# Stress and Strain Analysis in Cup Drawing Process for Different Materials using ANSYS Software

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**Received: 25 June 2021, Revised: 29 September 2021, Accepted: 5 October 2021**

**Abstract:** Sheet metal forming is widely used in automotive and aerospace industry. In this paper analysis of sheet metal forming process by deep drawing was discussed. Static analysis on the deep drawing operation was carried out to find the stresses, strains and total deformation of deep drawing cup. CAD models are generated using CATIA from the dimensions obtained by theoretical calculations and analysis is carried out using ANSYS software. The force required to develop the cup, deformation and defect like tearing, wrinkles etc. can be obtained through simulation. By using this method it is easy to make stress and strain analysis for different materials. From the analysis it is observed that Titanium has the maximum stress with standing ability when compared to copper and Aluminum.

**Keywords:** ANSYS, CATIA, Cup Drawing

**Reference:** Kondapalli Siva Prasad, Gurram Ravi Teja, "Stress and Strain Analysis in Cup Drawing Process for Different Materials using ANSYS Software" , Int J of Advanced Design and Manufacturing Technology, Vol. 14/No. 4, 2021, pp. 45-50. DOI: 10.30495/admt.2021.1934048.1294

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## 1 INTRODUCTION

Deep drawing is a process of converting metal sheet into cylindrical or box shaped structure with or without changing its length and thickness. Many cylindrical parts like metal can, pots, container for food and beverages, kitchen sinks, automobile fuel tank etc. are deep drawing product.

The blank is placed over an open circular die with the help of blank holder. The blank holder provides a necessary force to hold the blank. The punch which is attached with a mechanical or hydraulic press moves downward and provides a necessary drawing force at blank. This force tends to deform metal sheet and forces it into the die cavity and convert it into a cup shape structure. If this force is high, it causes elongation of cup wall to thin and if excessive, it causes tearing of sheet. So the punch force should remain a certain limit to avoid tearing during operation. The deep drawing assembly is shown in "Fig. 1" .

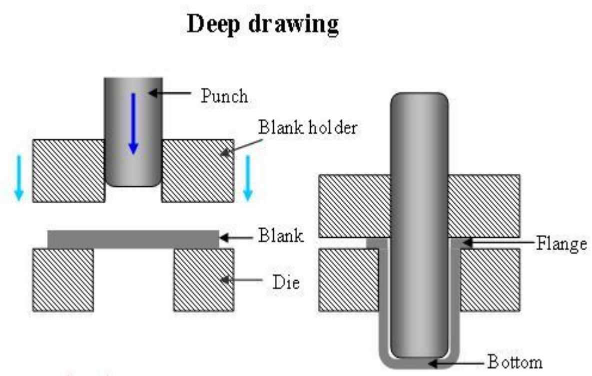


**Fig. 1** Deep Drawing Assembly.

The works reported by earlier researchers on analysis of drawing process are presented.

Mark Colgan, John Monaghan [1] carried out analysis on deep drawing process by combined experimental and Finite Element Analysis (FEA) of a deep drawing process. Raju & et al. [2] studied the effect of equipment and tooling parameters in deep drawing process and found that thickness variation in the formed part may cause stress concentration and may lead to hastening of damage. Kopanathi gowtham & et al. [3] simulated main process variant namely die radius using finite element analysis. Padmanabhan & et al. [4] determined the optimum values of the process parameters in sheet metal forming. Venkat Reddy & et al. [5] studied the principal aspects that effect of various factors like BHF, punch radius, dies edge radius, and coefficient of friction on the wrinkling of cylindrical parts in deep drawing process.

Marumo & et al. [6] studied the influence of sheet thickness on blank holding force and limiting drawing ratio. It is revealed that variation in the blank holding force is required for the elimination of wrinkling and the limiting drawing ratio with sheet thickness. Fallahi Arezodar and Eghbali [7] discussed defects such as wrinkling, tearing, spring back, and thickness variation in different locations of produced cups in deep drawing process. They focused on punch/die shoulder radius, blank holder force, friction between sheet and die/punch/holder. Joshi & et al. [8] optimized process parameters in deep drawing process with the use of different techniques. The formability of sheet metals is affected by many parameters, like material parameters, process parameters and strain bounding criteria.

Young Hoon Moon & et al. [9] examined the possibilities of relaxing the above limitation through the deep drawing with internal air-pressing, aiming towards a process with an increased drawing ratio. Saniee, and Montazeran, [10] studied different methods of analysis such as analytical, numerical and experimental techniques are employed to estimate the required drawing force for a typical component. Verma, Chandra [11] studied the drawing ratio based on material selection and the tool design.

Li & et al. [12] applied optimization method and numerical simulation technology in sheet metal forming process to improve design quality and shorten design cycle. Ravindra Reddy & et al. [13] carried out simulation and FEM analysis of the process by varying process parameters that can interpret concentration of flowing stresses during deep drawing process in advance before actual production of parts, thus anticipation of defect free product can be predicted before actually going for production. Mehta & et al. [14] studied physical defects which occur during metal forming processes. These defects, which may occur on the surface or be internal, are undesirable not only because of the surface appearance, but because they may adversely affect the strength, formability and other manufacturing characteristics of the material.

There are many processing and material parameters which are affecting deep drawing process. Some of the functions are there which cover most of the material and processing parameters affecting the thickness distribution and also the quality of the product. During the last decade many researchers have provided those functions which increase the efficiency of the process and reduce the undesirable features like earing and wrinkles. Some of the functions which are covering most of the material and processing parameters and also the effect of different material and processing parameters are shown. In the present paper analysis is carried on three different work piece materials namely Aluminium, Copper and Titanium at different punch pressures.

## 2 DESIGN CALCULATIONS

The materials used for blank, blank holder, die and punch are presented in "Table 1" .

**Table 1** Dimensions of assembly

| S.No | Part Name | Material | Dimensions(mm) |
|---|---|---|---|
| 1. | Blank | Aluminium, Copper, Titanium | Radius:45<br>Thickness:2 |
| 2. | Blank Holder | Structural steel | Inner radius:20<br>Outerradius:40<br>Thickness:5 |
| 3. | Die | Structural steel | Height:20<br>Fillet radius:2.5<br>Inner radius:17<br>Outer radius:40 |
| 4. | Punch | Structural steel | Radius:15<br>Height:20<br>Fillet radius:2.5 |

**Effective Stress:** Von Mises or effective stress is defined as follows:

$$\bar{\sigma} = \sqrt{\frac{1}{2}\left[(\sigma_r - \sigma_\theta)^2 + (\sigma_\theta - \sigma_t)^2 + (\sigma_t - \sigma_r)^2\right]} \quad (1)$$

Where, σ represents tress.

**Effective Strain:** The effective incremental strain can be stated as:

$$d\bar{\varepsilon} = \sqrt{\frac{4}{3}\left[(d\varepsilon_\theta - d\varepsilon_t)^2 - d\varepsilon_\theta d\varepsilon_t\right]} \quad (2)$$

Where, ε represents strain.

## 3 MODELLING AND SIMULATION

### 3.1. Modelling

In this paper, 3D modeling was carried out using CATIA and the obtained assembly is as shown in "Fig. 2" . All the individually produced components with suitable dimensions are now put together and are assembled to produce the final product. All the parts are inserted into the assembly workbench. All the components are assembled by using surface contact and offset constraints. The axes of the mating components are aligned priorly before using these constraints

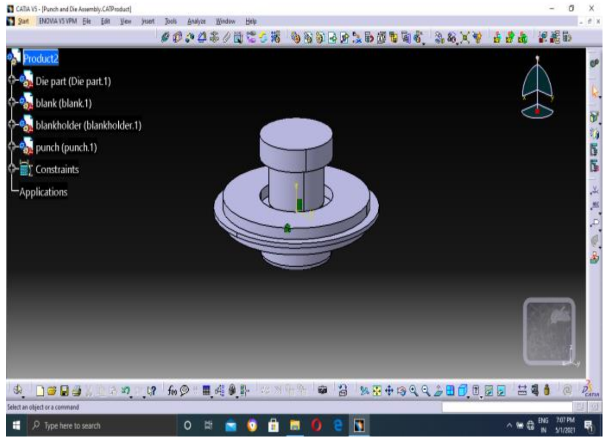


**Fig .2** Deep drawing assembly file in CATIA.

### 3.2. Simulation

The assembly file is imported into the ANSYS workbench as shown in "Fig. 3" for the purpose of analysis and simulation. Material is assigned to each of the parts. Structural steel is considered for punch,die and blank holder and Aluminium, copper and titanium for the blank.

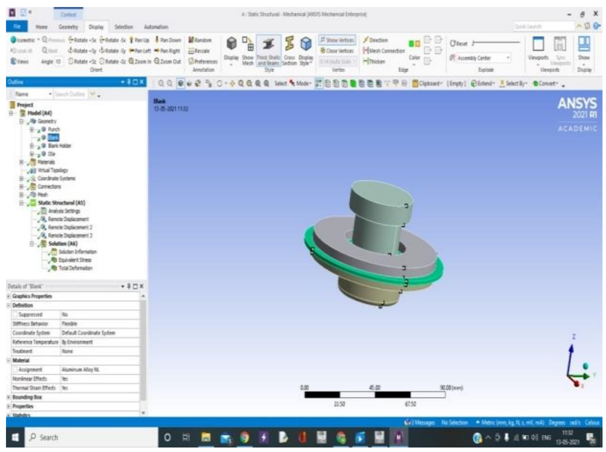


**Fig. 3** Imported File in ANSYS.

**Connections**: Here all the contacts are taken as frictional contacts with the friction coefficient as 0.1.

The Blank is taken as the contact body and the target bodies are punch, blank holder and die, respectively. The connections between the contact and target bodies are as follows:

- ➢ Blank to Punch
- ➢ Blank to Blank Holder
- ➢ Blank to Die

Meshing is performed on the deep drawing assembly as shown in "Fig. 4" .

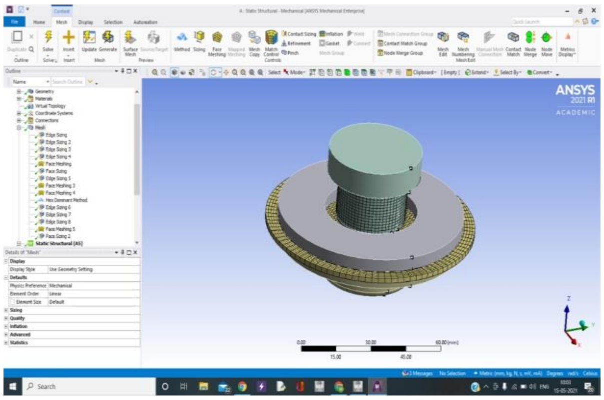


**Fig. 4** Meshing Assembly.

**Remote displacement:** The Remote displacement boundary condition is used to guide the displacement of a face or edge of a structure from a remote point. This provides several advantages compared to the classical displacement boundary condition such as:

- Remote Displacement A is applied to the DIE bottom surface where displacements in all directions are taken as zero i.e (x,y,z)=(0,0,0).
- Remote Displacement B is applied to the top surface of the BLANK HOLDER where displacements in all directions are taken as zero i.e (x,y,z)=(0,0,0).
- Remote Displacement C is applied to the top surface of the PUNCH HEAD where displacements in x and y directions are taken as zero and 15mm in z direction i.e (x,y,z)=(0,0,15).

The displacements that are obtained in ANSYS are shown in the below "Fig. 5" .

Tabular Data

| | Steps | Time [s] | X [mm] | Y [mm] | Z [mm] | RX [°] | RY [°] | RZ [°] |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 2 | 1 | 0.2 | = 0. | = 0. | = -1.5 | = 0. | = 0. | = 0. |
| 3 | 2 | 0.4 | = 0. | = 0. | = -3. | = 0. | = 0. | = 0. |
| 4 | 3 | 0.6 | = 0. | = 0. | = -4.5 | = 0. | = 0. | = 0. |
| 5 | 4 | 0.8 | = 0. | = 0. | = -6. | = 0. | = 0. | = 0. |
| 6 | 5 | 1. | = 0. | = 0. | = -7.5 | = 0. | = 0. | = 0. |
| 7 | 6 | 1.2 | = 0. | = 0. | = -9. | = 0. | = 0. | = 0. |
| 8 | 7 | 1.4 | = 0. | = 0. | = -10.5 | = 0. | = 0. | = 0. |
| 9 | 8 | 1.6 | = 0. | = 0. | = -12. | = 0. | = 0. | = 0. |
| 10 | 9 | 1.8 | = 0. | = 0. | = -13.5 | = 0. | = 0. | = 0. |
| 11 | 10 | 2. | = 0. | = 0. | -15. | = 0. | = 0. | = 0. |
| * | | | | | | | | |

**Fig. 5** Tabulated data of Displacements.

After considering all of the above conditions, analysis is carried out using ANSYS. Total deformation,stress and strain are considered for all the three materials considered. After solving the blank is drawn into the desired cup.

## 4 RESULTS AND DISCUSSION

### 4.1. Aluminium

The Von mises stress is indicated in the above "Fig. 6". The maximum and minimum stresses that are generated in the cup are 990.36 MPa and 149.48 MPa, respectively.

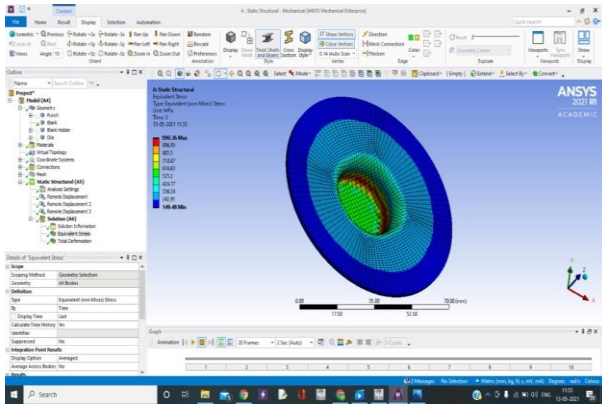


**Fig. 6** Stress in Al cup.

The total deformation in the cup is shown in "Fig. 7" . The maximum deformation in the cup is recorded as 15.432mm and the minimum deformation is recorded as 0mm.

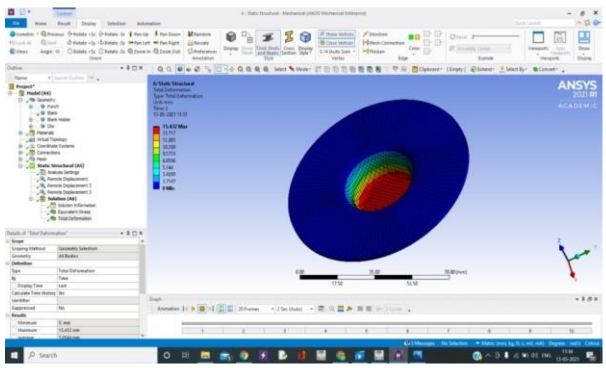


**Fig. 7** Total Deformation in Al cup.

The strain in the cup is as shown in "Fig. 8" . The maximum and minimum strain in the cup are recorded as 0.014408 and 0.0021085.

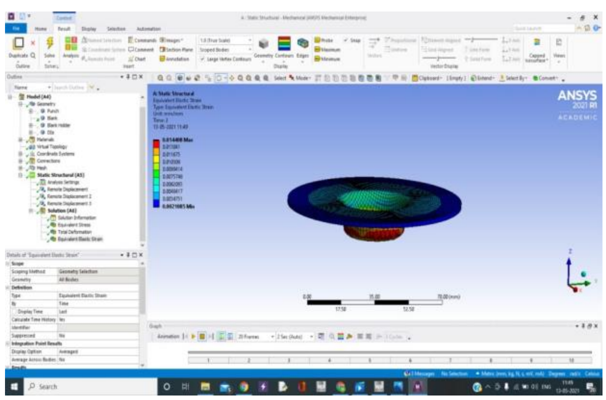


**Fig. 8** Strain in Al cup.

### 4.2. Copper

The Von mises stress is indicated in the above "Fig. 9" . The maximum and minimum stresses that are generated in the cup are 1269.1 MPa and 273.21 MPa, respectively.

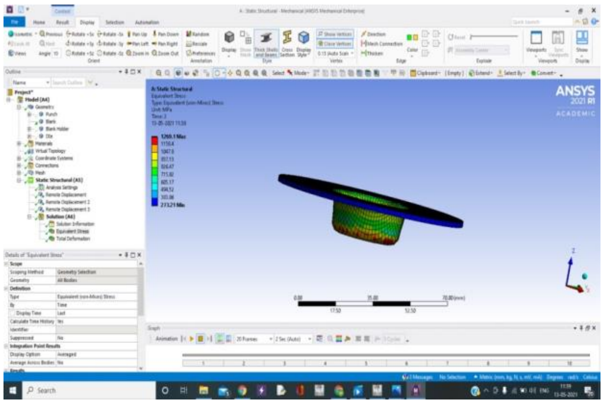

**Fig. 9** Stresses in Cu cup

The total deformation in the cup is shown in "Fig. 10" . The maximum deformation in the cup is recorded as 15.309 mm and the minimum deformation is recorded as 0mm.

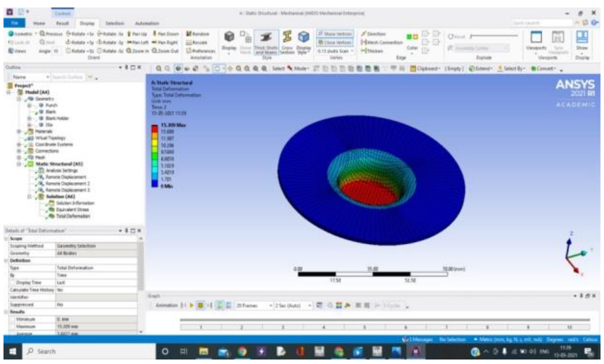

**Fig. 10** Total deformation in Cu cup

The strain in the cup is as shown in "Fig. 11" . The maximum and minimum strain in the cup are recorded as 0.012918 and 0.002462.

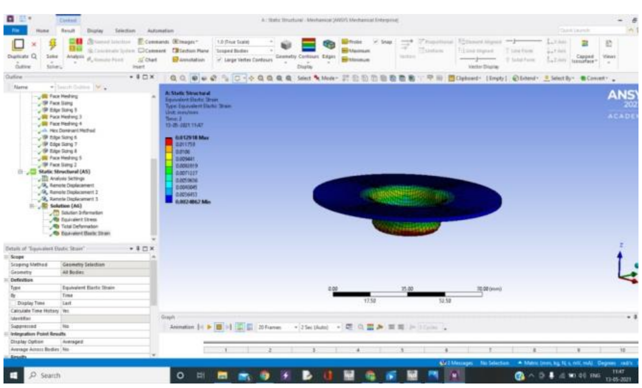

**Fig. 11** Strain in Cu cup.

### 4.3. Titanium

The Von mises stress is indicated in the below "Fig. 12" . The maximum and minimum stresses that are generated in the cup are 3408.9 MPa and 564.71 MPa, respectively.

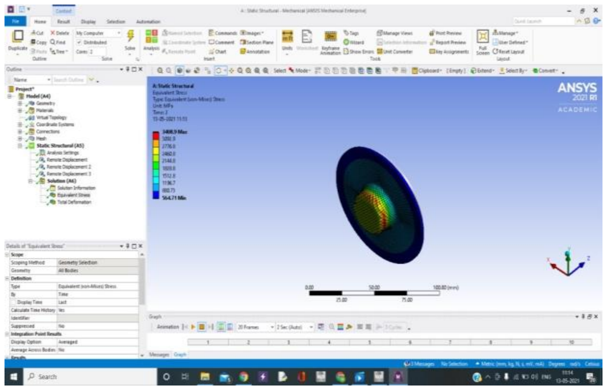

**Fig. 12** Stresses in Titanium cup.

The total deformation in the cup is shown in "Fig. 13" . The maximum deformation in the cup is recorded as 15.423 mm and the minimum deformation is recorded as 0mm.

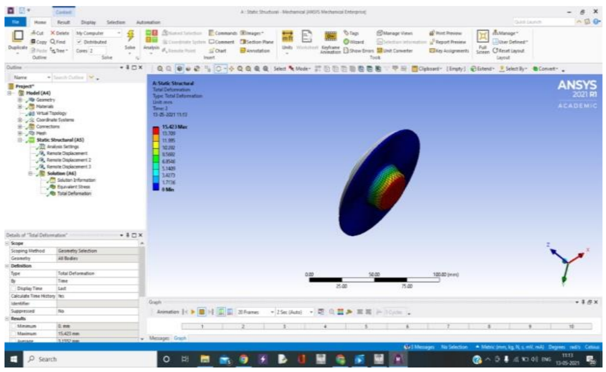

**Fig .13** Total Deformation in Titanium cup

The strain in the cup is as shown in above "Fig. 14" . The maximum and minimum strain in the cup are recorded as 0.037512 and 0.0058912.

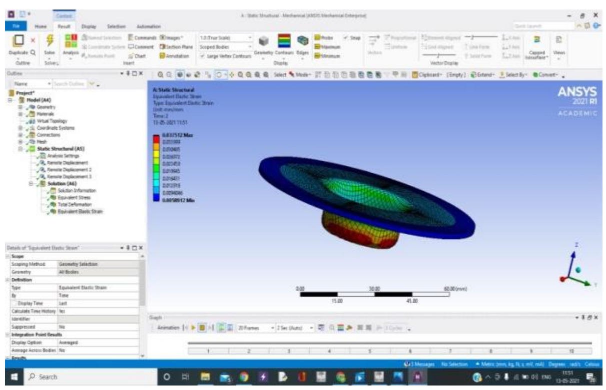

**Fig. 14** Strain in Titanium cup.

From the analysis carried out, the following results are obtained as presented in “Table 2” .

**Table 2** Comparison between the stress, strain and total deformation

| S. No | Material | Stress ( MPa) | Strain | Total Deformation (mm) |
|---|---|---|---|---|
| 1. | Aluminium | 990.36 | 0.014408 | 15.432 |
| 2. | Copper | 1296.1 | 0.012918 | 15.309 |
| 3. | Titanium | 3408.9 | 0.037512 | 15.423 |

The above “Table 2” compares the maximum values of stress, strain and deformation of different materials. We can observe that the maximum stress and strain are generated in Titanium alloy. Whereas the maximum total deformation is generated in Aluminium alloy.

## 5 CONCLUSIONS

Based on the analysis carried out using ANSYS software on cup drawing process, the following conclusions are drawn:

- The maximum withstanding stress is obtained in Titanium and minimum was noticed in Aluminium.
- The strain developed is maximum for Aluminium and minimum for Titanium.
- The deformation is minimum for Copper and maximum for Aluminium.
- It is revealed that from the various stress patterns in the cup drawn, flange region has the minimum stress and punch bottom region has the maximum stress.

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