 0.65 | 0.63 | 3.07% |
| 45 | 0.60 | 0.635 | 5.8% |
| 65 | 0.54 | 0.642 | 18.8% |
| 80 | 0.58 | 0.647 | 11.5% |
| 90 | 0.64 | 0.651 | 1.71% |
| 100 | 0.65 | 0.654 | 0.61% |
| 111 | 0.66 | 0.658 | 0.303% |
| 120 | 0.68 | 0.661 | 2.7% |
| 128 | 0.69 | 0.664 | 3.7% |
| 135 | 0.70 | 0.667 | 4.71% |
| 143 | 0.70 | 0.669 | 4.42% |

## 5. Conclusion

It is found that the thickness variation (thinning) is maximum at the bottom corner radius of the cup i.e., 11 – 25%. Hence the bottom corner radius of cup is a source of initial fracture. This is true in all the cases and for different materials

The variation in thickness in cup walls is found to be minimum for drawing ratio 1.72 for brass, GI and stainless steel materials.

The variation in thickness in cup walls is found increase with increase in sheet thickness.

## References


1. *Claudio Garicia Diego Celetano Flores Fernando Ponthot Jean-Philippe and Oliva Omar (2006), "Numerical Modelling and Experimental Validation of Steel Deep Drawing Process Part-II Application", Journal of Material Processing Technology, Vol. 172, 461-471.*

2. *Brabie G Costache E M Nanu N and Chirita Vasile Alecsandri B (2013), "Prediction and Minimisation of Sheet Thickness Variation During Deep Drawing of Micro/Milli Parts", International Journal of Mechanical Sciences, Vol.68, 277-290.*

3. *Natarajan S Venkataswamy S and Bagavathiperumal P (2002), "A Note of Deep Drawing Process: Numerical Simulation and Experimental Validation", Journal of Materials Processing Technology, Vol. 127, 64-67.*

4. *Signorelli Serenelli M J and Bertinetti M A (2012), "Experimental and Numerical Study of the Role of Crystallographic Texture on the Formability of an Electro-Galvanized Steel sheet", Journal of Materials Processing Technology, Vol. 212, 1367-1376.*

5. *Peled A Rubin M B and Tirosh J (2004), "Analysis of Blank Thickening in Deep Drawing Processes Using the Tehory of a Cosserat Generalized Membrane", Journal of the Mechanics and Physics of Solids,Vol.52, 317-341.*

6. *Thiruvarudchelvan S Wang H B and Seet G (1998), "Hydraulic Pressure Enhancement of the Deep-Drawing Process to Yield Deeper Cups", Journal of Materials Processing Technology, Vol. 82, 156-164.*

7. *Tahir Altinbalik (2012), "Numerial and Experimental Study of Sheet Thickness Variation In Deep Drawing Process", International Journal of Modern Manufacturing Technologies, ISSN 2067-3604, Vol. 4, No.2.*

8. *Magar S M (2013), "Studies on Deep Drawing of Steel Cups for the Variation of Yield Strength and Drawing Ratio Using FEA", MIT International Journal of Mechanical Engineering, Vol. 3, No. 1, MIT Publications.*

9. *Najmeddin Arab (2013), "Theoretical and Experimental Analysis of Deep Drawing Cylindrical Cup", Journal of Minerals and Materials Characterization and Engineering, Vol. 1, 336-342.*

10. *Sekhara Redy A C (2013), "Experimental Study on Strain Variation and Thickness Distribution in Deep Drawing of Axisymmetric Components", International Journal of Engineering Research & Technlogy (IJERT) ISSN: 2278-0181, Vol. 2 Issue. 12.*

11. *Ketaki N and Joshi (2014), "Optimization of Variation in Wall Thickness of a Deep Drawn Cup using Virtual Design of Experiments", IRACST – Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498, Vol.4, No.5.*

12. *Swadesh kumar singh and Ravi Kumar D (2004), "Numerical Prediction of Limiting Draw Ratio and Thickness Variation in Hydro-mechanical Deep Drawing", International Journal of Materials and Product Technology, Vol.21, No. ½, 106-123.*

13. *Younis A D "The effect of drawing ratio in deep drawing process on thickness distribution along the cup", Vol. 18, No. 4, Iraq academy of scientific journals (iasj).*

14. *Ozek Cebeli and Muhammet Bal (2009), "The effect of die/punch radius and drawing ratio on the wall thickness in deep drawing dies", Journal of the faculty of engineering and architecture of Gazi university, Vol. 24.1, 33-41.*

15. *Hassan M A Hassab-Allah I M Hezam L M A Mardi N A and Hamdi M (2015), "Deep Drawing of Asymmetric Cups through Conical Die without Blank Holder", In Proceedings of the World Congress on Engineering, Vol. 2.*

16. *Seah K H W and Lee K S (1987), "Parametric Studies in Deep Drawing", Journal Of Manufacturing Engineering (SME).*

17. *Jenn-terng Gau Chi-Han Chen and Zhong-Yi Yang (2009), "Studying the Micro Deep Drawing Process through Drawing Brass Micro", Journal of Manufacturing Engineering (SME).*

18. *Wilbur A and Cleveland (1985), "Deep Drawing Of Metals", Journal of Manufacturing Engineering (SME).*

19. *Dennis J and Taylor (1993), "Deep Drawing Of Large Parts", Journal of Manufacturing Engineering (SME).*