IMPACT OF DRAWING RATIO AND SHAPE ON THICKNESS DISTRIBUTION 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. Different shapes and sizes of products for automotive bodies, structural parts, utensils and beverage cans are manufactured by this process. Using bimetallic strip in preparing the various products by deep drawing has become the recent trend in manufacturing process. The main reason to carry out such a process is taking the advantages of different materials such as high strength, low density and corrosion resistibility, at the same time and in a single component. The cost of the component gets reduced too. 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.*

This work is related to deep drawing of cups which are made using bimetallic strip. The objective of this work is to study the variation in thickness along the side walls of deep drawn cups which are made using bimetallic material i.e. Cu-Al and also to determine the optimum drawing ratio for producing a cup of specific size. The study was carried out in Amba Bhavani tool crafts and Metal Forming lab of CBIT. In this work the variation in thickness along the walls of cup for three different shapes, i.e: circular, square, heart. were investigated. The studies reveal that the variation in thickness is different for different shaped cups and also the variation in sheet thickness is different when Copper and Aluminium are in turn made as inside surfaces of bimetallic cups.

Key words: *Bimetallic, Deep Drawing, Thickness Variation*

1. INTRODUCTION

1.1 Deep Drawing

Deep drawing is a manufacturing process that is used extensively in the forming of sheet metal into cup or box like structures . Pots and pans for cooking, containers, sinks, automobile parts, such as panels and gas tanks, are among a few of the items manufactured by deep drawing.. A basic deep drawing operation could be the forming of a flat sheet into a three dimensional cup, or a box. 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. It is best to design the shape of deep drawn parts to be as simple as possible. For the primary sheet metal deep drawing process the part will have a flat base and straight sides. The significant independent variables in deep drawing are properties of the sheet metal, the ratio of the blank diameter to the punch diameter, the thickness of the sheet, the clearance between the punch and the die, the corner radii of the punch and the die etc.

Sheet metal thickness is an important aspect of deep drawing process design. Thickness to diameter ratio is a main factor used to quantify the geometry of a blank and can be calculated by t/Db. Thickness is represented by t, and Db is the diameter of the blank. For noncircular sheet metal parts the maximum diameter is sometimes used.

Wrinkling and Tearing are the most common defects which occur during deep drawing. The cup wall which is already formed is subjected to principal longitudinal stress. Elongation causes the cup wall to thin, if excessive it causes tearing. Excessive thinning in areas of the sheet metal is also an unwanted defect. Causes of these are mostly too high or improper force distribution and material considerations. Many times the reduction ratio needs to be evaluated. Ratios for initial reduction are usually 35% to 45%, but can be lower. Usually maximum thinning of the cup wall occurs near the base. For this reason, tearing of the sheet metal is most likely to occur in this region even if the stress is originating somewhere else.

Another reason for the tearing of the sheet metal may be excessive force caused by material impediments, due to an inefficient blank shape. When tearing occurs at the corners of the wall it may indicate a problem with the blank's geometry. Surface finish of the blank is important also, gouges, scratches and pits can all cause propagation of cracks. Blank holder force must be sufficient. However, friction between blank holder, blank and die surfaces will act to resist the movement of the blank's material into the die. Thus, excess friction will increase the force the punch exerts to draw the sheet metal. Higher punch forces usually cause a tear in the weakest spot, predominately in the cup wall near the base. For this reason, the blank holder force must not be too high.

1.2 About Bimetallic Metals

Bimetal refers to an object that is composed of two separate metals joined together. Instead of being a mixture of two or more metals, like alloys, bi-metallic objects consist of layers of different metals. Trimetal and tetra-metal refer to objects composed of three and four separate metals respectively. Bimetallic sheets are formed by explosive welding process. The explosive welding process is capable of joining high surface areas due to its ability to distribute high energy density through explosion. Up to now, similar metals (low carbon steel, steel to steel, Al–Al, stainless steel to steel), dissimilar metals such as steel and Aluminium, steel and titanium, nickel film and Aluminium alloys, iron and Copper, Aluminium, Copper and magnesium, Copper, titanium and steel, Aluminium and Copper and also metallic glasses were cladded successfully

One of the many uses for bimetallic strips is in electrical circuit breakers where excessive current through the strip heats it and bends it to trip the switch and interrupt the current. They are also used in manufacturing products like Clocks, Thermostats, Thermometers, Heat engine, Electrical devices beverage cans, kitchen utensils etc. Some of the applications of bimetallics is shown in Fig. 1.

(a) Beverage Cans (b) Kitchen Utensil

Fig 1. Applications of Deep Drawing Process

1.3 Making Bimetallic Products

The bimetallic cups are drawn from bimetallic strip which in turn is made by rolling a bimetallic billet. The cups are formed from the bimetallic strip by first blanking a disc and then forcing or drawing the disc through a die. The blanking and drawing operations may be performed in rapid sequence, almost simultaneously. This cold forming works the metal to varying degrees, different in different portions of the cup. For instance, there is very little cold work on the base of the cup, a slightly greater amount at the bottom of the side wall and various amounts in the side wall increasing toward the top of the cup.

1.4 Importance of Thickness Distribution

In deep drawing the sheet metal thickness varies throughout the regions of cup . Thickness variation depends on process parameters. But it is of great importance to know the wall thickness profile of drawn cup since thickness distribution will not only influence the material consumption but also dictate structure performance. Using thickness profile as a criterion, fracture point can be estimated experimentally and other forces can also be known.

2. METHODOLOGY

The steps involved in this work are indicated in Fig. 2.

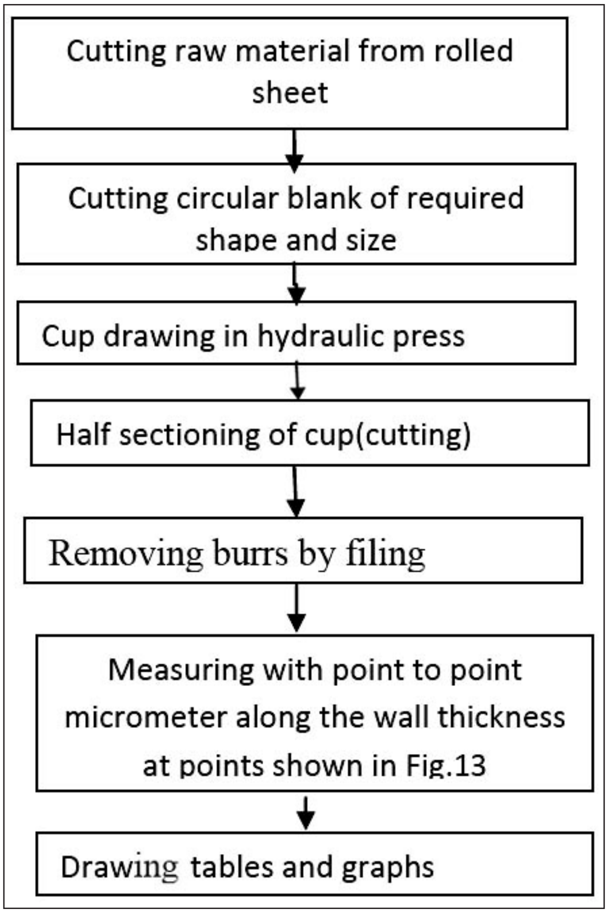

Fig 2. Steps Involved in Carrying out the Present Work

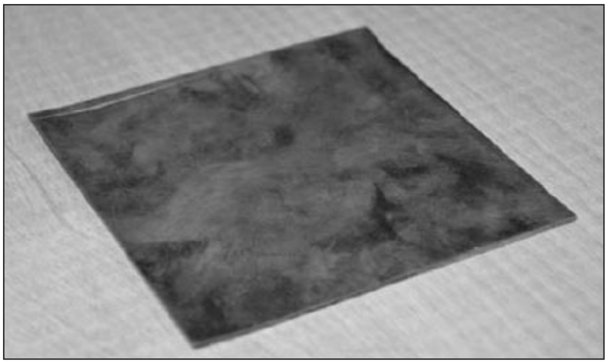

Fig 3. Cu-Al Bimetallic Sheet used in this Work

Cutting Of Raw Material From Rolled Sheet: Raw material is cut from the large rolled sheets into required sizes as shown in Fig. 3.

Cutting Circular Blank Of Required Shape And Size : Blanking is the process of cutting the initial sheet stock into round or shaped flats required for deep drawing. A bimetallic sheet (Al-Cu) is taken and is cut into circular blanks of required sizes by using a blanking die. The required shape is obtained by blanking operation. This circular blank is put in the die and the force is applied. The force acting on the punch is used to draw the cup.

Fig 4. Hydraulic Press used to Draw Cups

Fig 5. Cu- Ai Bimetallic Cup with Cu Inside

Cup Drawing in Hydraulic Press : The blank is then drawn into cups which is shown in Fig. 4. During drawing of sheet into the die, there is thickening of the sheet up to 12%. Therefore, clearance is provided between the punch and die which is equal to the sheet thickness plus the thickening of sheet. Punch pushes the bottom of the sheet into the die cavity. The flat portion of the sheet under the holding plate moves towards the die axis, then bends over the die profile. After bending over the die profile the sheet unbends to flow downward along the side wall. The vertical

Fig 6. Cu- Ai Bimetallic Cup with Al Inside

Fig 7. Square Bimetallic Cup with Cu Inside

Fig 8. Square Bimetallic Cup with Al Inside

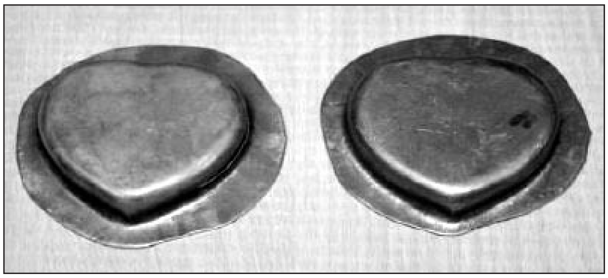

Fig 9. Heart Shaped Bimetallic Cup with Cu Outside

Fig 10. Half Sectioned Circular Cups

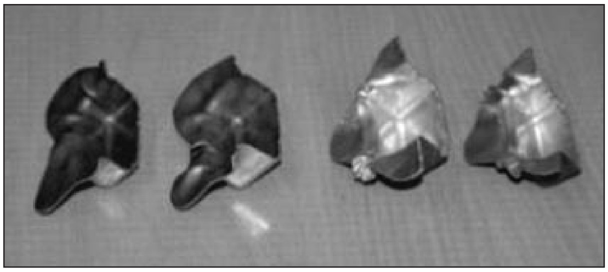

Fig 11. Half Sectioned Square Cups

portion of the sheet then slips past the die surface. More metal is drawn towards the centre of the die in order to replace the metal that has already flown into the die wall. Friction between holding plate and blank and that between die and blank has to be overcome by the blank during its horizontal flow. Fig 5 and 6 show deep drawn bimetallic cups.

Fig 7 and 8 show square shaped bimetallic cups and Fig 9 shows heart shaped bimetallic cups.

Half Sectioning Of Cup: Cutting methods include both mechanical cutting operations such as cutting with a blade, crushing or water jet cutting and thermal operations such as flame or laser cutting. In this work hack saw and grinding wheel are used for cutting. Fig 10, 11 and 12 show cups which are sectioned in the middle.

Removing the Burrs: Some of the burrs get chipped off in sectioning and remaining is removed by fine

Fig 12. Half Sectioned Heart Shaped Cups

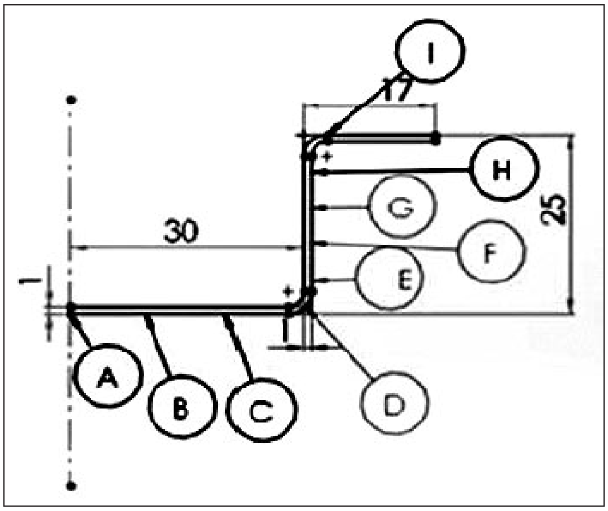

Fig 13. Thickness Measuring Points along the Cup Walls

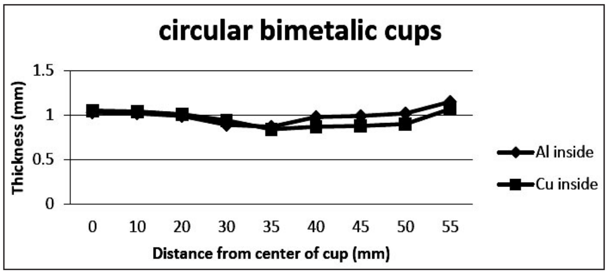

Fig 14. Relationship Between Thickness Variation and Distance from Centre for Circular Cup with Aluminium and Copper inside as Sample 1 and 2

filing tool and emery papers.

Measuring Wall Thickness: The cup that is drawn is cut into two halves using hack-saw and burrs are also removed. . Thickness of the walls is measured by using point to point micrometer at different regions of the cup. It is measured from the center of the half sectioned cup at different points on the wall of the cup as shown in Fig 13.

Specification and Values of parameters used: The various specifications of parameters used in this work are shown in Table 1. Sheet thickness of 1mm is used in this work.

3. RESULTS AND DISCUSSION

Fig 14 shows the variation of wall thickness with distance from Centre of cup for Aluminium - Copper bimetallic circular cup with Aluminium as inside surface for sample 1 and Copper as inside surface for sample 2 of thickness 1 mm. With a blank diameter of 98 mm and cup diameter of 60mm, drawing ratio is found to be 1.63 and cup height is 31 mm. Die and punch corner radii are taken as 5mm.

Thickness is measured from the center of the half sectioned cup at different points on the walls of the cup. It is seen from Fig 14 that the thickness gradually decreases up to E = 35mm and again starts increasing till I=55 mm. Maximum thickness is found to be 1.15mm at the last point I=55 which is flange portion and minimum thickness is found to be 0.87mm at E =35 which is just above the corner point of the cup.

Thickness variation range = maximum thickness value –minimum thickness value

= 1.15-0.87 = 0.28 mm

In the case of sample 2 with Copper inside for sheet thickness 1 mm and with a blank diameter of 98 mm and cup diameter of 60mm, limiting drawing ratio is found to be 1.63 and cup height is 31 mm. It is seen that the wall Thickness decreases upto E=35 mm and then increases from 0.87mm to 1.07 till I=55 mm. Maximum

Table 1: Specifications of Blank Diameter, Cup Dimension and Drawing Ratio used in this Work

S.No	Blank diameter (mm)	Cup diameter (mm)/side	Drawing ratio = D/d
1	98	60	1.63
2	92.5	50	1.81
3	90	65	1.38

Table 2: Values of Minimum Thickness Obtained for Various Shapes

Type of Cup	Shape of cup	Range of Thickness variation in (mm)
Al-Cu Bimetallic Cup (Aluminum Inside)	Circular	0.28
	Square	0.18
	Heart	0.14
Al-Cu Bimetallic Cup (Copper Inside)	Circular	0.23
	Square	0.18
	Heart shaped	0.16

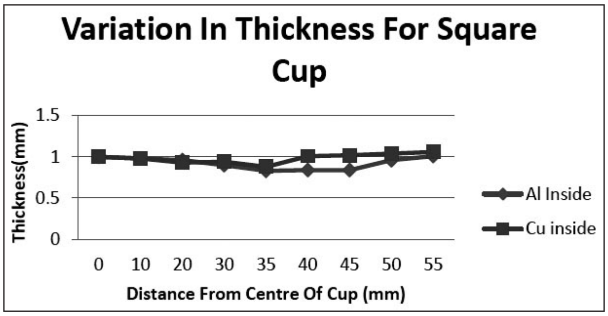

Fig 15. Relationship Between Thickness Variation and Distance from Centre for Square Cup with Aluminium and Copper Inside

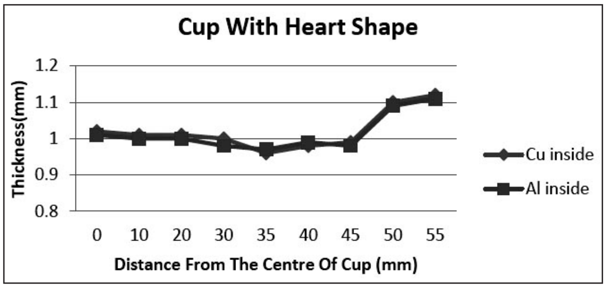

Fig 16. Relationship Between Thickness Variation and Distance from Centre of Heart Shaped Cup

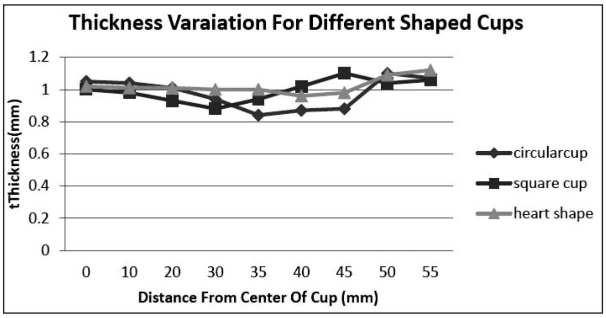

Fig 17. Thickness Variation for Bimetallic Cups of Different Shapes

thickness is found to be 1.07mm at last point I=55 mm which is flange portion and minimum thickness is found to be 0.9mm at E=35 which is just above the corner point of the cup.

Thickness variation range = maximum thickness value – minimum thickness value

= 1.07 – 0.0.84=0.23mm

Fig 15 shows the variation of wall thickness with distance from the centre for Aluminium and Copper bimetallic square cup with Aluminium as inside surface for sheet thickness 1 mm. With a blank diameter of 92.5mm and dimension of side of cup as 50 mm, limiting drawing ratio is found to be 1.8 and cup height is 26 mm. Die corner radius and punch corner radius are taken as 5mm.

It is evident from Fig. 15 that the thickness gradually decreases up to E=35 and again starts increasing till I=55. Maximum thickness is found to be 1.01mm at last point I=55 which is flange portion and minimum thickness is found to be 0.83mm at E=35 which is the point just above bottom corner point of the cup.

Thickness variation range = maximum thickness value –minimum thickness value

= 1.01 – 0.83=0.18mm

For sample 2 (square cup) with Copper as inside surface and with a blank diameter of 92.5mm and with side of cup = 60mm the limiting drawing ratio is found to be 1.8 and cup height is 26 mm. It is seen from Fig.15 that thickness gradually decreases up to E=35 and again starts increasing till I=55. Maximum thickness is found to be 1.06mm at last point I=55 mm which is flange portion and minimum thickness is found to be 0.88mm at E=35 mm which is the region above corner point of the cup.

Thickness variation range = maximum thickness value –minimum thickness value

= 1.06 – 0.88 = 0.18 mm

Figure 16 shows the variation between wall thickness and distance from centre of cup for Aluminium and Copper bimetallic heart shaped cup with Aluminium as inside surface. It is observed that thickness gradually decreases up to E=35 and then increases upto I =55 mm. Maximum thickness is found to be 1.11mm at last point I=55 which is top portion and minimum thickness is found to be 0.97mm at E=35 which is above the corner point of the cup.

Thickness variation range = maximum thickness value – minimum thickness value = 1.11 – 0.97=0.14mm.

For heart shaped cup with Copper as inside surface and with a blank diameter of 90 mm and cup dimension of 60mm the limiting drawing ratio is found to be 1.38. Die corner radius and punch corner radius are taken as 5mm.

It is seen that thickness decreases up to E=35 and then increases till I=55. Maximum thickness is found to be 1.12 mm at last point I=55 which is top portion and minimum thickness is found to be 0.96 mm at F=35mm which is above the corner point of the cup.

Thickness variation range = maximum thickness value– minimum thickness value

= 1.120 – 0.96=0.16mm

Figure 17 shows variation in wall thickness for 3 different shapes Viz. circular, square and heart shaped cups.

The deep drawn cup can be divided into 3 regions Viz. the outer annual region which lies between the die and bottom blank holder, inner annual region which is not in contact with die and punch and the central region of the blank which is only in contact with the punch. The outer annual region under the influence of tensile stress continues decreasing in radius and is subjected to hoops stresses which cause increase in material thickness. The inner annual region undergoes thinning due to plastic bending and sliding under the effect of tensile stresses over the die profile. The bottom of the cup (central region) is not subjected to any strains hence there is no variation in thickness. It can be said that the variation in thickness is due the different regions of cup being subjected to different states of stress and strains. In all the cases From Fig. 14 to 17 it can be seen that the thickness variation as well as strain inducement starts at the bottom corner of the cup wall and all the values such as major strain, minor strain and thickness variation increase while moving towards the top end of the cup. The variation in thickness for different shaped cups may due to the variation in load that is being applied and the outer profile of the cup.

4. CONCLUSION

- It is found that the thickness variation (thinning) is maximum at region just above the bottom corner radius of the cup. Hence this region of cup is a source of initial fracture. This is true in all the cases .
- For deep drawn circular cup with Aluminium as inside surface the minimum thickness variation is found to be 0.28mm and with Copper as inside surface the minimum thickness variation is found to be 0.23mm .
- For deep drawn cup with square shape, minimum thickness variation is found to be 0.18mm in both the cases i.e with Aluminum and Copper as inside surfaces.
- For deep drawn cup with heart shape, the minimum thickness variation is found to be 0.14mm with Aluminium as inside surface and is equal to 0.16mm with Copper as inside surface .
- For deep drawn cup with circular shape, minimum thickness variation is found to be in the case of cups with Copper as inside surface.
- The thickness variation is found to be minimum for Heart shaped cups as compared to circular and Square shaped cups.

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