EXPERIMENTAL INVESTIGATION AND ANALYSIS OF TENSILE AND FORMING BEHAVIOUR OF COLD ROLLED SHEET METAL

K. Logesh
Research Scholar, Department of Mechanical Engineering, Sathyabama University, Chennai, TamilNadu, India

V. K. Bupesh Raja
Professor & Head, Department of Automobile Engineering, Sathyabama University, Chennai, TamilNadu, India

D. Gokula Krishnan, Md Azeemudeen M, A. Nikhil Andrew and K.S. Hariprasath
UG Scholar, Department of Mechanical Engineering, Veltech Dr.RR & Dr.SR University, Chennai, Tamil Nadu, India

ABSTRACT
Automotive and aircraft industries extensively use sheet metals for creating body sheet and instruments panels. Improper handling during the production process and misapplied load would result in defects such as wrinkling, localized thinning and tearing of the finished part. Literature articles published from past research activities throws little light on the formation and control of defects in sheet metal during its working. This paper makes an attempt to understand the formability parameters which influences the quality of finished part during sheet metal forming process. DYNAFORM and LS-DYNA 10 were used to simulate and optimize the deep drawing processes of the sheet metal through Finite Element Analysis. Theoretical results were validated with experimental work. It was found that the theoretical results were in similar to the experimental values

Key words: Formability parameters, Simulate, optimize, Deep drawing behaviour, Finite Element Analysis

http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=11
1. INTRODUCTION

1.1. Sheet Metal Forming

Sheet metal Forming is one of the prominent and conventional methods in the manufacturing industry for converting raw material into finished product. Metal forming is a process of changing the shape of sheet metal through plastic deformation [1]. After converting solid metal piece into product form by metal forming processes, the mass as well as volume remains unchanged. The bulk metal work piece deformed plastically has high volume to surface area ratio. For example forging, extrusion etc. [2].

In case of sheet metal forming there is a high ratio of surface area to thickness. Some typical examples are some of the home appliances like fridge, washer, DVD players etc. The designing of dies, selection of sheet materials and lubricants is still more of an art than a science [1].

1.2. Deep Drawing Process

Deep drawing is a method of forming under compressive and tensile load conditions, whereby a sheet metal blank is transformed into a hollow cup. Hollow cups are formed by placing a blank of the optimized size in the vicinity of the die and the punch wherein the cup is formed by pressing the blank in the die with the help of the punch. The outer periphery of the die which supports the blank holder is termed as a flange [3]. It is desirable to avoid the forming defects during deep drawing and there is a need to know the mechanism of forming [4].

In a deep drawing process, only the punch force is the dependent variable. The prominent independent variables are given below:

- The material properties of the sheet metal
- The ratio between blank diameter and punch diameter.
- Thickness of sheet material.
- The clearance between the punch and the die.
- Punch and die corner radii.
- Friction & lubrication at the punch, die and workplace interfaces.

During the course of deep drawing, the following five processes take place:

- Pure radial drawing between die and blank holder with one principal strain tensile in nature and the others in compressive nature [5].
- Bending and sliding over the die profile.
- Stretching between the die and the punch (Biaxial tensile strain).
- Bending and sliding over the punch profile radius.
- Stretching along the punch bottom (Biaxial tensile strain).

1.3. Formability Problems

The ultimate defect in a formed sheet metal chip or part is the development of crack which destroys its structural integrity and finishing of the material. The usefulness of the part may also be destroyed by local thinning, necking or by buckling in regions of compressive stress [6]. Some of the problems are: Fracturing, Buckling, Shape distortion, loose metal.
1.4. Formability Tests
There are different types of tests to examine the formability for a deep drawing process some of them are: tensile test, cup test, hemispherical dome test and Fukui conical cup test.

2. OBJECTIVE OF STUDY
The combination of DYNAFORM-PC and LS-DYNA is used for finite element analysis of the sheet metal [1]. The objectives of this study include:

- Determination of weak areas,
- Percentage reduction in the blank thickness,
- Stress and strain distribution,
- Forming Limit Diagram for the blank material,
- Failures in sheet metal formability, etc.

2.1. Need for Study
The need of the study about optimization of sheet metal forming includes:

- Reduction in lead times of forming,
- Reduction in number of die-punch sets used,
- Reduction in experimentation work, etc.

3. MATERIAL
The cold rolled steel sheet JED 657 of thickness 2.5 mm is considered for the study. The actual chemical composition of the sheet is presented in the Table 1. [3].

<table>
<thead>
<tr>
<th>Composition</th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. %</td>
<td>0.066</td>
<td>0.347</td>
<td>0.006</td>
<td>0.012</td>
</tr>
</tbody>
</table>

4. EXPERIMENTAL PROCEDURE

4.1. Finite Element Modeling and simulation
Determination of material properties is done through tensile test and the pre-processing which includes meshing, defining of tools, material definition and providing boundary conditions for deep drawing of the drum brake cylinder is elaborated. DYNAFORM is used as a design tool for the punch, die, binder and blank and is than exported in IGES format which in turn is used as an import file for LS-DYNA pre-processor [6-7].

4.1.1. Finite Element Model Building
DYNAFORM software can be used to develop punch, die, binder and sheet blank for a sheet metal forming operation. During the design of punch and die, an appropriate clearance is to be provided between them. This clearance should be greater than sheet thickness and can be obtained from equation [8].

\[ c = t + K\sqrt{10 + t} \] (1)
Where,
c = clearance
t = material thickness
K = coefficient

4.1.2. Die
A die is a specialized tool used in manufacturing industries to fissure or tailor material using a press. Like molds, dies are generally customized and specialized to the item they are used to create.

Create a center line by selecting Pre-process -> Line/Points -> Line. Type the x, y, z coordinates to draw the line by mentioning the end points.

- Create horizontal and vertical lines as per the dimensions of the outer profile of the die with the same options as mentioned above.
- Select Pre process -> Line/Points -> Circle, draw an arc tangent to the two lines with Tangent to two lines option and select the two lines and type the radius of the arc as per the profile of die and click Ok.
- Select Pre process -> Line/Points -> Combine and combine the lines forming die profile.
- Select Pre process -> Surface -> Revolve, choose points and select the centre line as the axis of die and then select combined line. Click Ok.
- Select Part from the main menu and type PUNCH, and then click Ok.

4.1.3. Punch
Select Part -> current; in the option bar choose PUNCH to make current working part as punch. Select Part -> Turn on/off; in the option bar choose PUNCH to make other parts invisible. Repeat the steps in the modeling of die as per the dimensions of the punch to create a punch. Select Part from the main menu and type BLANK. Then click Ok.

4.1.4. Blank

- Select Part -> Current in the option bar and choose BLANK to make current working part as blank. Select Part -> Turn on/off; in the option bar choose BLANK to make other parts invisible.
- Create a centerline by selecting Preprocess -> Line/Points -> Line. Type the x, y, z coordinates to draw the line by mentioning the end points.
- Select Preprocess -> Line/Points -> Circle, draw a circle by typing radius with Center radius option and then click Ok.
- Select Tools -> Define Blank and select the part blank, then select Tools -> Blank generator and the pick the draw circle for the blank surface to be generated.
- Determine the Blank material. Select Part from the main menu and type BINDER, and then click Ok.

4.2. Tensile Test
Material properties like young’s modulus (E), yield stress, strain hardening factors, anisotropic factor and the true stress versus true strain curve are some of the basic input factors and parameters required. The basic input parameter required for deep drawing process need to be procured and get the result from Tensile Test and this test is the mostly used as per
the ASTM E8/E8M standards shown in Figure 1. A Test specimen of 50 mm long and 12.5mm wide is used [8].

![Figure 1](image)

**Figure 1** A Tensile test specimen strip as per ASTM E8/E8M [8]

Tensile test specimens were prepared along three directions, with the specimen taken such that they are aligned 0°, 45° and 90° to direction of rolling of the sheet. These samples were tested in a universal testing machine and the result was noted down. The prepared specimens are shown in Figure 2.

![Figure 2](image)

**Figure 2** Specimen prepared for tensile test

### 4.2.1. Tensile Properties

The standard tensile properties like yield stress ($\sigma_y$) and ultimate tensile stress ($\sigma_u$) can be found out from the stress versus strain data. The engineering stress-strain curve does not give the true indication of the deformation characteristics of the material since it is based entirely on the original dimensions of the specimen. Whereas in real case, the work piece undergoes appreciable change in cross sectional area [10-11].

$$\sigma = s (e + 1)$$

True strain ($\varepsilon$) was determined from the engineering strain by using the relation:

$$\varepsilon = \ln (e + 1)$$

Where, $\sigma$ - True stress

$\varepsilon$ - True strain

### 4.2.2. Strain Hardening Coefficient (n) and Strength Coefficient (k)

The strain hardening coefficient (n) and strength coefficient (k) of the work piece is determined from the slope of the true stress v/s true strain curve when plotted on the
logarithmic coordinates assuming the uniform plastic deformation. A plot of logarithmic value of true stress and logarithmic value of true strain up to the maximum load results in a straight line. The slope of the line ‘n’ is strain hardening and strength coefficient ‘k’ is the true stress at \( \varepsilon = 1.0 \). The values of (n) and (k) are calculated from log – log plot and are recorded [12].

4.2.3. Plastic Strain Ratio
Plastic strain ratio is the resistance of steel sheet to thinning during forming operation. This is the ratio of the true strain in width to the true strain in thickness of the plastically strained sheet metal [7].

\[
\begin{align*}
  r &= \frac{\varepsilon_w}{\varepsilon_t} \\
  \varepsilon_w &= \ln \left( \frac{w}{w_0} \right) \\
  \varepsilon_t &= \ln \left( \frac{t}{t_0} \right) = \ln \left( \frac{L_0 w_0}{Lw} \right)
\end{align*}
\]

Where,

- \( w \) - change in width
- \( w_0 \) - original width
- \( t \) - Change in thickness
- \( t_0 \) - original thickness

To determine the \( r \) value, change in the width and final gauge length of the specimen should be measured in addition to the initial width and gauge length [8-9]. The value of \( r \) varies with respect to the test direction in the anisotropic materials. An average value \( (r_m) \) represents the normal plastic anisotropy of the sheet. The \( (r_m) \) value can be calculated using the equation and is recorded in Table 2.

\[
r_m = \frac{r_0 + 2r_{45} + r_{90}}{4}
\]

Where, \( r_0 \), \( r_{45} \) and \( r_{90} \) are the plastic strain ratio in 0°, 45° and 90° orientation to the rolling direction.

<table>
<thead>
<tr>
<th></th>
<th>( r_0 )</th>
<th>( r_{45} )</th>
<th>( r_{90} )</th>
<th>( r_m )</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.8653</td>
<td>1.6322</td>
<td>1.8829</td>
<td>1.7934</td>
<td>0.2005</td>
</tr>
</tbody>
</table>

5. RESULT AND DISCUSSION
The post-processing of the two stages of the drum brake cylinder whose simulation was done using LS-DYNA solver [10,12].

5.1. Post Processing
Post-processing provides the details like stress distribution in all the directions, nodal displacement, shell thickness at various elements, percentage thickness reduction in the component, FLD plot for the component, energy levels, elemental view, vector representation
of displacement and strain at various elements. Moreover the percentage thickness reduction of various analysis performed during the study is presented [10] [12].

5.1.1. Stress Distribution
The analysis was performed initially for the first stage and then the component obtained after the first stage was used as the blank for the second stage for subsequent forming. The stress distribution in the component after first and second stage Figure 3 is represented [13-14].

![Figure 3 Stress distribution analysis](image)

5.1.2. Nodal Displacement
It is essential for the elements to be properly meshed throughout the material at all nodes [13-14]. The nodal vectors like the displacement viz, rotation, translation are available at the nodes. When the nodes displace, they drag and take the elements along in a certain manner dictated by the element formulation. In other words, displacements of any points in the elements are interpolated from the nodal displacements shown in Figure 4, and this is the main reason for the approximation and ambiguous nature of the solution [13-14].

![Figure 4 Nodal Displacement of Material Analysis.](image)

5.1.3. Shell Thickness
The metal at the center of the blank surface gets attached to the punch surface and in doing so it is thinned down. The metal in this region is subjected to biaxial tensile stress due to the action of the punch. Due to the biaxial tensile stress caused by the punch, metal blank gets drawn radially towards the die cavity. As the blank gets drawn in, the exterior circumference is continuously decreased and reduced from that of the original blank. This means that it is
subjected to a compressive strain near blank in circumferential direction and tensile strain in radial direction [14]. As a result of these two principal strains there is continuous increase in the thickness as the metal moves inward literally. However as the metal passes over and top of the die radius, it is first bent and then straightened while at the same time subjected to tensile stress. The representation of shell thickness is shown in Figure 5. This plastic bending due to the tension leads to the thinning caused by circumferential shrinkage[15-16].

Figure 5 Shell thickness representation

5.1.4. Forming Limit Representation
Sheet metal can be blemished only to a certain stage before local thinning and fracture occur. This level depends principally on the combination of strains imposed, that is, the ratio of major and minor strains. The lowest level occurs at or near plane strain, that is, when minor strain is zero. This information can be plotted graphically and is known as forming limit curve [15].

For plotting an appropriate FLD curve in LS-DYNA we need to provide some basic parameters like allowable thinning and anisotropic value to the system. The software provides the output showing the areas with good quality of forming, cracks and risk of cracks, severe thinning, wrinkling and wrinkling tendencies [15-18]. FLD representation for the first and second stage is represented in Figure 6&7.

Figure 6 FLD representation for first stage
5.1.5. Forming Limiting Diagram

FLD representation can be plotted on a graph which is shown Figure 8.

5.1.6. Elemental Representation

The deformation of nodes leads to distortion of the elements. The h-adaptive method is used to subdivide an element into smaller element whenever an error indicator will show that subdivision of element will provide improved accuracy. As there is an element restriction in our case are shown in Figure 9, the number of elements is seized at 9999. [19-25].
6. OUTPUT

Since the quarter portion of the component was considered for analysis, as it reduces the analysis time, the output from the first stage and second stage can be mirrored and displayed as a whole cup. The output of first and second stage is represented in Figure 10 & 11. [26-27].

Blank material forms the raw material for sheet metal forming. Appropriate blank size will reduce the raw material wastage and helps in reduction of inventory required [24-25]. The blank diameter can be optimized with the help of simulation technique. The optimized blank diameter for our component is found to be 316 mm. The structure of blank is shown in Figure 12. The current blank diameter used is 320 mm. So reducing the diameter to 316 mm will lead to 2.4% saving of material [26-30].
Simulation was performed changing various parameters like velocity given to the die, die force and binder force. The maximum thinning level in each case is reflected in the following Table 3. Considerable reduction in thinning was observed with increase of die velocity to a certain limit i.e. 500 mm/sec. It was also observed that the component had undergone tearing with increase in velocity to great extent. The waving of the blank material at the center of the blank was arrested with the help of appropriate pad which did not affect the thinning in the component as shown in Figure 13. The stress and the strain for each of the orientation through which the specimen were cut, i.e., 0°, 45° and 90° respectively. The results obtained are discussed below.

### Table 3 Simulation results

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Velocity</th>
<th>Die Force</th>
<th>Binder Force</th>
<th>Percentage Thinning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>90</td>
<td>30</td>
<td>32.63</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>80</td>
<td>20</td>
<td>32.75</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>32.89</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>90</td>
<td>30</td>
<td>29.93</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>80</td>
<td>20</td>
<td>30.12</td>
</tr>
<tr>
<td>6</td>
<td>200</td>
<td>-</td>
<td>-</td>
<td>30.27</td>
</tr>
<tr>
<td>7</td>
<td>300</td>
<td>90</td>
<td>30</td>
<td>25.14</td>
</tr>
<tr>
<td>8</td>
<td>300</td>
<td>80</td>
<td>20</td>
<td>25.45</td>
</tr>
<tr>
<td>9</td>
<td>300</td>
<td>-</td>
<td>-</td>
<td>25.56</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>-</td>
<td>-</td>
<td>24.39</td>
</tr>
</tbody>
</table>

Simulation was performed changing various parameters like velocity given to the die, die force and binder force. The maximum thinning level in each case is reflected in the following Table 3. Considerable reduction in thinning was observed with increase of die velocity to a certain limit i.e. 500 mm/sec. It was also observed that the component had undergone tearing with increase in velocity to great extent. The waving of the blank material at the center of the blank was arrested with the help of appropriate pad which did not affect the thinning in the component as shown in Figure 13. The stress and the strain for each of the orientation through which the specimen were cut, i.e., 0°, 45° and 90° respectively. The results obtained are discussed below.

## 7. CONCLUSIONS

- The modeling software DYNAFORM and the finite element analysis software LS-DYNA were used to model and simulate the sheet metal forming process for the drum brake cylinder of JED 657 material and 2.5 mm thick and the tensile tests was performed using Universal Testing machine for the material provided to obtain its material properties and stress v/s strain curve.

- Virtual try outs were performed duplicating the actual process and the blank diameter was optimized. The optimized blank diameter was found out to be 316 mm and hence 2.4% saving in material is observed.

- It can be observed that the flange of the cup and the small portion of the wall adjacent to the flange is identified to have wrinkling tendency and hence can be considered as a weak area. This can be seen from its FLD representation.

- Simulations were performed by varying various parameters like velocity for die, die force and binder cushioning force and their dependency on thickness reduction was observed. It was observed that there is considerable less thinning in the case where velocity of the die was specified to be 500mm/sec. With the higher velocity of the die, cracks were observed in the component and hence leading to failure at the first stage itself.

- Since the quarter section of the cup was considered for the simulation purpose, it was observed that there was waving in the center portion on the blank. It was found that the waving can be arrested with the use of appropriate pad during the first phase of forming operation i.e. closing without affecting the shell thickness of the component.
REFERENCES


