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Design & Analysis of Sheet Metal Die For Deep Drawing Operations

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Abstract - *The process in which a punch forces a flat sheet metal blank into a die cavity is known as deep drawing. Flat thin sheets (blanks circular or rectangular) are formed into cup shaped components by pressing the central portion of the sheet into die opening using a punch to draw the metal into the desired shape. Deep drawing is an important process used for producing cups from sheet metal in large quantities. The deep drawing is affected by many process variables, such as blank shapes, profile radius of punch and die, formability of materials and so on. Especially, in order to obtain the optimal products in deep drawing process, blank and die shapes are very important formability factor. So in this Project we are designing die for deep drawing operations using CATIA and perform the stress analysis of the die for different material and different blank thickness using ANSYS Software.*

Key Words: - *Deep Drawing, Stress Analysis, CATIA, ANSYS*

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I. INTRODUCTION

Sheet Metal Forming:-

Sheet metal forming is one of the most important manufacturing processes, which is inexpensive for mass production in industries. Sheet metal forming involves conversion of flat thin sheet metal blanks into parts of desired shape and size by subjecting the material to large plastic deformation. Metal forming processes are classified into bulk forming processes and sheet metal forming processes. In both types of process, the surface of the deforming metal and tools in contact and friction between them may have major influences on material flow. The bulk forming processes are rolling, forging, wire drawing and extrusion. Sheet metal forming processes like deep drawing, stretching, bending etc. are widely used to produce a large number of simple to complex components in automotive and aircraft industries, household appliances etc.

Sheet-metal die is an inseparable constituent of the development process of any given automotive or consumer appliance. The process of sheet metal stamping (or drawing) involves placing sheet metal (the blank) between an upper and lower die, which are cut in the form of the desired part and are geometric negatives of each other , and driving upper die(or punch) into the lower die with high force using a press.

It is used to form sheet metal parts in several industries, ranging from doors and hoods in automobiles to housing in washing machines, and even kitchen sinks.

Deep drawing is a sheet metal forming process in which a sheet metal blank is vertically drawn into a forming die by the mechanical action of a punch. It is thus a shape transformation process with material retention. The process is considered "deep" drawing when the depth of the drawn part exceeds its diameter.

The success of a drawing operation depends upon the several factors including-

1. The formability of the material being drawn.
2. Limiting the drawing punch force to a lower value than that which will fracture the shell wall.
3. Adjustment of the blank holder force to prevent wrinkles without excessively retarding metal flow. [11]

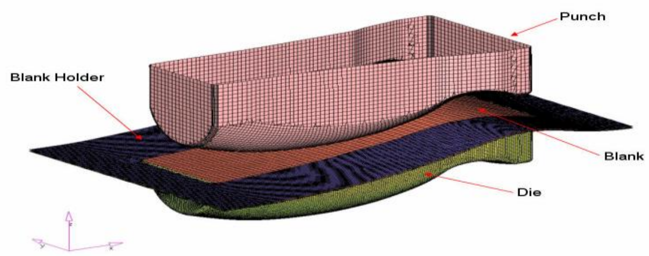


Figure No 1:- Sheet Metal Die

1.2 Deep Drawing:-

1.2.1 Basics of Deep Drawing:-

Deep Drawing (DD) is the sheet metal forming process which is used to produce containers from flat circular blanks. The central portion of sheet of blank is subjected to pressure applied by punch into a die opening to get a sheet metal of required shape without folding the corners. This generally requires the use of presses having a double action for blank holding force and punch force. DD can also be defined as the combined tensile and compression deformation of a sheet to form a hollow body, without intentional change in sheet thickness [2].

1.2.2 Principle of Deep Drawing:-

A flat blank of sheet metal is formed into a cylindrical cup by forcing a punch against the centre portion of a blank that rests on the die ring. The blank may be circular or rectangular, or of a more complex outline. Blank holder is loaded by a blank holder force, which is necessary to prevent wrinkling and to control the material flow into the die cavity. The punch is pushed into the die cavity, simultaneously transferring the specific shape of the punch and the die to the blank.

The material is drawn out of the blank holder die region during the forming stage and the material is subjected to compressive and tensile stresses in this portion. The principle of deep drawing is schematically represented in Figure No 1.

1.3 Types of Die Sets:-

The two basic types of die sets are:

1. Open die set and pillar die set. It is generally used to manufacture simple parts in small quantities and where loose tolerances are required.
2. Pillar die set is used where greater accuracy is required.

Dimensions of die set depend on part quantity, dimensional tolerance of the component, clearance between punch and die, and clearance between guideposts and bushings.

Type of die set is selected by considering size of the press opening, requirements for strength and stability of the tool, amount of downtime and cost to regrinding, maintenance and repairs and for assembly as well.

The sheet of metal is held between a blank-holder which runs around the die, as shown in previous fig and is stamped into the desired shape by the press. [8]

The process of sheet-metal *drawing* involves placing a sheet of metal (the *blank*) between an upper and a lower die, which are cut in the form of the desired part and are geometric negatives of each other, and driving the upper die (or *punch*) into the lower die with high force using a press as shown in Figure.

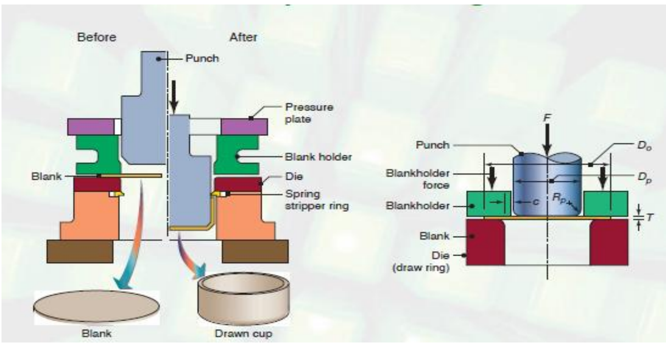


FIGURE NO 2:- Diagram of Deep Drawing Die

1.4 Defects in Deep Drawing:-Die design is a complex task, as forming dynamics involve interactions between the sheet-metal blank, the press, the blank-holder, and the die.

1.4.1 Wrinkling:-

Wrinkling is one of most severe defect in deep drawn product. Wrinkling may be defined as the formation of waves on the surface to minimise the compression stresses.

There are two regions where wrinkling may take place first one is flange and second one is cup wall.

Wrinkling on flange may be minimised by having optimum blank holder pressure but wrinkling on side walls cannot be prevented by any single parameters, so different parameters need to be set to minimise side wall wrinkling

1.4.2 Tearing:-

The process for drawing entails the use of hydraulic press since the rate of deformation has to be controlled throughout the operation of drawing.Tearing or splitting (caused by excessive tension), and (caused by elastic recovery of the metal).

1.4.3 Spring back:-
The deep drawing process is commonly used to manufacture sheet metal products. During the process initially curved or flat blank material is clamped between the die and the blank holder. When the punch is pushed into the die cavity, the blank is plastically deformed and the specific shape of the punch and the die is transferred to it. After the tools are removed, the elastically-driven change of the product shape, or so-called spring back, occurs
All the above defects are shown in figure

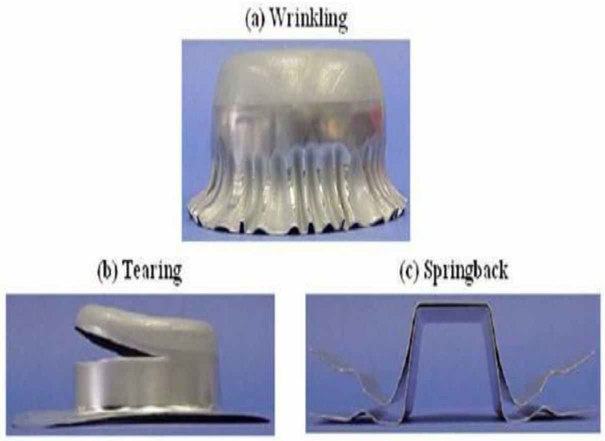


Figure No 3:- Diagram Showing defects in Sheet Metal Bending.

II. LITERATURE REVIEW

2.1. Sung-Bo Sim, Sung-Taeg Lee [3]:-
Concluded that the FEM simulation increased draw ability of production part for this progressive die development of five step drawing. The results of fine quality of production part were accomplished without fail by try out and its revision after die components making and assembling. The auto-feeding treatment with a relevant attachment was comparative effect for this
Production part material strip progression.

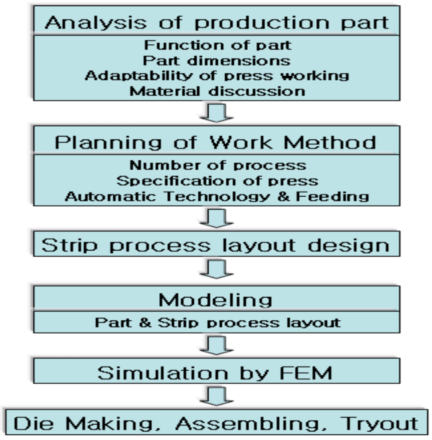


Figure No 4:- FEM Simulation Process

2.2. Peter kostka, Peter cekan [4]:-
Observed that ability to predict different process conditions in deep drawing is essential for die face designers, tooling, stamping and manufacturing engineers. These predictions in turn affect the speed, accuracy and cost of final produced products. This paper briefly discuss the possibilities of controlling the blank holder pressure distribution and shows some computer simulations done on DYNAFORM, with results being experimentally verified. Multi point cushion system, special tool concepts are necessary, to control the pressure between blank holder and draw ring and in this way we can also control the material flow. The modifications of pin forces have to result in corresponding modifications of the pressure between blank holders and draw ring in determined segment of the die. For this a new tool concept for multipoint cushion system has been developed.

Using it a working range between wrinkles and tears can be increased enormously. So the forming process gets more robust and more complex parts can be manufactured.

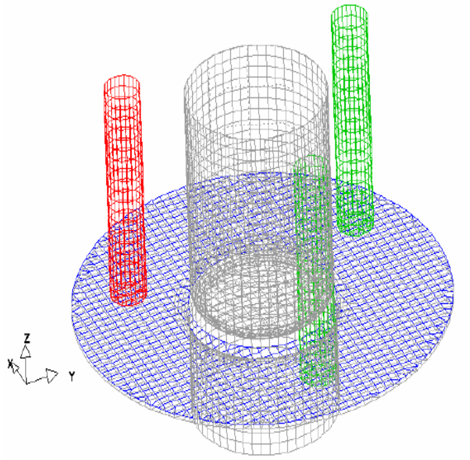


Figure No 5 :- Computer Simulation

2.3. Smith & Associates:-

Observed that a skilled die try-out technician will optimize the metal flow by making a series of trial parts and reworking the blank holder as needed. In some cases, it is necessary to increase draw ring and punch radii with the approval of the product designer. Minor product changes are often highly beneficial to reduce or eliminate the occurrence of fractures. The corner is the usual location of a fracture in a rectangular drawn shell. The localized thinning or necking, which can lead to a fracture, is the same failure mode that limits the severity of round deep cup drawing.

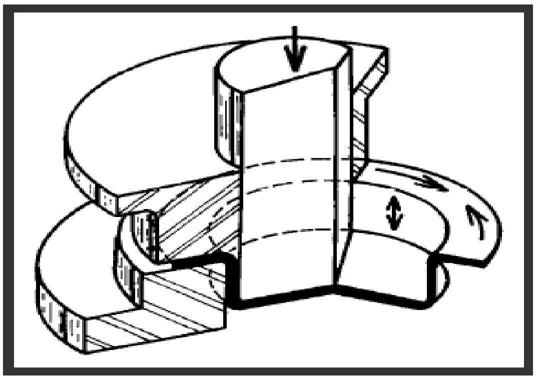


Figure No 6:- Blank Holder

2.5 Wifi* A. Mosallam [10]:-

Purpose: This paper presents a finite element-based assessment of the performance of some non-conventional blank-holding techniques. This includes friction actuted, pulsating, and pliable blank-holding techniques.

Design/methodology/approach: A 3-D explicit-finite element analysis is used to investigate the influence of various blank holder force (BHF) schemes on sheet metal formability limits especially wrinkling and tearing rupture. The role of relevant parameters of each blank-holding technique are also investigated. Three non-conventional blank-holders are considered, namely friction-actuated, elastic and pulsating blank-holders.

Findings: For the conditions considered in this study, comparison with fixed BHF scheme revealed that slight improvements in the formability are observed for the three BHF schemes under consideration.

Research limitations/implications: Only 5182 Al-alloy circular cups are considered. Further investigations should consider different materials and non-circular shapes because of their effect on sheet metal formability.

Practical implications: Cylindrical cups' drawing is responsible for the manufacture of billions of metal containers. This study can help improve working conditions leading to defect free products.

Originality/value**:** The 3D-explicit finite simulations presented for a number of non-conventional blank-holding techniques are useful in the assessment of their performance.

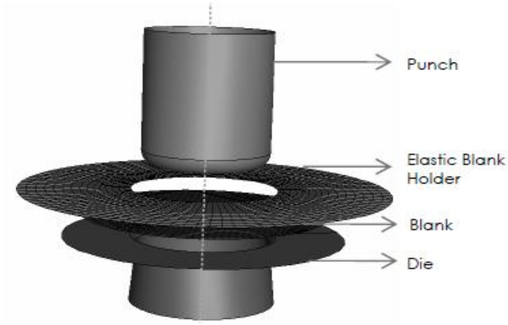


Figure No 7:- Blank Holding Technic

2.6 **S.B. Parka, Y. Choi b, B.M. Kim c,*, J.C. Choic**:-

It was developed the Automatic Generation of Forming Process Outlines (AGFPO) system for axisymmetric and monotone parts, produced by deep drawing. They suggested G&TR (Generate and Test and Rectify) strategy for the process planning of axisymmetric deep drawing products. The system relies only on experience-based die-design guidelines for its process-sequence design.

The results of the CAD system, Pro–Deep, are used for the design of die sets in the CAD: CAM system. The die sets of the system include three cases, which are a blanking die set, a first drawing die set and redrawing die set. The blanking die set is designed for circular blanking in a simple-action press. Also, the drawing die sets are designed for axisymmetric deep drawing in simple-action press. The drawing die sets are of the knock-out type with a blank holder. The structure of the die sets and the parts of the tool are determined.

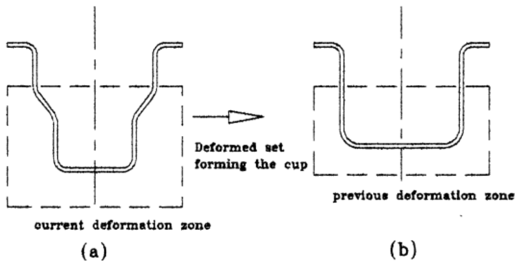


Figure No 8:- Deformation Zone

III. SHEET MODEL FOR TESTING

3.1 Drawing of existing sheet and Component

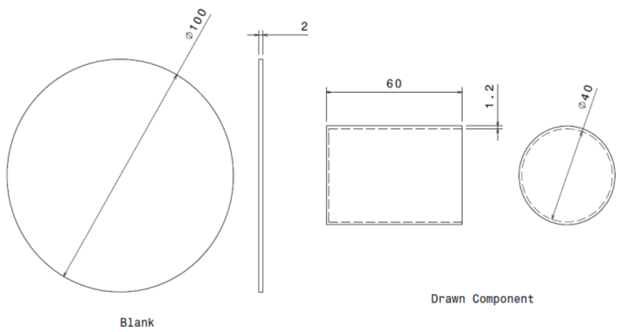
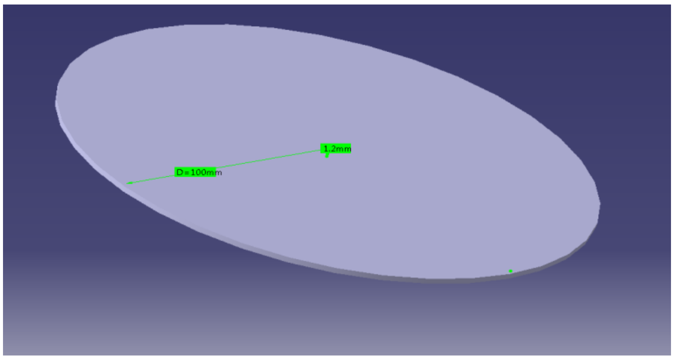


Fig No 9: Blank and component dimensions

3.2 Model of Sheet



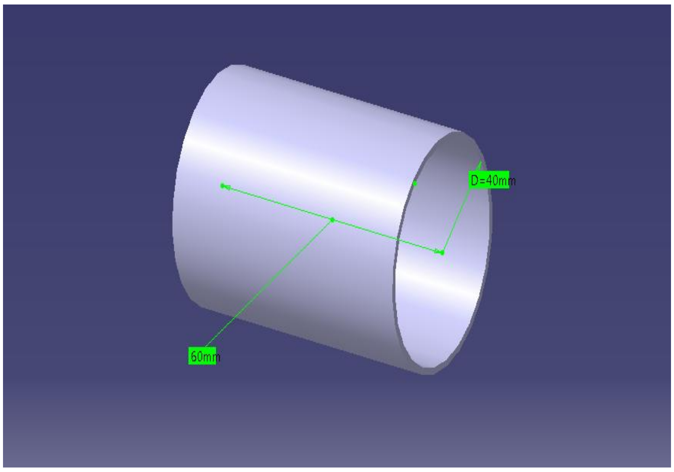


Fig No 10:- Component model

3.3 Software's used Information

CATIA V5 R20:- CATIA V5 provides three basic platforms: P1, P2 and P3. P1 is for small and medium sized process oriented companies that wish to grow toward the large scale digitized product Definition. P2 is for the advanced design engineering companies that require product, process and resource modeling. P3 is for the high-end design application and is basically for Aerospace Industry, where high quality surfacing or class-A surfacing is used for designing. A good feature is that any change made to the external data is notified to user and the model can be updated quickly. A workbench is defined as a specified environment consisting of a set of tool, which allows the user to specific design tasks in a particular area.

ANSYS 16.0:- Ansys is user friendly finite element analysis software which can also use for modeling and meshing varies kind of analysis can carried out in Ansys. ANYAS 16.0 include the following new enhancement that improves the solution procedure and features high performance computing due to shared memory parallel capability in Ansys distributed Ansys now run on windows 32- and 64-bit systems PCG Lanczos method provides a robust and efficient option for large modal analyses.

IV. DIE, PUNCH AND FORCE CALCULATION

4.1 PARAMETERS OF DRAW DIE:-

Where

D =Blank diameter

d_1=Inside work piece diameter after the first drawing operation

T = Material thickness

R_p =Draw ring

R_i =Punch radius

dp = Outside work piece diameter after the first drawing operation

-The radius of draw ring (R_p)

$R_p= 0.8[(D-d_1) * t]^{0.5}$…….(1)

-The height of the cylindrical part of the draw ring (h_0)

$h_0= (3/5)*t$ …………….(2)

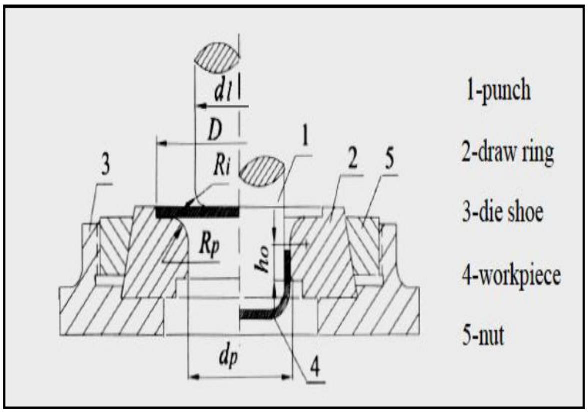


Figure No 11:- PARAMETERS OF DRAW DIE

The clearance between the walls of the punch and the die C
$C = t + k (10t)^{0.5}$ ……..... (3)
Where:
C = clearance
T = material thickness
k = coefficient

Material specification	EDD-513
Dimension	220 mm* 1.2 mm thick
Ultimate tensile strength (St)	260 MPa
Yield strength (Sy)	165 MPa

Material	Coefficient, k
Steel sheet	0.07
Aluminium sheet	0.02
Other metal sheet	0.04

Blank Holder Pressure (P_{d1}) - The value of blank-holder pressure is decided on the basis of sheet metal material which is to be deformed.

The blank holder force can be calculated by the following formula:
$F_{d1} = (\pi/4) * [D^2 - d_1^2] P_{d1}$ …………….. (4)

Draw force – draw force required for the operation is given by

$P_{draw} = A S_t n_c \ln(E_c)$………………...(5)
Where
$A = \pi d_1 T$
A-area of cross section of a shell
T- Thickness of sheet metal
St- Ultimate tensile strength of material
E_C- Cupping strain factor
n_c- Deformation efficiency of drawing process
The cupping strain factor E gives us the actual strain in the metal created by its elongation during the deep-drawing process, it is calculated by
$E = [(D/d_1) + 1] * 0.4$………………(6)
Deformation efficiency of drawing process (n_c) is selected based on the cupping strain factor using graph from Fig
DESIGN CALCULATIONS-
A. Input parameters-
-Sheet metal (Input part) details-
As the depth of drawn component is 30 mm, blank-holder travel is kept 31 mm for proper holding 1mm before the start of operation.

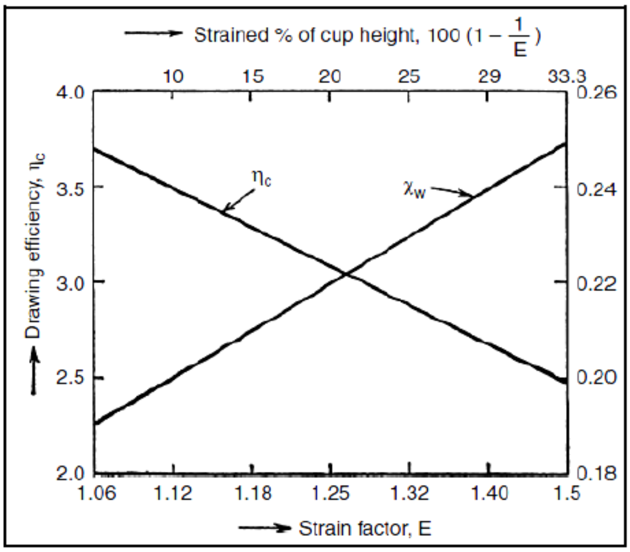


Fig No 12:- Deformation efficiency of drawing process (n_c)

Various parameters

- Blank Diameter (D)-100 mm
- Punch diameter (d_1)-39 mm
- Thickness of sheet (T)-1.2 mm

4.2.1 Draw ring radius (R_p) –

R_p= 0.8 * [(D-d_1) * t] $^{0.5}$
= 6.84 mm
≈ 7 mm

4.2.2 The height of the cylindrical part of the draw ring (h_0)

h_0= (3/5)*t
h_0= (3/5)*1.2
h_0=0.72 mm

4.2.3Clearance value between punch and cavity (C)-

C = t + k √ (10*t)
= 1.44 mm
≈ 1.5 mm

4.2.4 Cavity diameter (d_0)-

d_0 = d_1 + C
= 40.5 mm

4.2.5 Blank-holder force (P_{d1}) –

P_{d1} = P*area of sheet metal holding
= 1.25 X [100^2 - (π/4) *39^2]
= 11.007 kN

4.2.6 Draw Force (F) –

F= A $S_t n_c$ln(E)
A= π *d_1*t
=147.03 mm^2
E - Cupping strain factor
E = [(D/d_1) + 1]*0.4
= 1.43
From fig.6, n_c=2.3

F = 147.03 *260 *2.3* ln (1.43)
= 31.448 kN

Total ram force required (T) = Draw force + Blank-holder force

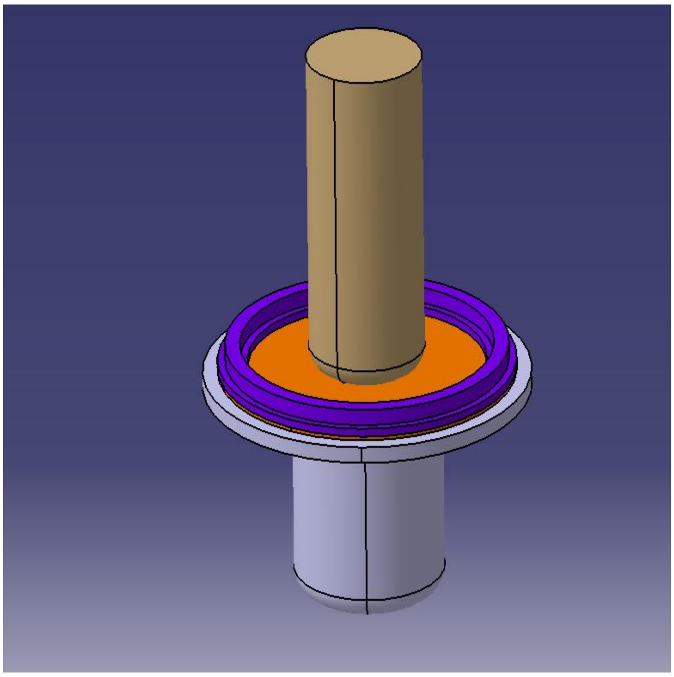
$= F + P_{d1}$
$= 31.448 + 11.007$
$= 42.455$
≈ 45 kN

V. ANALYSIS OF EXISTING DIE USING ANSYS 16.0

5.1 Explicit Dynamics: Explicit Dynamics is used to perform high-speed impact simulation i.e. collision of two objects. It is also used to perform drop test simulation i.e. an object falls down from a certain height onto floor.
A time integration method used in Explicit Dynamics analysis system. It is so named because the method calculates the response at current time using explicit information.
Once the body is meshed properly, the next step is to define initial conditions or boundary conditions. At least one initial condition is required to complete the set up.
After defining the initial conditions (initial velocity, Angular velocity), analysis setting has to be maintained as per the problem requirement. In analysis setting, time step has to be defined explicitly. The solution time is depends on the time steps.
The time steps include:-

- Initial time step
- Minimum time steps
- Maximum time step
- Time step safety factor

Deep drawing analysis is also a highly non-linear problem in which the collision takes place in between 'punch' and 'blank'. Punch moves down with certain velocity and exerts force on blank. Therefore it is prescribed to use explicit dynamics module in Ansys Workbench for Deep Drawing Analysis.



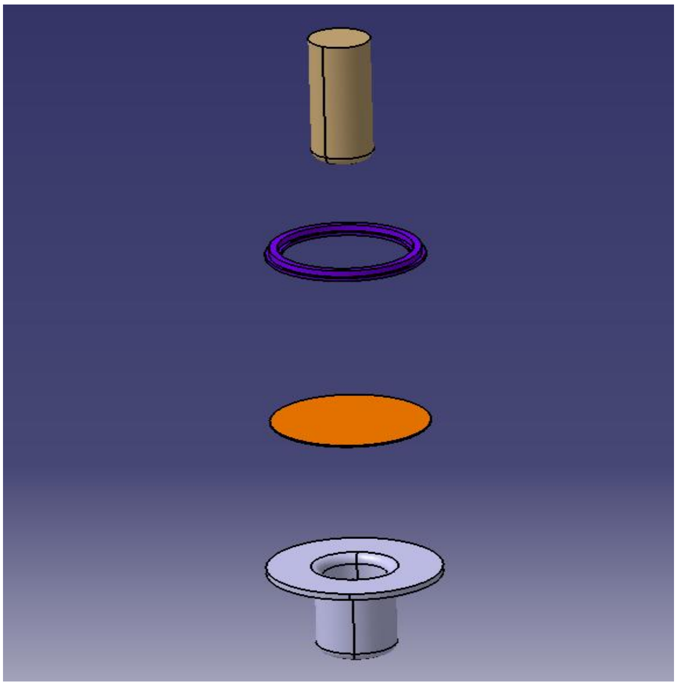


Fig. No 13:- Stress Distribution Study

VI. OPTIMIZATION ANALYSIS OF DIE USING ANSYS 16.0

Sr. No	Material
1	Steel (Existing)
2	Aluminium Alloy
3	Al 2024 T4
4	Al 6061 T6
5	Al 7075 T6

Table No 01:- Material effect on deep drawing (Stresses, strains, deformation)

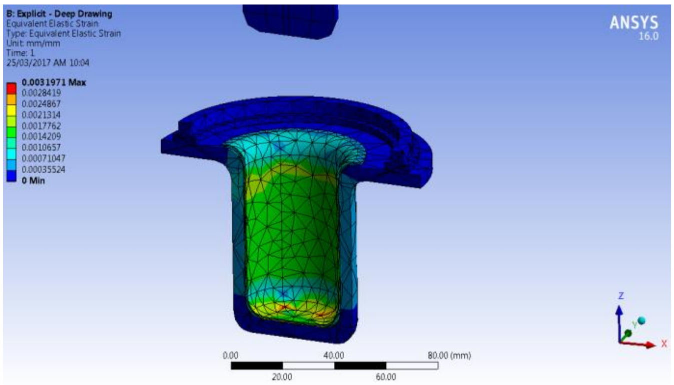


Figure No 14:- Stress Strain Deformation

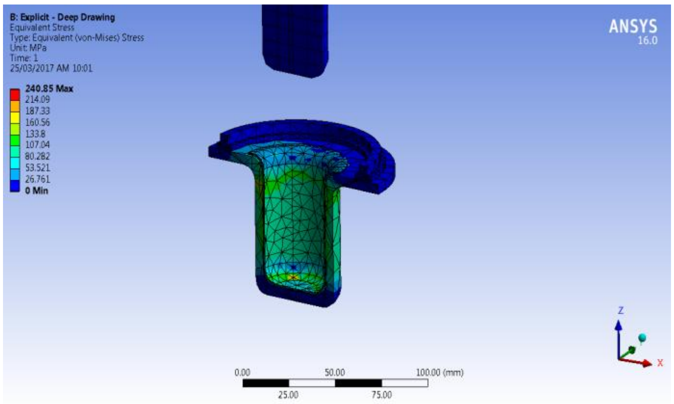
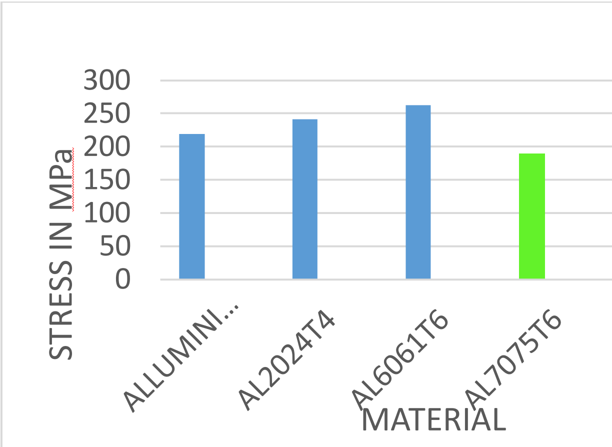
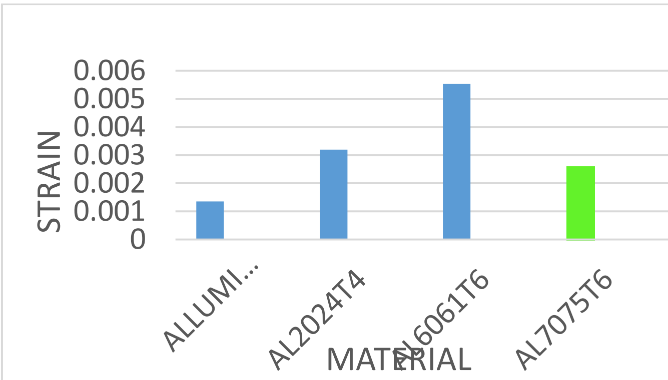


Figure No 15:- Stress Strain Deformation



Graph No 01:- Stress vs Material

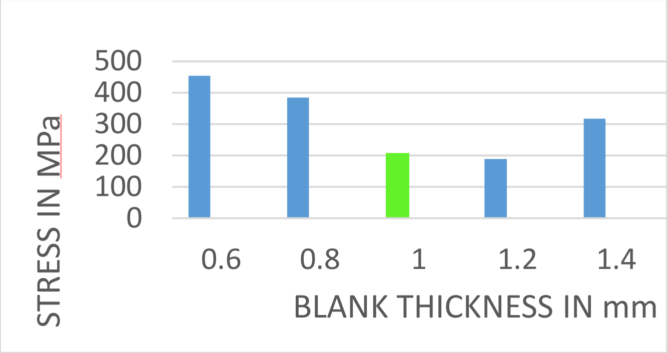


Graph No 02:- Strain vs Material

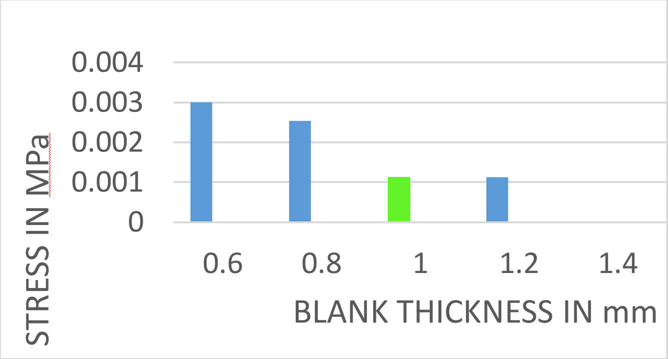
VII. FABRICATION AND TESTING OF OPTIMIZED SHEET FOR VALIDATION.

Fig No 16:- Actual Die

Experimental Results:-



Graph No 03:- Stress vs Blank Thickness



Graph No 04:- Strain vs Blank Thickness

VIII. CONCLUSION AND FUTURE SCOPE

Conclusion:-

- Deep Drawing Process studies in detail and verifying and overcome the defect in deep drawing process.
- Die design and the effect on the various materials can be tested. The stresses and strain are highly depend in the die shape and the material used.
- Thickness variations done and it is found that large stresses at nearby thickness of the existing thickness so that we can say in deep drawing is one of the important factor.
- Energy and cost of die are decreased with this die type. Especially in the die manufacturing it can be used at the first stage drawing instead of twice and/ or three times deep drawing.
- A Finite Element Model is developed to reach the optimum solution without many costly trials of production which is a common practice in the traditional production approaches.

Future Scope:-

- Different shape of the components can be tasted for the material change effect.
- The force of the punch can be change
- Shape of the die will be more complicated.
- Try for multi staging deep drawing processes

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