NUMERICAL AND EXPERIMENTAL INVESTIGATION OF CUP DRAWING PROCESS

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ABSTRACT

The cup drawing process of sheet plate takes an important place in forming metals on account of large of number of applications of such products. The traditional techniques of tool design for sheet forming operations used in industry are experimental and expensive. The cup drawing process is more complicated than most other metal forming operations. Hence a rigorous study was performed to understand the process. An extensive literature survey was performed and critical parameters affecting the process were identified. Die design calculations were done to produce sample cups. Die, Punch and blank holder were fabricated according to this design. The die set was then used to obtain cups from Al 1100, copper and Brass taking the help of a UTM and noting the load pattern. Finite Element Simulation of the cup drawing process using ANSYS 15.0 was also carried with the actual dimensions and properties that have been used in experimentation. Plane185, a four noded element was used to discretize the model. The Die, Punch and Blank holder were treated to be rigid. Axisymmetric condition was applied. Blank material was treated as a mild work hardening type. Load variation with punch travel, Stress pattern in the blank over different stages, thickness changes in the cup bottom and walls were analysed. Those results were found to be appropriate. The loads obtained are in close agreement with experimental values. Hence the simulation performed with material data, friction conditions and rate of loading are realistic. This work would definitely serve as a start up for tool designer and manufacturer doing work in this field.

Keywords: Cup Drawing Process, Anysys 15.0, Utm.

I.   INTRODUCTION

In the various industrial fields 85% of all metal is processed through so called casting operation to obtain products in simple forms like ingots and slabs, and these products are then used for further deformation operations. In manufacturing the deformation processes can be divided into groups depending on temperature, shape and size of the used work pieces and operation type. For example, there are three categories of processes based on temperature as a criterion, which are cold, warm and hot working. In dependence on the type of the deformation operation, the processes can be also classified as primary and secondary working. Primary working operations include taking pieces of metallic products that are generally in a cast state, and then they can be formed into other shaped parts such as slabs, plates and billets. Additional processing can be performed on some of those products through secondary working to produce the final shape of desired components such as bolts, sheet metal parts and wire.
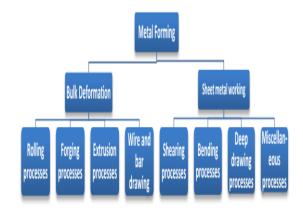

Fig-1: CLASSIFICATION OF METAL FORMING PROCESSES

A. Sheet Metal Forming Processes

Sheet metal working can be generally identified by cutting and forming operations performed on metallic sheets. In order to distinguish between the terms "sheet" and "plate", it is important to realize that the range of sheet thickness is typically from 0.4mm to 6mm, while the term plate usually refers to the product of thickness greater than 6mm. The work metal used in sheet metal forming, whether sheet or plate is produced by rolling, hence the significant importance of sheet metal forming outlines the importance of the rolling process. Traditionally sheet is available as coils if it is thin; otherwise it is supplied as flat sheet or plate. Sheet metal parts are utilized in different industrial applications such as automobile and truck bodies, aircraft, railway cars, farm and construction equipment, beverage cans, kitchen utensils, etc.

Fig-2 AUTOMOTIVE PARTS PRODUCED BY SHEET METAL FORMING

B.Cup Drawing Process

One of the most common and industrial applicable processes in sheet metal forming is cup drawing. It can fabricate a variety of objects with cylindrical, square or even complex shapes by using this technique. Cup drawing is defined as a manufacturing process through which a sheet metal work piece is subjected to tensile and compressive stresses by mechanical punch to press the blank into a die cavity as seen in Figure. The condition of the product to be deep drawn is that the final depth is greater than a half of the drawing punch diameter; otherwise the product is classified as a shallow part. In order to prevent the material blank from flowing freely into the die cavity through the process, a third forming tool, which is named blank holder, is employed to hold down the blank . This technique can be widely applied to manufacture metal products with an aspect ratio larger than unity. Currently, the deep drawing process has an extensive role in aerospace and automobile industries to manufacture structural components, and in computer and communication industries to produce covers and thin-walled part of devices, like laptop, cameras, and CD and DVD drivers. In addition, it is used in fabricating aluminium cans, canisters, sinks, baking pans, oil filters, home décor, etc.

In the Cup drawing technique, the flat piece obtained from a large sheet metal is named blank which is usually clamped on the top surface of the forming die by means of a rigid tool conventionally called blank-holder. In order to obtain a symmetric shape for a defects- free product, the centre point of the blank should coincide exactly with the centre of the die opening. In general, two main resources contribute in providing the force needed to form the sheet metal blank completely. The first force is that used to hold the sheet in contact with the upper surface of the die. This force is known as the blank holding force because it is applied through the blank holder to catch the blank. The other one is provided by the punch. The function of the punch force is to form the blank into the die cavity. Therefore, consequently the main tools required in deep drawing process are a male punch, a female die and a blank holder plate. Usually between the sides of the drawing punch and die, a

particular clearance is embraced and the value of this clearance is about 10% greater than the original blank thickness
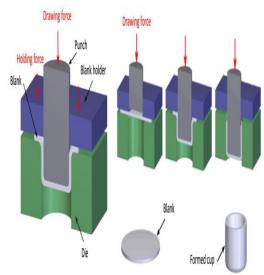

Fig-3: SCHEMATIC ILLUSTRATION OF CUP DRAWING PROCESS

Figureshows simple cup drawing operation of a cylindrical cup with the basic parameters. A rigid punch with a diameter (D_p) and nose radius (R_p) applies a drawing force (F) on a circular blank with initial diameter (D_b) and thickness (tb). Usually the blank is pressed into a die cavity with a corner radius (R_d) and is held down at the flange porting by the blank holder force (F_h). It can be observed that if the corners of the forming punch are sharp (R_p and R_d =0) then a cutting operation would be performed rather than a drawing operation. Also, it is essential to adopt a clearance between the sidewalls of the punch and the die cavity. This clearance is usually about 10% greater than the initial thickness of the blank used.
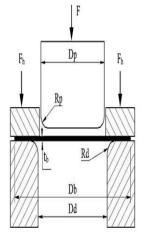

Fig-4: SCHEME OF CUP DRAWING PROCESS

II.   DIE DESIGN

Die is very important part of drawing operation for drawing of the materials. so proper die design ,proper selection of material for fabrication of die is done. In this chapter we design a die for circular cup. The blank used here for the drawing is aluminium, copper, and brass materials. In order to prepare a die with good design, many variables are to be considered such as the die should be dimensionally stable, variations in response to change in temperature need to be minimum, strong and durable, withstand the loads and shocks, finishing procedures are economical and easy to use.

Successful cup drawing depends on many factors. Ignoring even one of them during die design and building can prove disastrous. However, regardless of the many factors involved, the most important element to a successful deep drawing operation is initiating metal flow. The following are key elements affecting metal flow,

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and each of them should be considered when designing, building, or troubleshooting deep drawing dies. The cup drawing die is designed for the shell shown in figure (Aluminium 1100, Copper and Brass blank materials)
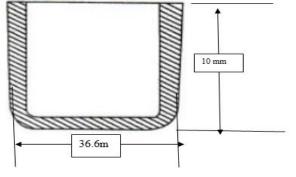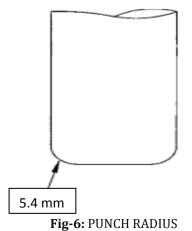

Fig-5: CUP DIMENSIONS

A. Elements of Punch Design

The punch diameter is selected with reference to the internal diameter of the cup to be drawn as shown in the figure. The punch diameter is selected as equal to internal diameter of the cup. Clearance is not necessary between outer diameter of punch and inner diameter of cup.

B. Corner Radius on Punch

There is no set rule for the size of the radius on the punch. A sharper radius will require higher forces when the metal is folded around the punch nosed and may result in excessive thinning or tearing at the bottom of the cup. A general rule to prevent excessive thinning is to design the punch with a radius 4 to 10 to times the metal thickness. If the radius must be less than four times the metal thickness, it may be necessary to form it over a large punch radius and then restrike it to develop the specify radius. The radius may be determined by product design when only one draw is necessary to complete the work piece because the cup bottom takes the shape of the punch nose. First drawing die radius: (6 to 10)t.

The blank size for all the material of our usage is 0.6mm so the punch radius of 5.4 mm is taken.

5.4 mm
Fig-6: PUNCH RADIUS

C.Punch Geometry Design

After selecting the punch diameter and the punch radius, the punch is designed to be held in a UTM machine for drawing operation. The collar of the punch is 45mm diameter and thickness 20mm is added to give additional strength. The length of the punch is the sum of cup height and travel in the die. Air vent is placed at the bottom of the punch because no drawing operation can be successful if appropriate air vents are missing from the body of a punch, as a drawn part has a tendency to stick to the punch around which it is wrapped, and remain there, by the force of vacuum thus created. The air vent is 4.5 mm diameter and 20 mm long inside the punch is shown in the below figure. And some of the standard air vent sizes are shown in below Table.

TABLE 1 Air vent sizes

Punch diameter (mm)	Air vent diameter (mm)
Up to 5	4.5
50 to 100	6.0
100 to 200	7.5
Over 200	10.5

D. Elements of Die Design

The radius on the draw die (draw ring) does not contribute to the cup shape, so as large as possible to permit to full freedom of metal flow as it passes over the radius. The draw ring causes the metal to being flowing plastically and aids in compressing and thickening the outer portion of the blank. However, if the draw radius is too large the metal will be released by the blank holder too soon and wrinkling will result. Too sharp a radius will hinder the normal flow of the metal and cause uneven thinning of the cup wall, with resultant tearing. The general rule is to make the draw radius four times the material thickness. The draw radius may be increased six to eight times the metal thickness when drawing shallow cups of heavy-gauge metals without a blank holder

Draw radius = 4t

        = 4 to 8t when the blank holder is used

In our design draw radius on die is taken as 4t .

Die Geometry

After selecting cup to be drawn and punch geometry, die is designed. For this draw radius on die, die clearance is selected from the above table according to the blank thickness. The height of the die is 40.5 mm and 75 mm diameter. In this above the die 0.5 mm thick wall is created to place the blank. Die land 12 mm is taken according the blank diameter.

E. Die- punch clearance

Die clearance is the gap left between the punch and die to allow for the flow of the work material. Generally enough clearance is left to allow for thicking depending upon the type of operation and the metal. When clearance is equal to the metal thickness or less, ironing or burnishing of the metal will occur near the top of the cup. A certain amount of ironing may be allowable on the more ductile metals from the uniformity of wall thickness is required. Thickness of the blank material is taken as 0.6mm for all the three material so the die clearance is chosen from the below table 3-2 for the first draw as 1.08t – 1.1t

Table draw clearance

t = thickness of the original blank

TABLE 2: Die - Punch Clearance

Blank thickness, mm	Die- Punch Clearance		
	First draws	Redraws	Sizing draw
Up to 0.38	1.07t -1.09t	1.08t-1.1t	1.04t – 1.05t
0.4-1.27	1.08t-1.1t	1.09t-1.12t	1.05t – 1.06t
1.3 – 3.18	1.1t -1.12t	1.12t-1.14t	1.07t – 1.09t
3.5 and Up	1.12t - .1.14t	1.15t-1.2t	1.08t – 1.1t

F. Blank Size

One of the first jobs of the draw die designer is to find the size of the blank to be used to for making a given cup. It is often difficult to find a blank of the exact size required for making a given shell, because of thinning and thickening of sheet during drawing. The calculation could be based on the volume, surface area or by layout.

The following gives the useful relations in calculating the blank diameter for cylindrical shells for relatively thin materials. $D = \sqrt{d^2 + 4dh}$

$D = \sqrt{d^2 + 4dh - 0.5r}$

$D = \sqrt{d^2 + 4dh - r}$

$D = \sqrt{(d - 2r)^2 + 4d(h - r) + 2\pi r(d - 0.7r)}$

Where r = corner radius on the punch

   h = height of the shell

   d= outer diameter of the shell

   D =blank diameter

In our case d/r is 6.5 and for this last formula is used to get the blank diameter D, some extra amount of blank material was included to trim after the drawing operation. In our case d =36.6mm, h =14mm, r = 5.6mm, so a blank diameter of 55mm was obtained.

G. Drawing Force

The amount of force required to shape a symmetrical cup by drawing operation plays a major role in design of die elements. For the different material the drawing force may be vary. In our case aluminium, copper, and brass blanks were used. The drawing force which is used for drawing cup is calculated by below formula.

$$P = \pi dt(UTS)(\frac{D}{d} - c)$$

Where P = drawing pressure

   D = shell OD

   D= blank diameter

   t = thickness of metal

 UTS = Ultimate tensile strength

   C= constant to cover friction and bending (0.6 to 0.7 for ductile materials)

The above formula is applicable to a symmetrical cupping operation only. The stretching and compression of metal in irregular parts is too unpredictable for predicting forces by formula. However, the above formula may be used to some extent in determining approximate forces for work pieces similar in configuration to a symmetrical cup.

 The drawing force is computed from the above formula

TABLE 3

Material	Draw Force Tonnes
Aluminium 1100 drawing force p	1.45
copper drawing force p is tons	3.22
For brass drawing force p is tons	3.66

H. Material Selection for Die Set

A valuable contribution to the successful drawing process is a properly selected die material. The choice is governed mainly by the material strength for die, dimensional stability, variations in response to change in temperature need to be minimum, strong and durable to withstand the designed forces and finishing procedures being economical and easy to use. The material here selected is EN-8 steel. The strength of the EN-8 steel is more than the drawing material. The cup work piece material arealuminium 1100, copper and brass.

III.   FABRICATION OF DIE, PUNCH AND BLANK HOLDER

EN-8 is used for preparation of Die, Punch and Blank holder. Material is drawn from our college work shop with the dimensions of 50mm diameter and 90mm long bar which is used for preparation of Punch. EN-8 steel of 80mm diameter and 100 mm long bar is taken for fabrication of Die and Blank holder.

EN-8 steel bar of 50mm diameter 90mm long bar is taken for manufacturing of Punch, three steps for manufacturing of Punch i,e Facing, Turning, Finishing are carried out.

Fig-7: SCHEMATIC REPRESENTATION FOR MANUFACTURING OF DIE

A. Steps Involved In Manufacturing of Die

There are five basic steps involved in manufacturing of Die.

1. Cutting

2. Facing

3. Turning

4. Drilling

5. Boring

6. Drilling and tapping

Cutting

As stated above the raw material is of dimensions 80mm diameter and 100mm long. We require 75mm diameter and 40.5mm long specimen. So the above long bar is cut into pieces of 50mm long bar, which are used for manufacturing of die. For the cutting purpose we use power saw.

Facing

After the work piece is cut into pieces by power saw, the surface finish of machined surface is not good; in order to get good surface finish the surface is faced, after the facing is done for all the five pieces then they are sent for the next process.

Turning

For the manufacturing of Die, the above 80mm dia and 45mm long should be turned to 75mm dia and 40.5 mm long. After the turning the component is finished then the machined work piece is sent to drilling section. Here Rough turning is done.

Drilling

After the turning process is finished, the machined component is to be drilled, the drill bit used for drilling is 19.58 mm diameter drill bit. The drill should be kept throughout the long bar. We required 40.5mm bore in the die. So we have to go to the boring operation in order to extend the hole to 40.5mm diameter.

Boring

In order to extend the hole from 19.58mm to 40.5mm boring operation is performed. Since the internal hole should have high surface finish, Machining is done at low feed and low depth of cut, after the boring operation is finished in order to get high surface finish, smooth emery paper is used. The use of emery paper gets the inner surface finish.

Tapped holes

For the assembly of Die, Blank holder Tapped holes are to be present in the die and cylinder, for that we are using vertical drilling machine. Tapped hole of size 0.5mm is drilled into the cylinder, Holes are kept at every 90^0 of the cylinder, there by 4 holes in the Die are drilled.

Finishing

In the above step, Die manufacturing is finished. For the drawing purpose high surface finish is required, low friction should be there, Finishing is done with the help of emery paper. There by high surface finish is obtained. The finished component is shown below figure.

FIG-8: DIE

B.Steps involved in manufacturing of Blank holder

1. Facing

2. Turning

3. Drilling

Facing

After the work piece is cut into pieces by power saw, the surface finish of machined surface is not good, in order to get good surface finish the surface is faced, after the facing is done for all the five pieces then they are sent for the next process.

Turning

For the manufacturing of Blank holder, The above 80mm dia and 40mm long should be turned to 75mm dia and 20mm long. After the turning is finished then the machined work piece is sent to drilling section. Here Rough turning is done.

Drilling

After the turning process is finished, the machined component is to be drilled, the drill bit used for drilling is 19.58mm dia drill bit. The drill should be kept for 20mm long. We require 20mm hole in the Blank holder , so we have to go to the boring operation in order to enlarge the hole to 20mm diameter.

FIG.9: BLANK HOLDER

IV.   EXPERIMENTAL PROCEDURE

A. Blank preparation

To prepare blanks, sheets have been cut into square strips approximately 10 mm greater than the required finish size. After that the squares were turned to make circular disks. This ensured that any work hardening effects at the rim of the disk caused by cutting were eliminated. A series of blanks with different material was produced 55mm diameter.

Circular-cups have been formed from circular blanks using a test rig installed on a universal testing machine. The machine jaw speed can be controlled in constant speed. However the punch speed selected for all tests was constant. No lubricated was used to blank and punch.

The material used in this study was aluminium 1100, copper and brass sheet with thicknesses of 0.6 mm and 55 mm diameter which is shown in figure 6.1. For each material, specimens have been cut along sheet during its manufacturing process.
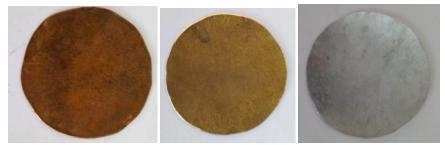

FIG-10: BLANK SHEET METALS ALUMINIUM, COPPER AND BRASS

B. Machine Setup

Experiments were carried out on a 1000-kN universal testing machine. Figureshows the cup drawing apparatus which mainly consists of the punch and the die. The punch including a centering part. Centering part is used for positioning the punch concentrically to the die opening to ensure uniform clearance between the punch and the die aperture. The die consists of 11.5 mm land and 5.2 mm die radius. The die is mounted on the base of a hydraulic press. However, punch mounted on the upper movable jaw of the universal testing machine. The die has long wall which is larger than land to facilitate disposal of drawn cups. At the fixed jaw dial indicator is attached to note the punch movements.

FIG-11: EXPERIMENTAL SETUP

The punch and die of EN-8 Steel were produced by lathe and other machining process. The chemical and mechanical properties of the used materials are shown in appendix. To the punch and die no heat treatment is applied, used in room temperature. All produced punches have flat heads with a profile radius of 5.6 mm, collar 20 mm and punch length 50 mm long. The die was designed to have two zones; the first zone is circular land while the second is wall which diameter is more than the die inner diameter.

C. Drawing Procedure

After the machine setup is completed power on the universal testing machine. With the constant speed punch moves downwards this is attached to the upper movable jaw. When punch touch the blank material load increases with punch travel one by one mm down the movement can seen from the dial indicator. Loads are obtained from the UTM. The punch through the die at the same time blank sheet wrap the die and it pushed toward down to from a cup shape with circular blank sheet. Same procedure was followed to all the materials. The below figure shows the finished cup
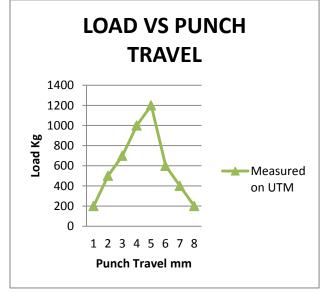
V.   RESULTS

The drawing of cups has been performed with three blank materials viz., Al 1100, Copper and Brass. Pictures below show the cups at the end drawing process. They need further trimming for getting useful form.

FIG-12: DRAWN CUP FROM THE AL 1100, COPPER AND BRASS

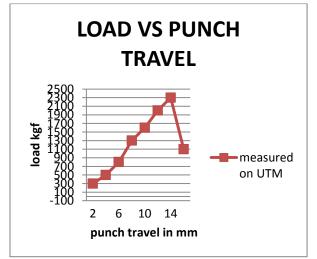Below show the load observed as the punch descends.

FIG-13(A) AL 1100 LOAD VS PUNCH TRAVEL ON EXPERIMENT

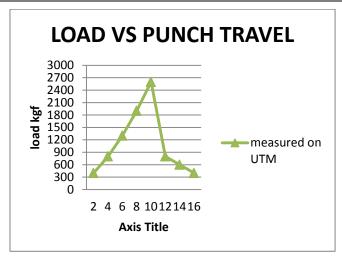**FIG-13(B)** COPPER LOAD VS PUNCH TRAVEL ON EXPERIMENT

FIG-13(C) BRASS LOAD VS PUNCH TRAVEL ON EXPERIMENT

As the punch moving down the load is gradually increasing. The maximum load was observed during the initiation of drawing process. Contact pressure and friction at the point of punch and die radius was increased at middle of the drawing process. The max load has observed at the ending of drawing process. The duration of time to complete drawing process was observed that aluminium and copper were taken less time than brass

VI.   CONCLUSIONS AND SCOPE FOR FUTURE WORK

- The project was successful in investigating the important variables affecting the process.
- The experiments resulted in cups with required dimensions showing that blank diameter calculations were fairly appropriate. Mild trimming of the rim is found to be necessary.
- The load observations are as follows.

TABLE-4(A)

Range of Loads: Material – Al 1100		
	Minimum Load	Maximum Load
Using ANSYS	290kgf	960kgf
Using Experiments	200kgf	1200kgf

TABLE-4(B)

Range of Loads: Material – Copper		
	Minimum Load	Maximum Load
Using ANSYS	453kgf	1935kgf
Using Experiments	300kgf	2300kgf

TABLE-4(C)

Range of Loads: Material – Brass		
	Minimum Load	Maximum Load
Using ANSYS	300kgf	2432kgf
Using Experiments	400kgf	2600kgf

We find that the ANSYS predicted values are mildly under predicted (maximum of 16%). Future work needs to bridge this mild gap. Since the sheet is generally rolled product, a degree of anisotropy would be responsible for this.

- The punch travel Vs load pattern was observed to be similar in both ANSYS simulation and experiments.
- Thickness distribution is obtained by FEA & compared with work of other researchers.
- From the experimental results it observed that the load on aluminium material is smallest compared to the same thickness of brass and copper sheet material.
- Lubricating effects need to be included.
- Temperature effects can be included.

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