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Effect of Different Parameters on Deep Drawing Process for Minimum Stress and Defects by Experimental and Simulation Study: A Review

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Abstract: *Optimization of process parameters in sheet metal forming is an important task to reduce manufacturing cost. To determine the optimum values of the process parameters, it is essential to find their influence on the deformation behavior of the sheet metal. For reduce various defects in deep drawing process it is essential to control or vary physical and geometric parameters of deep drawing process. A blank holding force, punch force, material property of sheet metal, thickness of sheet, velocity of punch, these are all affecting parameters in deep drawing process to regulate wrinkling effect, tearing effect and fracture defect. Therefore, with the help of experimental and simulation tools investigation of stress and strain distributions in the deep drawn cup were also done and the Finite element results can predict the same place of tearing and wrinkling error for bimetal cup as occurred in experimental tests. By analyzing these parameters, the defects like wrinkling, tearing, earing is reduced and also we can get the good quality product.*

Keywords- *Deep Drawing, Experimental work, Simulation study*

I. INTRODUCTION

Metal working process has been divided into categories such as forming, cutting, and joining. They above mention process can be used for different purposes depending on the requirement. Before carrying out operations, the work to be done on the metal should be marked out and/or measured depending on required product to be achieved. Marking is process of converting design or pattern to a work piece and it is primary step in metal working. It is done in industries as they need to mark out every piece. In metal treading marking out is transferring engineers' plant to work piece for preparation of next step which may be machining or manufacturing. Thus metal working is basically process of marking, planning and manufacturing by using various manufacturing process [1].

Drawing is a manufacturing process very used in the industry due to its versatility and good mechanical properties (as good surface finish and dimensional accuracy) of the parts. Successful drawing operations require careful selection of process parameters and consideration of many factors [2].

The main variables involved in this type of process are:

1. Die radius
2. Friction
3. Punch Radius
4. Blank Thickness.

The work piece plays an important role which provides sufficient formability which allows required amount of plastic deformation which is without cracks or defects. The main things measured in work piece are stress, strain, flow stress and temperature that material will be given. The local parameters between the work piece and die are temperature (T), contact pressure (p), shear stress (τ) which occurs mainly due to friction forces transferred from work piece to die. The other important parameter which plays important in metal forming process is the type of lubrication used [3].
Drawing is sheet metal forming operation used to make cup shaped, box shaped, and complex curved and concave cup. The common parts made by deep drawing process are beverage cans, ammunition shells, sinks, coking ports and automobile body parts. The sheet of metal is formed into 3-D product by deep drawing process. The main tools used in deep drawing process are blank, punch, die and blank holder. The geometry parameters used in deep drawing process are [4] Punch Radius (R_p), Punch Edge Radius (r_p), Blank Thickness (t), Blank Radius (R_b), Die Radius (R_d), Die Edge Radius (r_d).

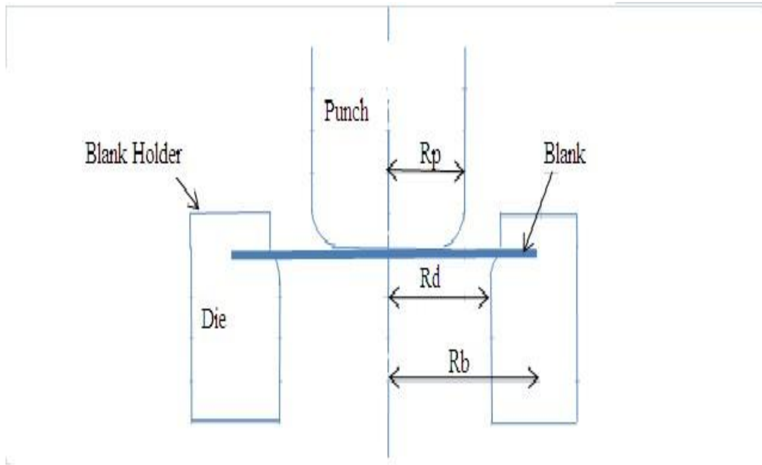


Figure 1: Tool geometry of deep drawing process [4].

Clearance is the important parameters which is obtain by the difference between die radius and punch radius (c= Rd-Rp). Clearance must be 25% larger than initial blank thickness. The above mention physical and geometrical parameters are explained in brief below [4].

Deep drawing process depends on type of blank material, blank holder force, punch speed, die edge radius (rd), lubrication and drawn depth. Blank holder force mainly produces effect on failure on sheet metal. [4] By reducing BHF wrinkling effect comes as failure and increasing BHF results in splitting and fracture. Die edge radius produces stress concentration which results in tearing effect on the edges of vertical wall of cup [5]. Proper lubrication results in reducing stress, wrinkling and hence results in reducing error in deep drawing process.

II. LITERATURE REVIEW

The blank holding force has the major influence in the deep drawing process. The die radius also has an influence in the process which is followed by punch nose radius.The failure in the component i.e. tearing in the cup was observed due to less punch nose radius. Wrinkling in the formed part was also seen during the experiments which occurred due to less blank holding force.

In the bending process, springbacks predicted by simulation are in agreement with experimental results. Friction conditions and clearance have only a small influence on the punch load.A model based on energy equilibrium method is presented to predict the minimum blank holding force required to prevent wrinkling.Spring-back angles of the work piece are studied by varying the punch angle, punch radius and die-lip radius by simulation.

The main variables involved in this type of process are:

- Die Radius
- Friction
- Punch Radius
- Blank Thickness

The finite element method has recently been sufficiently developed for the analysis of metal forming processes. Hence, much research has been performed using the finite element method. The purpose of this study is to clarify the mechanics of ductile fracture in bulk metal forming processes [2].

2.1. Experimental work

2.1.1. Preliminary Test

Brass is wide decorative applications and its thermal and electrical conductivities are much better and its specific heat is considerably less high, compared with those of the stainless steel. However, tarnish resistibility, strength/density ratio and surface quality of the stainless steel are higher than brass. Therefore, by making a parts made of brass and stainless steel, one can take different advantages of these metals at the identical time [6].

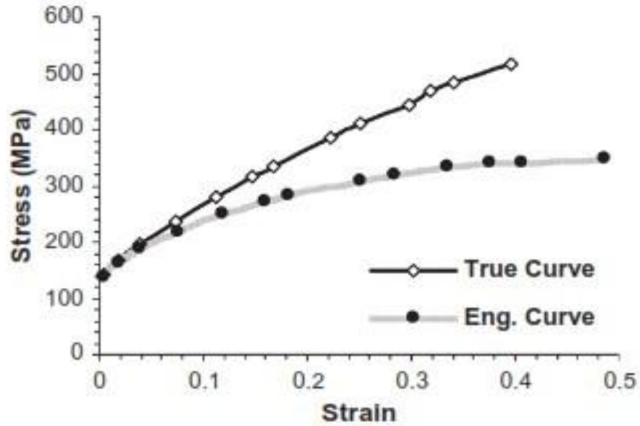


Figure 2: Engineering stress vs. strain diagram [6]

In the practical experiments, it is firstly necessary to find the mechanical properties of the selected materials as well as the Coulomb friction co-efficient between the sheet and the dies. These data are also required for performing the FE simulations of the process. For this case, the tensile tests, based on ASTM (E8M-98) standard, were used to specify the stress–strain curves of the brass and stainless steel under consideration. This type of test is usually adopted for sheet metal forming processes, because of the stress state involved. For more precise evaluation of strain, all the tensile tests were conducted using an extensometer. The thicknesses of the steel and brass sheets were 0.39 and 0.62 mm, respectively to meet enough clearance between the punch and die. [6]. Figs. 2 and 3 depict the true and engineering stress–strain curves of these alloys. To determine Coulomb friction coefficients under various conditions, the friction tests were employed. Fig. 4 represents schematically the fixture used for evaluation of the friction coefficients. For each frictional condition, a normal force (N) was applied to the sheet by the press and, then, the horizontal force (F) needed for initiation of motion of the sheet between the die faces was measured. Afterwards, using the Coulomb friction formula, the friction coefficient was calculated [6].

Three different frictional conditions were tried for both the steel and brass sheets.

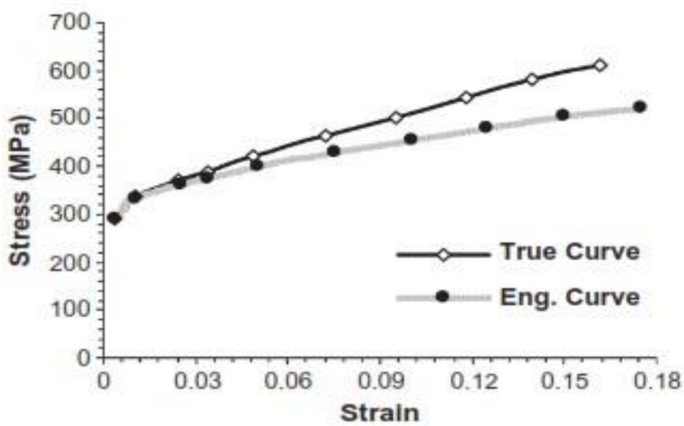


Figure 3: Engineering stainless steel diagram [6].

2.1.2. Deep drawing Test

The process variables selected for investigation were the layer stacking sequence, blank diameter, blank-holder force and lubrication. Therefore, blanks with three diameters 7.5, 8.5 and 10 cm from stainless steel and brass sheets were punched to make composite sheets. Lubrication with nylon film and dry condition were also two different contact conditions maintained between laminated sheet and punch, die and blank-holder. The blank holder force was adopted with three levels, namely 0.71, 2.14 and 3.56 KN. These values were selected considering the guidelines suggested by Johnson and Mellor [6]. The blank holder force was exerted by means of eight B-16/76 standard springs. This force was kept constant during each drawing experiment. It is helpful to note that recommended blank-holder force to have defect-less products must obey Equations.

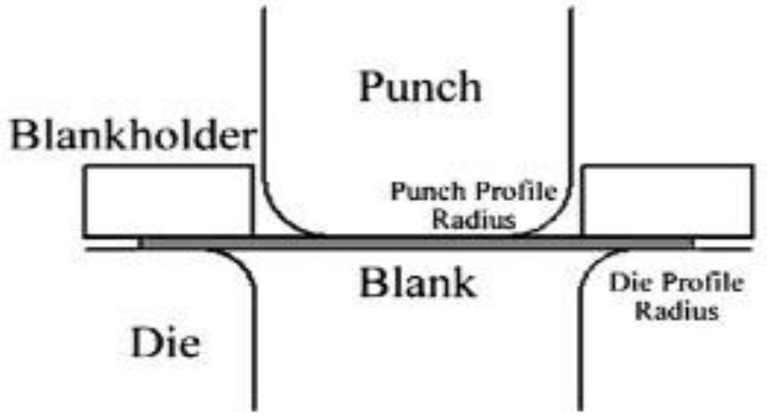


Figure 4: Engineering stainless steel diagram [6].

2.2. Simulation work

The first sandwich material to be used in industry was in 1994, wooden sandwich material consists of plywood and balsa which was used in air craft there was rapid development in aircraft industry whose demand was light, stiff, and strong material which led to wide spread development of different sandwich material. In 1987 and advance sandwich material to known as GLARE (Glass laminate aluminum reinforce epoxy). This sandwich material offers better damage tolerance, excellent corrosion and fire resistance with reduction of weight.

Earlier research work on the optimization in deep drawing used simple rule-of-thumb optimization techniques that play on less rigorous mathematical and analytical tools. The reason for that is due to the convolutedness of the mathematical models that describe the deep drawing process.

The work of Conry et al (1980) is a good example for that. They work out a nonlinear mathematical programming model to determine the unsurpassed die profile. This model turned to be very stubborn and complex to be solved mathematically. They evolved an iterative optimization approach combining regression curve fitting and the techniques for constrained optimization. Nevertheless, since there is no experimental or simulation verification of this study, there is no pledge for its realistic pertinence.

So, the Finite element (FE) simulation and analysis gives a fertile environment for improvement and optimization in deep drawing. To overcome the unconvinced in the mathematical models of the deep drawing process, some researchers worked on developing empirical formulas that are based on the FE simulation results. Such empirical formulas are simple to deal with using a suitable optimization algorithm.

The inverse approach is developed for sheet metal forming processes and it is a simplified efficient finite element method. It is based on the idea of estimating the large plastic strains in thin metallic plates. It is mainly express the knowledge of the 3D shape of the final work piece, and used to find the original position of each material point in the flat blank after that it is possible to estimate the strains and stresses in the final work piece [7].

2.2.1. Simulation Procedure for deep drawing process.

First of all, 2D model is created and give the material properties which selected for testing than load will applied as per experimental test and then check the results.

This simulation work follows following steps:

Preprocessing: defining the problem;

- Define key points/lines/areas/volumes (Solid Modeling)
- Define element type and material/geometric properties
- Mesh lines/areas/volumes as required

Solution: assigning loads, constraints and solving;

- Apply the loads (point or pressure),
- Specify constraints (translational and rotational)

Post processing: further processing and viewing of the results;

- Lists of nodal displacements and show the deformation
- Element forces and moments
- Stress/strain contour diagrams

1. Solid Modeling

The process of creating solid model in CAD system. A solid model is defined by volumes, areas, lines, and key points. By using various geometrical data of presented setup a solid modeling of the same is created in ANSYS. Solid modeling of the experimental set up is done by using various dimension of the geometry [8].

2. Elements

The type of element to be used in the analysis influences the exactness and accuracy of the results to a great extent. Literature review and examination of peer researchers' works show that PLANE42, 2-D elements with axis symmetric behavior have been conveniently used in the numerical analysis of axis symmetric forming process [8].

3. Material Properties

The material of back plates is mild steel IS 2062 grade. It was selected as a structural, non-linear, isotropic hardening material model in the presented ANSYS simulation. Various material properties like yield stress, Modulus of elasticity, Poisson's ratio etc, which are required for fem simulation are obtained from various authentic literature. Tools are assumed as rigid, so there is no need to define material, however the material of punch and die is tool steel [8].

4. ANSYS meshing

A quad mapped mesh was generated on all areas apart from the punch/die which is taken as rigid. This was done to achieve a higher number of elements along this line so a solution using contact conditions could be found easier [8].

5. Loading and boundary condition

As part of FE analysis, applying loads and constraints i.e. boundary conditions consists of defining which parts from geometrical model moves i.e. defining degree of freedom. Contact surfaces used in the presented work are top blank - bottom punch, bottom blank - top die. In current study movement of blank part is restricted in x- direction. Displacement load of the part of the blank which initially not in contact with die is given in y-direction. Movement of horizontal part of the blank which is on the die is restricted in x- direction as well as in y-direction both. The tools i.e. punch, die and blank holder, in finite element simulation are considered rigid because they are extreme stiff compared to the sheet. For this reason, the tool can be presented as a surface only [8].

6.Finite Element simulation model

Author Amir Atrian has presented result of simulation by finite element method and it is show in Figure-7 In which they have for each frictional condition, the average value of the friction coefficients obtained for brass and steel were used as the friction coefficient between the steel and brass layers. All parts of the die set were modeled rigid to reduce calculation time. Figure- 8 illustrates the deformed finite element model in ANSYS.

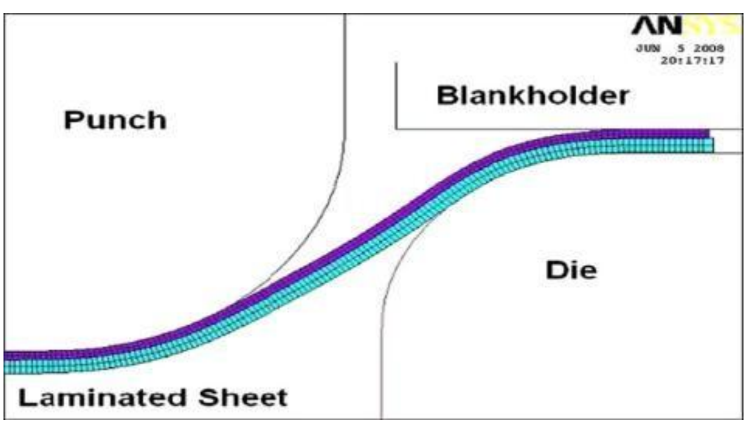


Figure 5: 2D Finite-element modeling of the deep drawing of composite sheets.

7. Results of FEM.

The effects of all the variables on the load–displacement curve are presented and discussed in this section. Fig. 8 typically compares the load–displacement curves obtained from two different solutions.

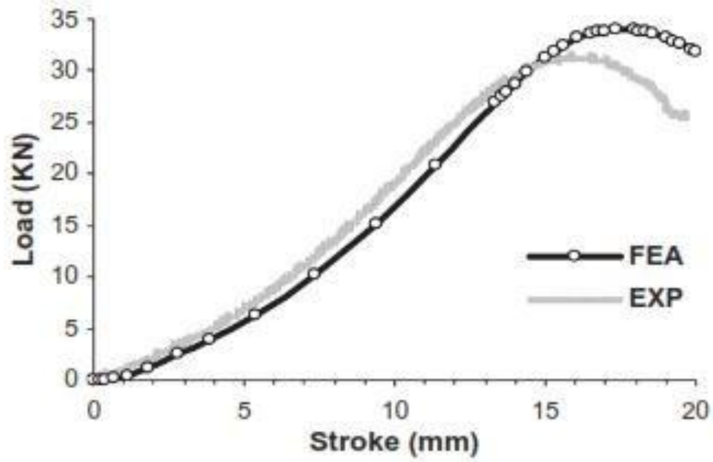


Figure 6: A typical comparison of experimental and finite element load–displacement curves.

This figure illustrates that FE results usually predict a greater forming load for doing the operation. This overestimation of the FE solution is about 10% and more or less is observed in other comparisons between the experimental and finite element results. Therefore, selection of the forming machine capacity based on the FE results includes a safety factor for having a successful operation.

In the composite sheet behavior in a forming process differs from single-layer sheets and depends on the layer sequence and thicknesses. Despite the effect of friction, the early part of the curve is also changed, as can be observed in Fig. 8. It was also observed that the friction condition can change the influence of the stacking sequence.

As an example, for dry condition, when the steel layer was in contact with the punch (BS), the maximum load was about 7% greater than the similar situation with SB case. But when nylon sheet was employed as lubricant, the SB condition needed nearly 14% greater force, compared with the BS case under similar conditions. These observations are almost confirmed by the FE finding. Under the dry condition, when the steel layer was in contact with the punch (BS), FE results showed that a greater force, about 1.5%, was needed compared with the other arrangements. However, with nylon lubricant, 8.5% greater force was required for the SB stacking sequence.

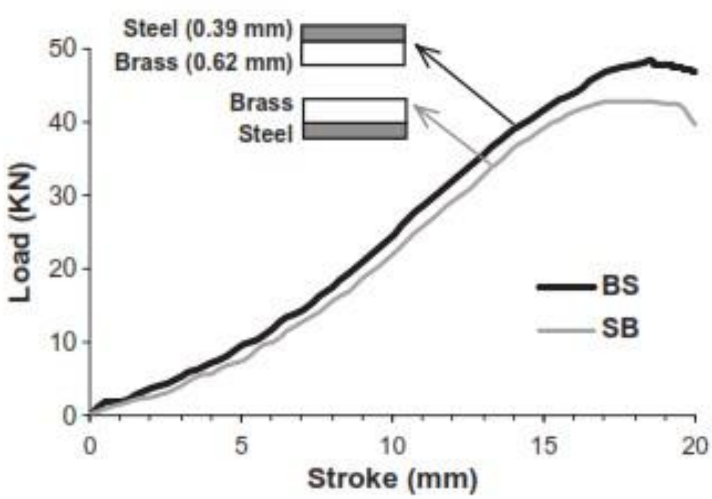


Figure 7: Effect of layer stacking sequence on the load–displacement curve for dry condition.

Figure 8: The effect of decreasing the blank holder force (from left to right) on occurrence of wrinkling at the edges of composite blanks.

Its good combination between experimental and finite element result which is show that Finite element method can be used in various industrial process. Sequence of layer is also important on the behavior of finished part. By changing the order of layer various defects can be observed in the deep drawing process of bi-metallic strip. Circumferential stress and thickness strain produced in drawn cup in the region of punch radius area which is most critical area for the drawn cup. From that point it is more chance to fracture and splitting.

III. EFFECT OF DIFFERENT PARAMETERS

3.1. Tool geometry parameter

1. Die shoulder radius

In deep drawing process the geometry of die influences the thickness distribution and thinning of sheet metal. Die shoulder radius plays important role in sheet metal thickness distribution [9].

2. Punch nose radius

The geometry of punch plays important role in the thickness distribution and thinning of sheet metal in deep drawing process. Punch nose radius plays important role in metal thickness distribution. When punch nose radius is less than three times thickness of blank the cup fails and when punch nose radius is greater than three-time thickness of blank, thinning is stable [10].

3. Blank thickness

The original blank thickness plays vital role in thickness distribution and thinning of sheet metal deep drawing process. The average distribution of blank thickness improves with increase in blank thickness. Also the percentage of thinning increases with increase of blank thickness. The blank thickness and punch diameter affect the limiting drawing ratio and limiting drawing ration decrease as the relative punch diameter increases. Thicker material can be gripped properly as diameter increases. Thicker sheets have more volume so it can be stretched greater extend with increasing [10].

4. Radial clearance

Radial clearance is difference between die radius and punch radius. Sheet metal thickness increase when radial clearance decreases. When radial clearance is less than blank thickness the cup fails due to increase in thinning. When the radial clearance is greater than blank thickness thinning is stable [10].

3.2. Physical parameter

1. Blank holder force

Blank holder force is required to hold a blank which is one third of drawing pressure. Higher the blank holder force greater will be the strain over the punch face. The process is limited by strain produce in the side wall. When tension reaches maximum value the side wall will fail by splitting. Cup collapse due to thinning with increase in blank holder force over 0.5 ton [9].

2. Cracking Load

The largest allowable drawing load is limited by the load that can be transmitted by the sheet in the region of the punch radius or at the transition form cup wall to bottom radius, which is known as cracking load. It must always be larger than the maximum drawing load [11].

3. Friction parameter

Friction is one of the important parameter in deep drawing process. Friction determines the punch force and blank holder force in case of deformation of sheet. Friction use energy which is needed to deform a sheet material. Friction plays vital role to determine stress and strain in the work piece. It is important to control friction between tool and work piece. In deep drawing process hollow bodies from metal blanks using punch, die and blank holder. In deep drawing process lubrication and friction is complex as compare to other process. In one operation low friction is required in one area and high friction is required in other area [12].

IV. RESULTS AND DISCUSSION

Different simulations with different die radii were performed. According to John Monaghon [13] et al., as the die radius is reduced, it increases the amount of force to draw the material, the increased force on the punch & greater difficulty getting the material around the die radius causes stretching marks on the cup wall and an uneven thickness distribution.
To verify the above experimental results and to validate the simulation done, several simulations were performed by varying the die radius.

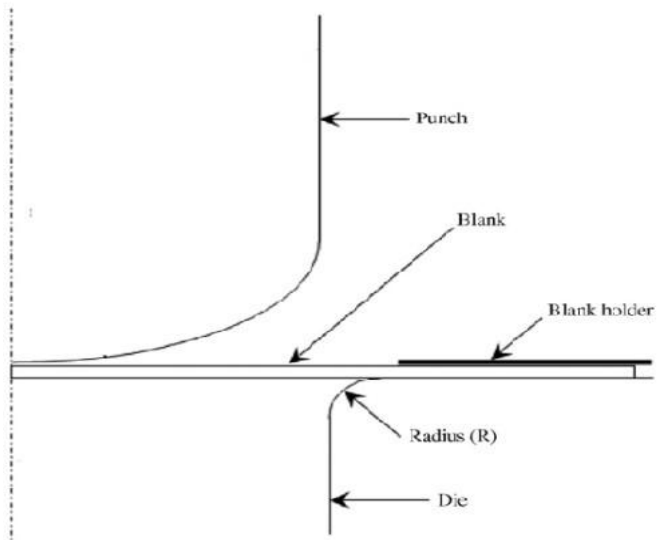


Fig. 9: Geometry of The Die Profile

The following figures from 6.1 to 6.5 are the drawn cups showing effective stress values for different die radii ranging from 4mm to 8mm respectively.

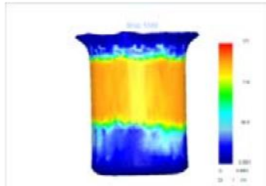


Fig. 10: Effective stress Values for 4mm Die radius.

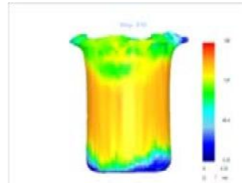
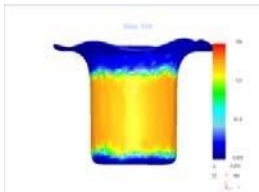


Fig. 11: Effective stress values for 5mm Die radius



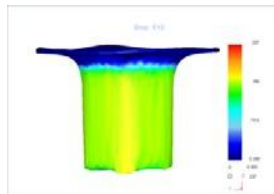


Fig. 12: Effective stress values Fig. 13: Effective stress values
for 6mm Die radiusfor 7mm Die radius

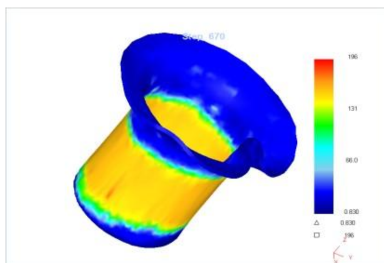


Fig. 14: Effective stress values for 8mm Die radius.

- Comparing the effective stress values of the drawn cups, it was found that, effective stress value was increasing as the die radius is decreased as shown in Fig. 6.1-6.5. Comparing the Max. principal stress values of the drawn cups, it was found that, max. Principal stress values are increasing as the die radius is decreasing.
- Comparing the effective strain values of the drawn cups, it was found that, effective strain value is decreasing as the die radius is decreasing.
- Comparing the Max. Principal strain values of the drawn cups, it was found that, max. Principal strain values are decreasing as the die radius is decreasing.
- Comparing the damage values of the drawn cups, it was found that, damage value is minimum for a die radius of 7mm and these die radii is recommended as an optimum die radii.
- Comparing the load required of the drawn cups, it was found that, load is increasing as the die radius is decreasing. Further, when the die radius was too small, the material, after considerable thinning process experienced Ear-ring type defect because, as the die radius was too small, the amount of force required to draw the material was large and the shear component of the load required in the deformation process is increased.

As for the above case, more force is needed to draw the material, it causes Stretching Marks and the end face of the cup twisted itself in its edge, forming earring type of error.

From the simulation performed, it is proved that, As the die radius is reduced,

- This increases the amount of force to draw the material
- The increased force on the punch & greater difficulty getting the material around the die radius causes stretching marks on the cup wall.
- Uneven thickness distribution.

With the above results, it can be seen that the simulation performed is validated [2].

V. CONCLUSIONS

It is a finite element analysis based simulation has been done using Deform-3D for the deep drawing process.

1. The effect of die radius on the formability and quality characteristics of deep drawing process has been done.
2. It has been found that as the die radius is reduced, the amount of fore required to draw the material is increased.
3. A decreased die radius created stretching marks and earring type quality problems.
4. Because of the above issues, an optimum die radius was an important parameter to be obtained from the simulation studies.
5. It has been found that a die radius of 7mm gave an optimum deform levels with minimum damage.
6. It was found that the result of the simulation studies were in line with the experiments conducted by prof. john monaghon [13] et al., whose results have been published in journal of material processing technology.
7. The developed model, as it is validated can be used to simulate any problems in deep drawing process for any material.

VI. ACKNOWLEDGEMENT

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