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Formability of Copper Sheet Metal in Deep Drawing

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Abstract*: Sheet metal is one of the most important semi-finished products used in the steel industry, and sheet metal forming technology is therefore an important engineering discipline within the area of mechanical engineering. Sheet metal forming is essentially change of a level sheet metal into a result of wanted shape without imperfection like crack or extreme confined diminishing. In sheet metal forming processes the evaluation of strains by circular grid analysis is obtained through circular grid marking, which has been effectively to solve the problems in metal forming. At the point when sheet metal is shaped, its surface is subjected to various anxieties. This outcomes into non uniform strains to be produced in the shaped part. Thus there will be regions of high strains as well as low strains, which may lead to wrinkling or fracturing of the material. The grid marking method can be easily identify the areas of high strain. The sheet metal is marked with grid before forming process is carried out. After sheet metal is deformed into desired shape, strain distribution can be visualized and critical areas of strain will be found by FLD (forming limit diagram). FLD indicates the limiting strains that sheet metal can sustain over a wide range of major to minor strains. FLD allows us to establish how severe a forming operation comparing the strains develops during forming operations to the limit strains plotted in the FLD. In fact, amid the outline of any new sheet metal part, FLD is utilized broadly to plan the last segment and tooling shape and to enhance the forming procedure parameters. In this study the forming process is carried out experimentally in three stages for copper sheet metal with rubber and without rubber to check the formability and calculated the major and minor strain values in every stage of forming. The strain values obtained for sheet metal forming with rubber and without rubber are compared in three stages. The major and minor strain values are calculated theoretically by Hill's Swift model and the results are compared with experimental results.

***Keywords*: Sheet metal forming, Forming limit diagram, Circular grid method, Strains, Modes of deformation, Rubber**

I. INTRODUCTION

Deep drawing process is a sheet metal forming process where a punch is used to drive a level sheet metal to stream into the hole between the punch and passes on surfaces. As a result, the sheet metal or blank will deformed into desired shape like cylindrical, conic, or boxed-shaped part and also complex parts which normally require redrawing processes by using progressive dies. Deep drawing is a well known determination because of its fast press process durations. Its capability of producing complicated shaped and geometries with low labours requirement is also an advantage in manufacturing industries. A couple of cases of profound drawing applications that is broadly utilize these days incorporate beverage cans, automotive bodies, aircrafts panels and sinks. The important variables which affect the formability of sheet metal in deep drawing process can be divided into two categories: Material and friction factors; and tooling and equipment factors. With the privilege and appropriate choice of these factors, the formability of the material can be process at its ideal outcome and lessening the imperfections in profound drawing process like crack, wrinkling and earing. Sheet metal forming process is used for both serial and mass production. Their characteristics are high productivity, highly efficient use for material, easy servicing machines, the ability to employ workers with relatively less basic skills and other advantageous economic aspects. Part that made from sheet metal has many attractive qualities: Good accuracy of dimension, adequate strength, light weight and a broad range of possible dimensions.
The properties considered to be important in sheet products designed for deep drawing include:

A. Piece, with a base measure of incorporations and leftover components adding to better drawability
B. Mechanical properties, of which the elongation as measured in a tensile test, the plastic strain ratio 'r', and the strain hardening exponent 'n' are of primary importance. The quality of the last part as measured by yield quality should likewise be considered, yet this is more an element of the application than shaping by profound drawing

C. Physical properties, including dimensions, modulus of elasticity, and any special requirement for maintaining shape after forming.

II. MODES OF DEFORMATION IN SHEET METAL FORMING

In sheet deformation process the most common feature is that the stress perpendicular to the surface of the sheet is small, compared with the stresses in the plane of the sheet (the membrane stresses). If we assume that this normal stress is zero, a major simplification is possible. Such a process is called plane stress deformation. Plane stress deformation of a work hardening theory is applied to some region of a sheet undergoing uniform, proportional deformation. If, by convention, we assign the major principal direction 1 to the direction of the greatest (most positive) principal stress and consequently greatest principal strain, then all points will be to the left of the right hand diagonal if Figure , i.e. left of the strain path in which $\beta = 1$.

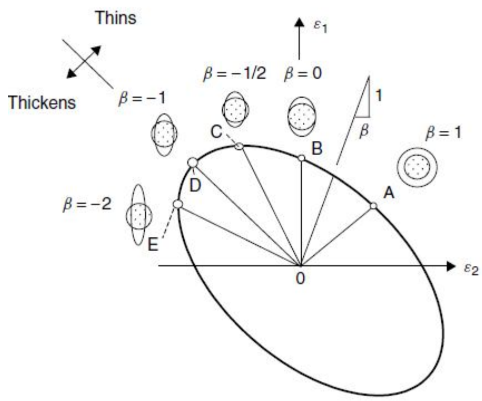

Figure 1**:** The strain diagram showing the different deformation modes corresponding to different strain ratios.

As stated above, the principal stress in the direction 1, will always be tensile or positive, i.e. $\sigma_1 \geq 0$. For the extreme case in which $\sigma_1 = 0$ we find from equations that $\alpha = -\infty$ and $\beta = -2$. Therefore all possible straining paths in sheet forming processes will lie between OA and OE and the strain ratio will be in range $-2 \leq \beta \leq 1$.

A. Equal biaxial stretching, $\beta = 1$

The path OA indicate equal biaxial stretching, sheet stretched over a conical punch will deform in this way at the center of the process shown in Figure1.8. The membrane strains are equal in all directions and a grid circle expands, but remains circular. As $\beta = 1$ the thickness strain is $\varepsilon_3 = -2\varepsilon_1$, so that the thickness decreases more rapidly with respect to ε_1 than in any other process.

B. Plane strain, $\beta = 0$

In this process illustrated by path, OB in Figure1.9, the sheet extends only in one direction and a circle becomes an ellipse in which the minor axis is unchanged. In long trough like parts, plane strain is observed in the sides as shown in Figure1.9. It will be demonstrated later that in plane strain, sheet is especially subject to disappointment by part.

C. Uniaxial tension, $\beta = -1/2$

The point C in Figure1.10 is the process in a tensile test and occurs in sheet when the minor stress is zero, i.e. when $\sigma_2 = 0$. The sheet stretches in one direction and contracts in the other. This process will occur whenever a free edge is stretched as in the case of hole extrusion.

D. Constant thickness or drawing, $\beta = -1$

In this process, point D, membrane stresses and strains are equal and opposite and the sheet deforms without change in thickness. It is called drawing as it is watched when sheet is drawn into a focalizing region. The process is also called pure shear and occurs in the flange of a deep drawn cup as shown in Figure1.11. The thickness strain is zero and work solidifying is steady. Part is impossible and in down to earth framing operations extensive strains are regularly experienced in this mode.

E. Uniaxial compression, $\beta = -2$

This process indicated by the point E, is an extreme case and occurs when the major stress σ_1 is zero, as in the edge of a deep drawn cup Figure1.12. The minor stress is compressive, i.e. $\sigma_2 = -\sigma_f$ and the effective strain and stress are $\bar{\varepsilon} = -\varepsilon_2$ and $\bar{\sigma} = -\sigma_2$ respectively. In this process, the sheet thickness and wrinkling is likely.

F. *Thinning and Thickening*

Plotting strains in this king of diagram, Figure1.13, is very useful in assessing sheet forming processes. Failure limits can be drawn also in such a space. The position of a point in this chart will likewise show how thickness is changing; if the fact is to right of drawing line, i.e. if $\beta > -1$, the sheet will thin. For a point below the drawing line, i.e. $\beta < -1$, the sheet becomes thicker.

III. EXPERIMENTAL APPROACH

In experimental approach the circular grid analysis is used. This involves etching a pattern of fine circles on the sheet metal before pressing. The sheet metal forming process is carried out for sheet metal with rubber and without rubber. The forming process is done in two trials. In the first trial the forming process is done in three stages with cone punches 110^0, 95^0, 84^0 respectively and in the second stage the forming is done directly by cone punch with 84^0. Here natural rubber is used in case of sheet metal forming with rubber.

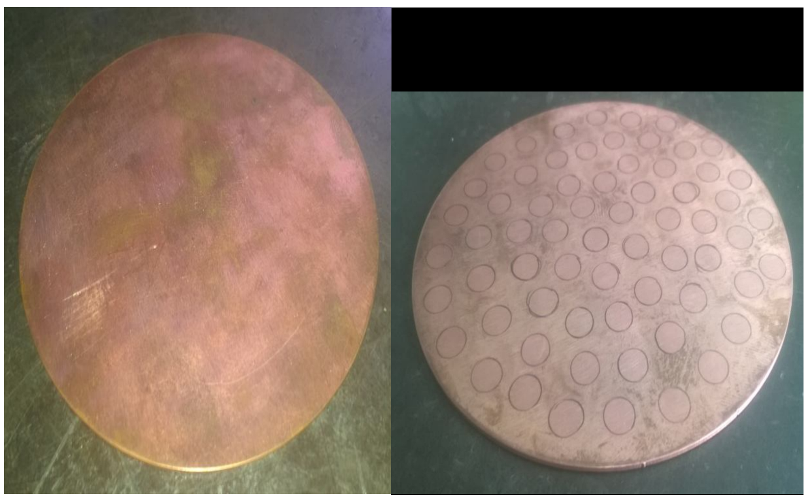

Figure 2: Sheet metal before and after chemical etching

A. *Experimental setup for forming*

The trials are done on the Hydraulic Press machine of Capcity 4-5ton. The Punch is fixed by U-clamps to the upper portion of the hydraulic ram which is movable in up and down motion.The Die is fixed to the table of the Hydraulic machine which is fixed. The workpiece or component is lubricated at bottom side of the component or sheet with grease and placed on die where the clearance is given for the component to sit in the slot. We have to place the blank holder on the sheet or blank and the allen screws are fastened to the die cavity. Care to be taken that the allen screws are not tigthened very hard,

Figure3: Experimental setup

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Once the setup is done. We have to ensure that the punch and die are fixed in their positions. Swith on the machine. The machine is operated to gradually lower the hydraulic ram to which the punch is fixed. The punch has to lower with uniform stroke length. Once the Punch is butted with the Die when the limit is reached and the component been formed. Now the punch has to retrieve to its original position by lifting it upwards. After the Machine is switched off , the allen screws are removed and the blank has to be cleaned. The Die and punch are also cleaned and the setup is ready for the next drawing process.

B. Forming in trial I

In trial I the forming porcess is done in three stages with cone punches 110^0, 95^0, 84^0 resepectively for sheet metal with rubber and without rubber

1) tage I with cone punch 1100

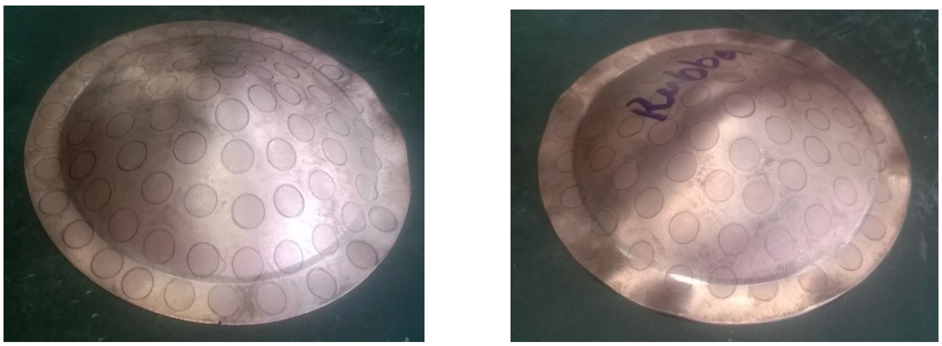

Figure 4: Sheet metal forming with rubber and without rubber in stage I

2) Stage II with cone punch 950

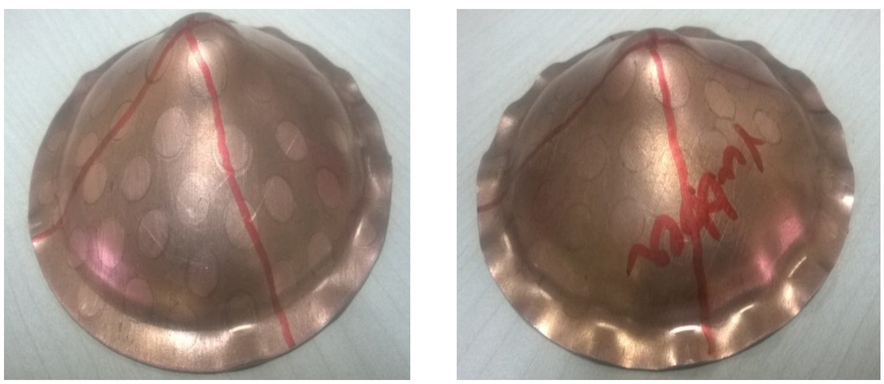

Figure 5: Sheet metal forming with rubber and without rubber in stage II

3) Stage III with cone punch 840

Figure 6: Sheet metal forming with rubber and without rubber in stage III

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C. Forming in Trial II with cone punch directly by 840

In second trial the forming is done in single stage with cone punch directly by 84^0.

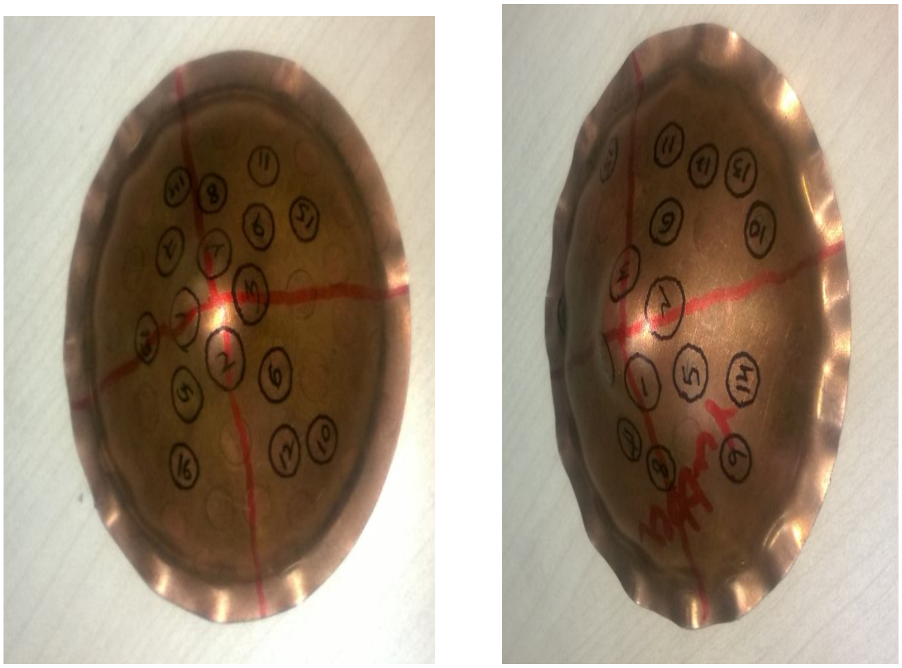

Figure 7**:** Sheet metal forming with rubber and without rubber by conepunch 84^0

D. Calculations for Forming limit diagram

A forming limit outline, otherwise called a shaping point of confinement bend, is utilized as a part of sheet metal shaping for anticipating framing conduct of sheet metal [1]. FLD offer a convenient and useful tool in sheet products manufacturing analysis. They demonstrate the basic mixes of significant strain and minor strain in the sheet surface at the beginning of necking disappointment. Formability in the context of multiple phase operations strongly depends of the deformation history and therefore demand an investigation of every particular case. The essential idea of the FLD was first presented by Keeler and Backofen, who built up the correct hand side of the FLD. Goodwin extended this diagram to the left hand side. Keeler and Goodwin propose framework strain investigation which includes drawing an example of fine circles on the sheet metal before many pressings the circles will be distorted into ovals which can be measured to demonstrate major and minor strains created in the part. An estimate of how circle the metal is to failure is obtained by reference to the FLD, which is a plot of the major and minor strains at fracture over a wide range of conditions. Forming limit diagrams indicate the limiting strains that sheet metals can sustain over a wide range of major to minor strain ratios. An important tool in developing sheet metal forming is the Keller-Goodman forming limit diagram.. The permissible range of the major and minor strains is actually available for a wide range of sheet metals and used considerably for designing of deep drawing operations. The major strain, ε_1 and minor strain, ε_2 of the blank can be calculated by using the formula as shown in Equation

$$\text{Major strain } \varepsilon_1 = \frac{D_{1,cg(major)} - D_{0,cg(major)}}{D_{0,cg(major)}}$$

$$\text{Minor strain } \varepsilon_2 = \frac{D_{1,cg(minor)} - D_{0,cg(minor)}}{D_{0,cg(minor)}}$$

Where,

D_0 = Diameter of circle grid before deformation (mm)

D_1 = Diameter of circle grid after deformation (mm)

1) Experimental results in trial I and trial II

Table 1: The strain values in stage I with cone punch 110^0

S.No	Without rubber		With rubber	
	Major true strain	Minor true strain	Major true strain	Minor true strain
1	0.13714	0.0685	0.088571	0.057142
2	0.1028	0.0685	0.09714	0.01428
3	0.117142	0.01714	0.07142	0.0457142
4	0.09428	0.0485	0.06857	-0.005714
5	0.0914	0.02	0.09428	-0.04
6	0.01714	0.0114	0.06285	-0.09142
7	0.08285	-0.08	0.06	-0.08571
8	0.06285	-0.00857	0.0142	-0.02
9	0.05428	0.005714	0.05714	-0.008571
10	0.0971	-0.002857	0.03142	-0.04
11	0.03142	0	0.06	-0.03142
12	0.03142	0.0057142	0.04571	-0.1171
13	0.037142	-0.04	0.04	-0.07428
14	0.05714	-0.05428	0.03714	-0.08285
15	0.04285	-0.08	0.0142	0.1028

Table 2: The strain values in stage II with cone punch 95^0

S.No	Without rubber		With rubber	
	Major true strain	Minor true strain	Major true strain	Minor true strain
1	0.18285	0.08	0.1442	0.0742
2	0.15428	0.12	0.1171	0.0114
3	0.1457	0.0742	0.09142	0.02285
4	0.15142	0.134285	0.09714	0.005714
5	0.05714	0.008571	0.1228	0.005714
6	0.11714	0.01428	0.1342	0.00571
7	0.11428	0.01142	0.10857	-0.00571
8	0.0628	0	0.03	-0.0142
9	0.07428	-0.0485	0.05428	-0.0657
10	0.05142	-0.1685	0.07714	-0.05428
11	0.08857	-0.01714	0.04	-0.1
12	0.1485	-0.03428	0.0542	-0.1342
13	0.06285	-0.04571	0.014	-0.1
14	0.10285	-0.02	0.04	-0.16
15	0.1057	-0.02571	0.02285	-0.1028

Table 3: The strain values in stage III with cone punch 84^0

S.No	Without rubber		With rubber	
	Major true strain	Minor true strain	Major true strain	Minor true strain
1	0.23142	0.1514	0.1471	0.1314
2	0.2857	0.1628	0.21142	0.01142
3	0.2914	0.12	0.1828	0.0285
4	0.2828	0.1428	0.1971	0.01142
5	0.1442	0.01428	0.1257	-0.04
6	0.1457	0.04	0.0742	-0.03142
7	0.1228	0.0171	0.1057	-0.0542
8	0.1428	0.0314	0.0885	-0.06857
9	0.1285	-0.0257	0.0857	-0.02285
10	0.1142	-0.0142	0.08285	-0.01142
11	0.1028	-0.0628	0.09428	-0.0485
12	0.09142	-0.0457	0.0542	-0.1085
13	0.0685	-0.01142	0.05142	-0.0657
14	0.0742	-0.0657	0.04571	-0.08
15	0.0828	-0.1085	.0828	-0.0628

Table 4: The strain values in trail II with cone punch 84^0

S.No	Without rubber		With rubber	
	Major true strain	Minor true strain	Major true strain	Minor true strain
1	0.305714	0.091428	0.29142	0.1171428
2	0.2857142	0.114285	0.277142	0.08571
3	0.274285	0.1314285	0.237142	0.16285
4	0.3	0.14285	0.26	0.108571
5	0.245714	0.06	0.171428	0.045714
6	0.217142	0.06	0.15428	0.014285
7	0.1057142	0.0285	0.131428	0.014285
8	0.131428	-0.0114285	0.177142	0.0114285
9	0.1628571	-0.03428	0.06571	0.01428
10	0.131428	0	0.131428	-0.08
11	0.065714	-0.01428	0.14	-0.054285
12	0.1171428	-0.034285	0.137142	-0.037142
13	0.10285	-0.025714	0.08571	-0.09142
14	0.094285	-0.0685714	0.06	-0.005714
15	0.13714	-0.028571	0.0857	-0.065714

IV. THEORETICAL APPROACH

In sheet metal shaping the essential criteria is choosing a material are identified with capacity of the part qualities, for example, quality, thickness, solidness and consumption resistance. For sheet metal the ability to be shaped in a given process, often called its formability, should also be considered. To evaluate formability, we should have the capacity to portray the conduct of the sheet precisy and express properties in numerical shape. In sheet metal framing there are two administrations of intrigue i.e. versatile and plastic misshapening. Forming a sheet to some shape obviously incorporates enduring "plastic" stream and the strains in the sheet could be extremely considerable. Whenever there is a stress on a sheet element, there will also be some elastic strain. This will be small, typically less than one part in one thousand. It is often neglected, but it can have an important effect. In theoretical approach the major and minor strains are calculated theoretically by using Hill's-Swift model.

A. Hill's - Swift model

The limit strain values of forming limit diagram can be provided by the basis of the swifts diffuse theory and the hill localized instability theory and where Swift's and Hill's theories are used to calculate the forming limit strains on the left and right side of the FLD respectively [5]. Assuming that the stress- strain relationship of sheets can be expressed by Holloman's equation.

$$\sigma = k\varepsilon^{n}$$

As indicated by Swift's and Hill's measure the formulae computing as far as possible strains can be composed as take after, with $\alpha = \frac{\sigma_2}{\sigma_1}$

For $\varepsilon_2 < 0$:

$$\varepsilon_1 = \frac{1+(1-\alpha)r_m}{1+\alpha} n$$

$$\varepsilon_2 = \frac{\alpha-(1-\alpha)r_m}{1+\alpha} n$$

For $\varepsilon_2 > 0$:

$$\varepsilon_1 = \frac{[1+(1-\alpha)r]\left[1-\frac{2r_m}{1+r}\alpha+\alpha^2\right]}{(1+\alpha)(1+r_m)\left[1-\frac{1+4r_m+2r_m^2}{(1+r)^2}\alpha+\alpha^2\right]} n$$

$$\varepsilon_2 = \frac{[(1+r_m)\alpha-r_m]\left[1-\frac{2r_m}{1+r}\alpha+\alpha^2\right]}{(1+\alpha)(1+r_m)\left[1-\frac{1+4r_m+2r_m^2}{(1+r)^2}\alpha+\alpha^2\right]} n$$

B. Theoretical strain results for copper sheet metal from Hill's-Swift model

From the tensile properties of 1mm copper sheet metal
Strain hardening component (n) = 0.44
Plastic strain ratio (r) = 1
α = 0.1 to 0.9

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Table 5: Theoretical strain values of copper sheet metal

Stress ratio(α)	$\varepsilon_2 < 0$		$\varepsilon_2 > 0$	
	Major true strain (ε_1)	Minor true strain (ε_2)	Major true strain (ε_1)	Minor true strain
0.1	0.76	-0.32	0.4122	-0.1735
0.2	0.66	-0.22	0.4017	-0.1339
0.3	0.575	-0.1353	0.4022	-0.0946
0.4	0.5028	-0.06	0.4154	-0.0519
0.5	0.44	0	0.44	0
0.6	0.385	0.055	0.4719	0.0674
0.7	0.3364	0.10532	0.5015	0.1543
0.8	0.2933	0.146	0.47384	0.2571
0.9	0.2547	0.18526	0.493	0.358

V. RESULTS AND DISCUSSION

The forming is done for the copper sheet metal. The experiment is carried out in two trials. In first trial the experiment is done in three stages with cone punch 110^0, 95^0 and 84^0 and in the second trial the experiment is done directly by cone punch 84^0. In the experiment the strain values are calculated by using grid analysis method. In both trials the experiment is carried out for sheet metal with rubber and without rubber. The major true strain and minor true strain values are compared for sheet metal with rubber and without rubber. The strains are calculated theoretically and compare the results with experimental results.

The FLD is compared for sheet metal forming with rubber and without rubber and the experimental results are compared with theoretical results.

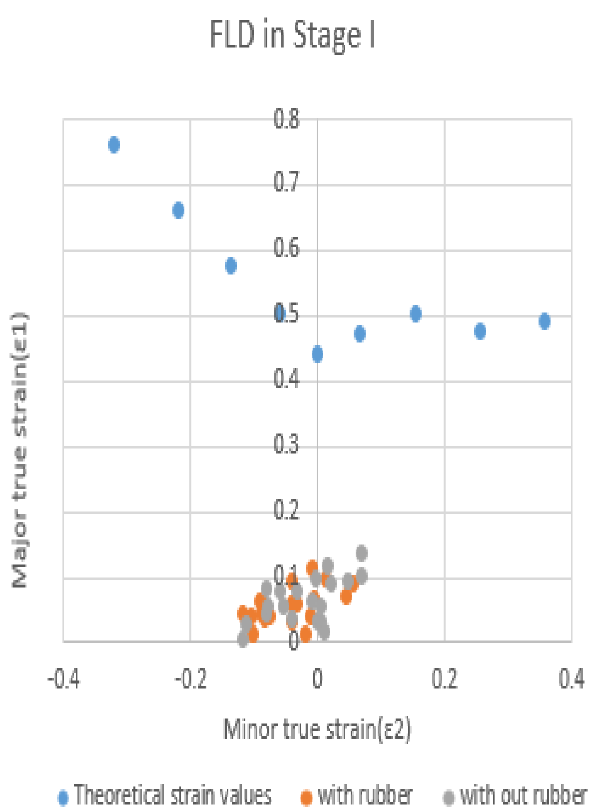

Figure 8: Stage I (cone punch 110^0) in trail I

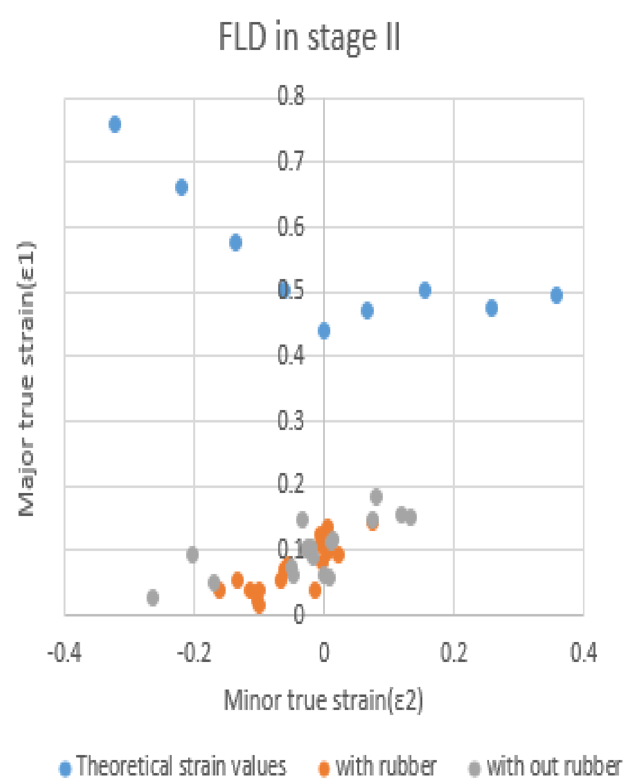

Figure 9: Stage II (cone punch 95^0) in trail I

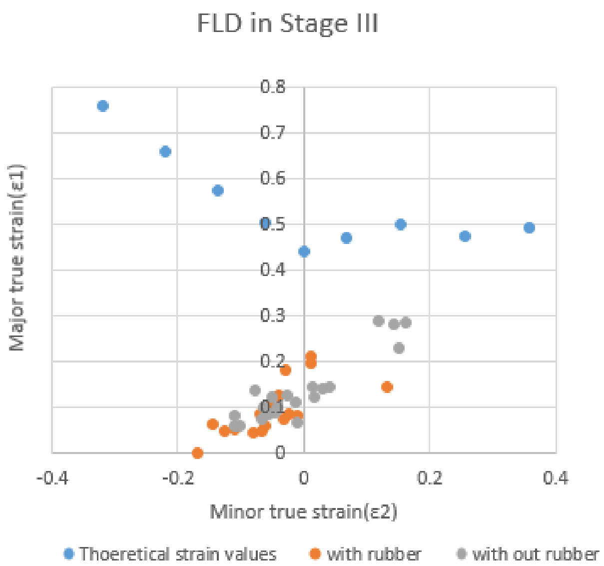

Figure 10: Stage III (cone punch 84^0) in trail I

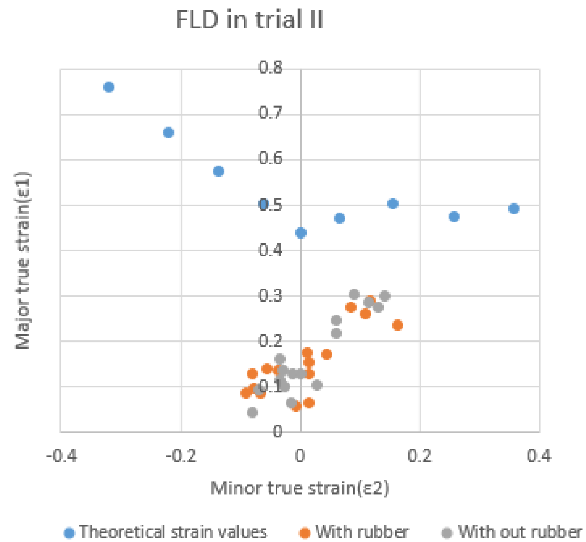

Figure 11: Trail II (cone punch 84^0)

The above FLD' s shows that the major true strain and minor true strain values obtained in sheet metal forming without rubber is more than that of the major and minor true strain values obtained in sheet metal forming with rubber in all stages of experiment. Areas of high strain values are observed. From the graph it shows the right side positive values represent the critical area of forming. Hill's-Swift model is very good to calculate the theoretical strain values. And theoretical values are calculated by using this model. The experimental values compared with theoretical values and all the experimental values are below the theoretical values for pure copper from Hill's-Swift model. The above graphs shows the experimental values are below the theoretical values that means if the experimental values are above the theoretical values the component may fail.

VI. CONCLUSION

The present thesis covers the formability of copper sheet metal in deep drawing. It deals with the theoretical, experimental and for predicting the formability behaviour of copper sheet metal. Grid analysis method had been done to calculate the major and minor true strains. The experimental approach has been carried out in two trials. In the first trial the forming is done in three stages with cone punches 110^0, 95^0 and 84 . In second trial the forming is done directly with cone punch 84^0. The sheet metal forming is done for with rubber and without rubber in both the trials, calculated the major and minor true strains and FLD is plotted for both the trials finally the results obtained in the sheet metal forming with rubber and without rubber were compared. The obtained experimental results of sheet metal without rubber are more than the sheet metal with rubber. The experimental values are below the theoretical forming limit diagram of copper sheet metal.

By using Hill's- Swift model we can calculate the major true strain and minor true strain are calculated individually. The major and minor true strain values are calculated theoretically by using this model. The theoretical and experimental results were compared; the theoretical results have good agreement with experimental results obtained in both the trials. The experimental results are below the theoretical FLD. Here Forming limit diagram is used for predicting the forming behaviour. In fact during the outline phase of any new sheet metal segment FLD is utilized broadly to plan the last part, tooling shape and to enhance the framing procedure parameters in sheet metal shaping.

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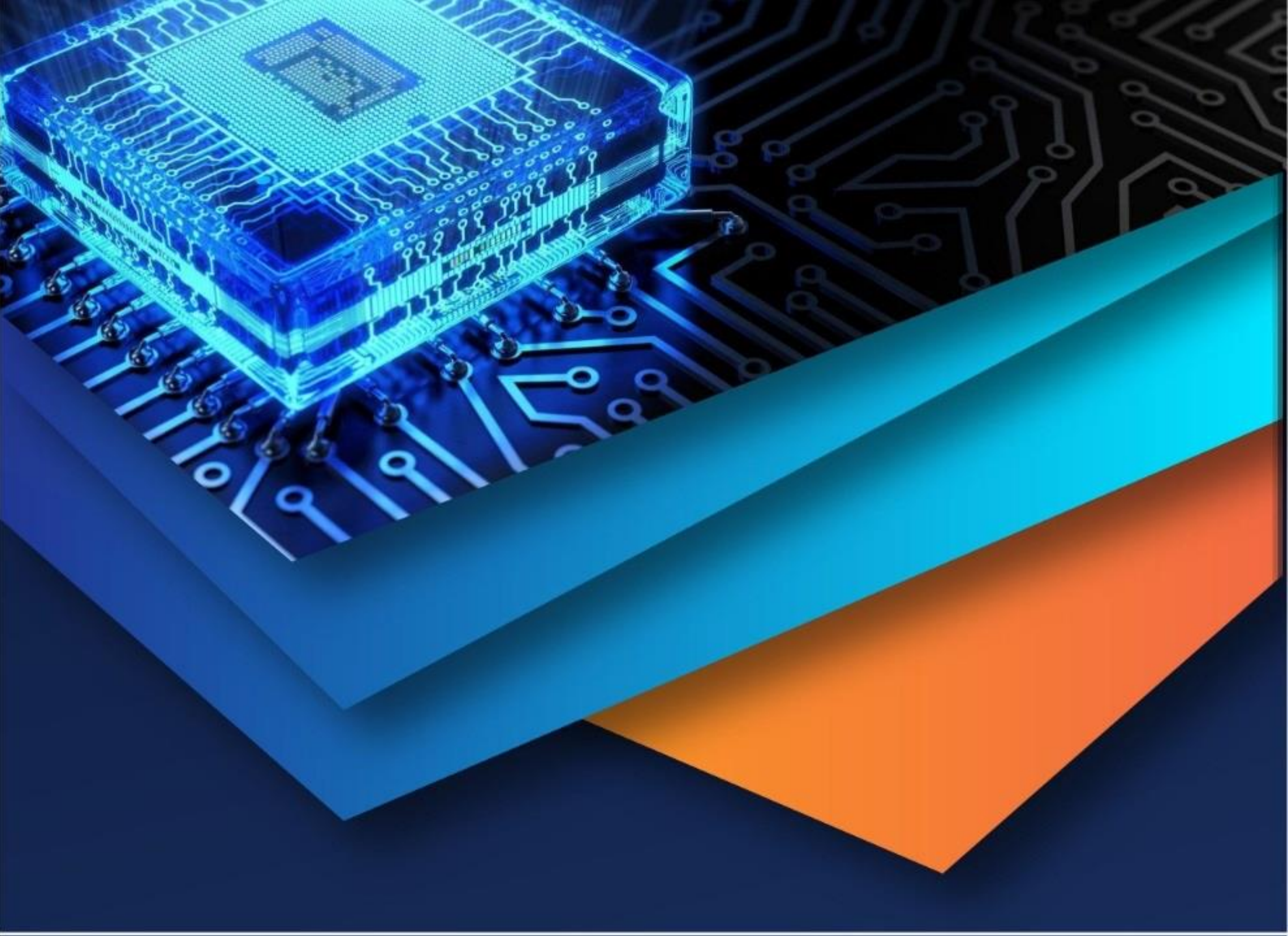

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