Formability Analysis of Copper 27200 Sheets on Single Point Incremental Forming using CNC Vertical Milling Machine

S. Milkin Sudharson
Student of Mechanical Engineering,
Anna University (BIT),
Tiruchirappalli-620024

M. Pavithran
Student of Mechanical Engineering,
Anna University (BIT),
Tiruchirappalli-620024

S. Muthupandi
Student of Mechanical Engineering,
Anna University (BIT),
Tiruchirappalli-620024

Dr. T. Parameshwaranpillai
Faculty of Mechanical Engineering,
Anna University (BIT),
Tiruchirappalli-620024

***Abstract*:- New trends in sheet metal forming are emerging rapidly and different process have been developed and used to accomplish the required goals of flexibility and reduction of cost in production. One of the inovative process in sheet metal forming process is the Incremental Sheet metal Forming process for small batch production which eliminates the die,punch and errors. In this work, Single Point Incremental Forming(SPIF) technique was carried out on copper 27200 sheets. Straight groove and cupping test were carried using hemispherical ended tool in CNC vertical milling machine. Deformation for the various incremental step depths were measured on straight groove with different lengths. On cupping test different wall angle cups formed and their respective deformation for various incremental step depths were measured and tabulated. The Forming Limit Diagrams (FLD) for both the test were plotted. It is also found that the formability decreases as the step depth increases during the SPIF process.**

Keywords:Formabilty,Single point incremental forming,Forming limit diagram, Deformation, Sheet metal forming.

I. INTRODUCTION

Sheet metals are manufactured by the rolling processes. Sheet metals have various applications starting from a simple sheet metal tray to complicated parts used in aircraft, automative, construction. The other applications are house hold appliances, food and beverage containers, boilers, kitchen equipment, office equipment etc. A flat sheet metal is formed into complicated shapes by using the die and punch. The sheet metals are ductile in nature. They can be formed only to a certain limit. Beyond this limit failures like necking and fracture occur. The strain at the failure is called forming limit strain it is a measure of formability of sheet metals. The conventional sheet metal forming uses the punch and die. It results in less limiting strain. It involves various problems like friction between die and sheet metal, difficulty in lubrication, high severity of forming. This is due to complicated shapes of the component produced. Moreover, the cost of the die and punch is also high. The press forming processes for sheet metal forming is limited due to the formation of necking, fracture, wrinkling or earing. The strain values are measured at the onset of these failures under tension-tension region, tension-compression region, and plane strain regions. These are used to construct the Forming Limit Diagram (FLD). The FLD is an effective tool to study the formability of sheet metals. It gives the limiting strain under all strain conditions. The FLD is also influenced by strain paths, blank holding pressure, and severity of forming process, friction and lubrication. The conventional press forming process become costlier for small batch production. This is due to the dedicated punch and die, hydraulic press and skilled tool designer. In conventional forming, the varying strain path and severe strains reduces the formability of complex shape. These problems can be rectified in incremental sheet forming. In Single Point Incremental Forming (SPIF), a ball ended forming tool is moved in user specified paths. It incrementally develops a desired shape. Since the total deformation is incrementally achieved, the limiting strain is increased. The Incremental Sheet Forming (ISF) eliminates the use of die and punch. The amount of friction between forming tool and sheet metal is very less in incremental forming. Ofcourse, the deformation is incremental, local in nature and gradual. These enhance the limiting strain during ISF. It is an growing process. Therefore, a wide analysis is recquired to develop the theory of incremental forming. In the present stage, only less number of research works has been carried out in this area. Brasses are copper zinc alloys with the wide range of engineering uses. The addition of zinc to copper rises the strength and gives the range of properties and the process are a very versatile range of materials. They are used for their strength, corrosion, resistance, apperance and color and ease of working and joining. The single phase alpha process, containing upto abouth 37% zinc, are very ductile and easy to cold work, weld and braze. The dual phase alpha beta process are usually hot worked. There are many brasses with properties tailored for specific applications by the level of addition of zinc. Minor amounts of other alloying elements may also be added.

II. MATERIALS AND EXPERIMENTAL SETUP

2.1 Sheet Metal

The ISF is more suitable for the sheets having low thicknesses. Therefore, commercially available copper 27200 sheet with 2mm thickness was chosen for this study. The sheets were cut into 190*90 mm blanks by shearing operation. One side of the blanks were grid marked by using permanent ink. The grids were circles in rectangular array. They were having a diameter of 2.5mm. These gird circles were used to facilitate the strain measurement after forming.

2.2 CNC Vertical milling machine setup

The SPIF can be carried out using a CNC Vertical milling machine or robots. A CNC vertical machine shown in figure was chosen for this work.

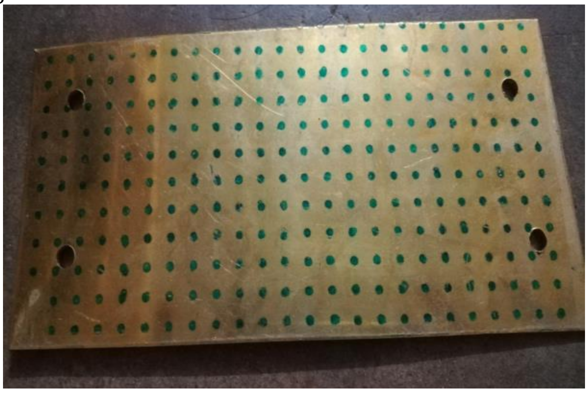


Fig.1.Plate with grid marking

Specification of CNC machine:
Table size : 810*400mm
Travel : x-axis:510mm, y-axis:400mm, Z-axis:400mm
Feed rate : 1-7000 mm/min
Spindle speed : 60-800 rpm

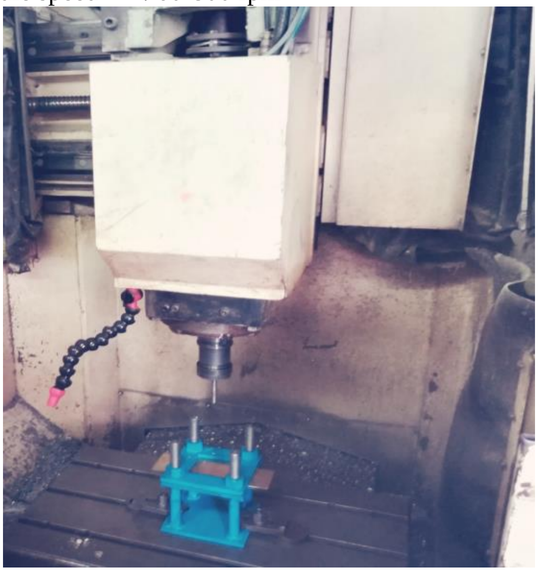


Fig.2.CNC Vertical milling machine setup

2.3 Forming tool

The forming tool used is shown in Figure.3. It is made up of Carbide. The length of the tool is 45mm and its one end is shaped into hemisphere with a diameter of 12mm.

III. TESTS

3.1 Tensile Test

Material strength testing, using the tensile or tension test method, involves applying an ever-increasing load to a test sample upto the point of failure.

Fig.3.Forming Tool for SPIF

The process creates a stress/strain curve showing how the material reacts throughout the tensile test. Here ASTM E8 test method was chosen for this work. The copper sheet was cut into required dimension according to test standard along rolling direction, transverse direction and 45^{o} to rolling direction. The data generated during tensile testing is used to determine the mechanical properties of copper 27200 are as follow

Tensile Test Result

DIRECTION	TENSILE STRENGTH(MPa)
Rolling direction	317.334
Transverse direction	319.361
45^{o} to Rolling	337.442

From the above graphs it is seen that tensile test is maximum on 45^{o} to rolling direction. Therefore formability will be better in this direction. Hence this direction was selected for Straight Groove test.

3.2 Straight Groove Test

The straight groove test was conducted using the CNC vertical milling machine. To study the incremental formability of copper 27200 straight groove test was conducted. The sheet was clamped using a fixture on the machine table. A hemispherical ended tool as shown in Figure 3 was mounted on the spindle of CNC vertical milling machine. The CNC Programme was prepared to form a straight groove in the sheet blank. The steps in making straight groove are as follows:

Step 1: SPIF tool was made to touch the surface of the sheet blank.

Step 2: SPIF tool was made to penetrate by a programmed depth into the sheet blank.

Step 3: SPIF tool was made to move on a straight path to make a straight groove.

Step 4: SPIF tool was brought to the starting of groove and depth of penetration was increased by programmed quantity.

Step 5: Steps 3 & 4 were repeated until fracture occurs in the sheet balnks.

In this work, the different incremental depths of penetration used are 2mm, 4mm, 6mm and so on until fracture occurs. The grid circle will become ellipses with change in major and minor diameter. The change in diameter of the grid circle printed was measured. Then the major strain and minor strain were calculated using the below equations respectively. The forming limit diagram was drawn by taking major strain in Y-axis and minor strain in X-axis.

$$\text{Major strain} = \ln\left(\frac{\text{Major axis length}}{\text{orginal circle diameter}}\right)$$

$$\text{Minor strain} = \ln\left(\frac{\text{Minor axis length}}{\text{Original circle diameter}}\right)$$

3.3 Cupping Test

In cupping test, the copper 27200 sheet blank was formed into cup. The cup is a truncated cone in shape. The top diameter of the cup kept at constant and the wall angle was varied. The sample of the formed cup is shown in figure.5. Initially, the tool was made to touch the sheet blank. Then the tool was moved in a circular path. When it reaches the starting point, the tool was given with an increment in radial and depth direction. Then, the tool was moved in circular path again. This procedure was repeated until fracture occurs. The strains were measured from the diameter of deformed circles. Using these strain values, the FLD for SPIF was plotted.

Fig.4 Sample Formed in Straight Groove Test

Fig.5. Sample formed in cupping test

S.No	Step Depth (mm)	Major Diameter (mm)	Minor Diameter (mm)	Major Strain	Minor Strain
1	4	2.8	2.52	0.113	0.008
		2.85	2.5	0.131	0.000
		2.9	2.51	0.133	0.004
2	8	3.1	2.52	0.215	0.008
		3.15	2.51	0.231	0.004
		3.2	2.52	0.247	0.008
3	12	3.58	2.53	0.359	0.012
		3.6	2.51	0.365	0.004
		3.62	2.52	0.370	0.008
4	16	3.98	2.53	0.465	0.012
		4.05	2.53	0.482	0.012
		4.01	2.52	0.495	0.008

IV. RESULT AND DISCUSSION

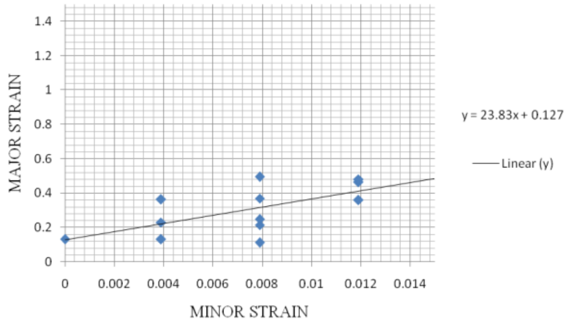
4.1 Straight Groove Test

Table 1 shows the major strain and minor strain in Straight Groove test for 40mm groove length. These strain values are different depth increments and along 45° to rolling direction.

From the above FLD for SPIF of copper 27200, 2mm thick sheet along 45° to rolling dierection,the relation between the major and minor strain is obtained as follows

$$\varepsilon_{major} + \varepsilon_{minor} = 0.2756$$

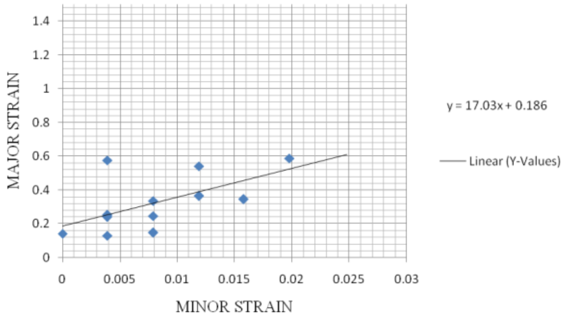
Slope = 23.83



Graph 4. FLD for Straight groove length of 40mm

Table 2 shows the major strain and minor strain in Straight Groove test for 50mm groove length. These strain values are different depth increments and along 45° to rolling direction.

S.No	Step Depth (mm)	Major Diameter (mm)	Minor Diameter (mm)	Major Strain	Minor Strain
1	4	2.88	2.5	0.141	0.000
		2.85	2.51	0.131	0.004
		2.9	2.52	0.148	0.008
2	8	3.18	2.51	0.241	0.004
		3.2	2.52	0.247	0.008
		3.22	2.51	0.253	0.004
3	12	3.5	2.52	0.337	0.008
		3.53	2.54	0.345	0.016
		3.6	2.53	0.365	0.012
4	16	4.3	2.53	0.542	0.012
		4.45	2.51	0.577	0.004
		4.5	2.55	0.588	0.020



Graph 5. FLD for Straight groove length of 50mm

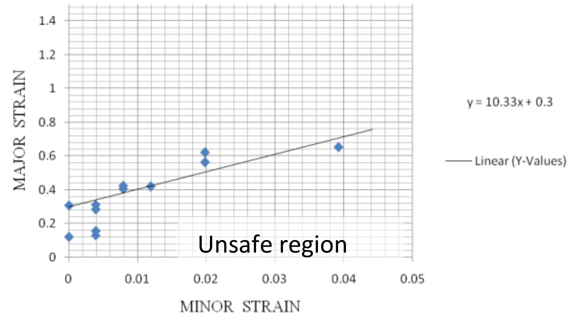
From the above FLD for SPIF of copper 27200, 2mm thick sheet along 45° to rolling dierection,the relation between the major and minor strain is obtained as follows

$$\varepsilon_{major} + \varepsilon_{minor} = 0.2930$$

Slope = 17.03

Table 3 shows the major strain and minor strain in Straight Groove test for 60mm groove length. These strain values are different depth increments and along 45° to rolling direction.

S.No	Step Depth (mm)	Major Diameter (mm)	Minor Diameter (mm)	Major Strain	Minor Strain
1	4	2.82	2.5	0.120	0.000
		2.85	2.51	0.131	0.004
		2.92	2.51	0.155	0.004
2	8	3.05	2.51	0.284	0.004
		3.2	2.53	0.308	0.000
		3.25	2.52	0.313	0.004
3	12	3.75	2.52	0.406	0.008
		3.8	2.53	0.419	0.012
		3.82	2.52	0.424	0.008
4	16	4.4	2.55	0.563	0.020
		4.65	2.55	0.621	0.020
		4.8	2.6	0.652	0.039

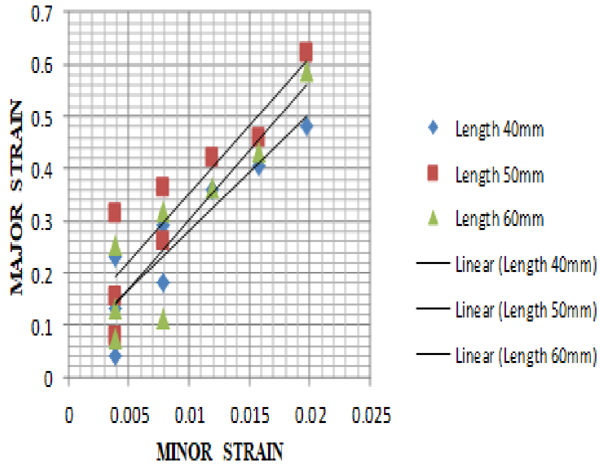


Graph 6. FLD for Straight groove length of 60mm

From the above FLD for SPIF of copper 27200, 2mm thick sheet along 45° to rolling dierection,the relation between the major and minor strain is obtained as follows

$$\varepsilon_{major} + \varepsilon_{minor} = 0.3514$$

Slope = 10.33



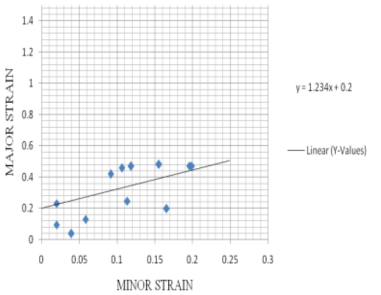
Graph 7.Combined FLD for Straight Groove Length of 40mm, 50mm and 60mm.

From the above FLD figure, it appears as that these three linear lines shows the formability limit for three different groove length.

It is clear from the chart the formability limit is maximum for straight groove length of 60mm followed by 50mm and 40mm. Therefore, we can say that the length is also a major factor influences the incremental formability . The region above the linear is unsafe region and below is safe region.

Table 4 shows the result of Cupping test with wall angle of 40°

S.No	Step Depth (mm)	Major Diameter (mm)	Minor Diameter (mm)	Major Strain	Minor Strain
1	5	2.85	2.65	0.131	0.0582
		2.6	2.6	0.039	0.0392
		2.75	2.55	0.095	0.0198
2	10	3.05	2.95	0.198	0.1653
		3.2	2.8	0.246	0.1133
		3.15	2.55	0.231	0.0198
3	15	4	2.8	0.47	0.1183
		3.95	2.78	0.457	0.1062
		3.8	2.74	0.418	0.0917
4	20	4.01	3.05	0.472	0.1988
		4.05	2.92	0.482	0.1553
		4.01	3.04	0.472	0.1955



Graph 8. FLD for cupping test with Wall angle of 40°

From the above FLD for SPIF of copper 27200, 2mm thick sheet with Wall angle of 40°, the relation between the major and minor strain is obtained as follows

$$\varepsilon_{major} + \varepsilon_{minor} = 0.4164$$

Slope = 1.234

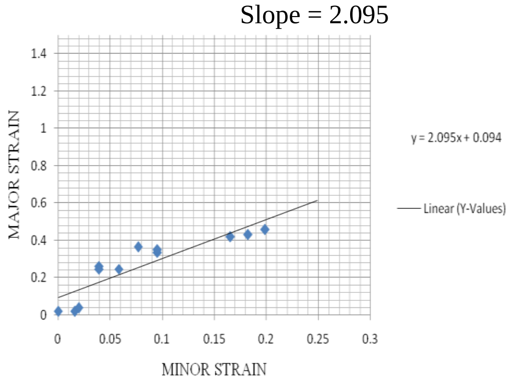
Table 5 shows the result of Cupping test with Wall angle of 45°

S.No	Step Depth (mm)	Major Diameter (mm)	Minor Diameter (mm)	Major Strain	Minor Strain
1	5	2.55	2.54	0.020	0.016
		2.6	2.55	0.039	0.020
		2.55	2.5	0.020	0.000
2	10	3.25	2.6	0.262	0.039
		3.2	2.65	0.247	0.058
		3.2	2.6	0.247	0.039
3	15	3.5	2.75	0.337	0.095
		3.6	2.7	0.365	0.077
		3.55	2.75	0.351	0.095
4	20	3.85	3	0.432	0.182
		3.95	3.05	0.457	0.199
		3.8	2.95	0.419	0.166

From the above FLD for SPIF of copper 27200, 2mm thick sheet with Wall angle of 45°, the relation between the major and minor strain is obtained as follows

$$\varepsilon_{major} + \varepsilon_{minor} = 0.3631$$

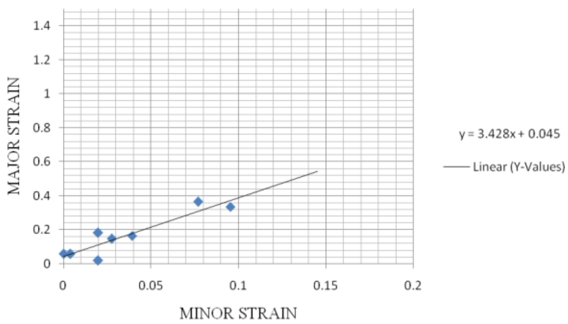
Slope = 2.095



Graph 9. FLD for Cupping test with Wall anlge of 45°

Table 6 shows the Cupping test with Wall anlge of 50°

S.No	Step Depth (mm)	Major Diameter (mm)	Minor Diameter (mm)	Major Strain	Minor Strain
1	5	2.6	2.55	0.019	0.0198
		2.65	2.5	0.058	0
		2.65	2.51	0.058	0.0039
2	10	3	2.55	0.182	0.0198
		2.95	2.6	0.165	0.0392
		2.9	2.57	0.148	0.0276
3	15	3.6	2.7	0.364	0.0769
		3.5	2.75	0.336	0.0953
		3.55	2.7	0.350	0.0769



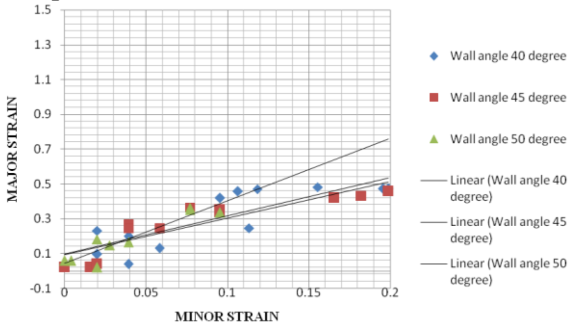
Graph 10. FLD for Cupping tes twith Wall angle of 50°

From the above FLD for SPIF of copper 27200, 2mm thick sheet with Wall angle of 50°, the relation between the major and minor strain is obtained as follows

$\varepsilon_{major} + \varepsilon_{minor} = 0.3039$ Safe region Slope = 3.428

Graph 11. Combines FLD for Cupping test with Wall angle of 40°, 45° and 50°.

- From the above FLD figure, it appears as that these three linear lines shows the formability limit for three different Wall angles.
- It is clear from the chart the incremental formability is maximum for Wall angle 50°.
- The region above the linear is unsafe region and below is safe region.



V. CONCLUSION

The copper 27200 sheet with 2mm thickness was chosen for the formability analysis. The SPIF using hemispherical ended tool was carried out using a CNC vertical milling machine. The straight groove and cupping tests were conducted and their FLDs in a peculiar pattern were plotted. It shows the unsafe and safe region of formability in SPIF on Copper 27200 .The FLDs in this SPIF of Copper 27200 is governed by the following equations

$\varepsilon_{major} + \varepsilon_{minor} = 0.2756$ (from Straight groove test of 40mm length)

$\varepsilon_{major} + \varepsilon_{minor} = 0.2930$ (from Straight groove test of 50mm length)

$\varepsilon_{major} + \varepsilon_{minor} = 0.3514$ (from Straight groove test of 60mm length)

$\varepsilon_{major} + \varepsilon_{minor} = 0.4164$ (from Cupping test with Wall angle of 40º)

$\varepsilon_{major} + \varepsilon_{minor} = 0.3631$ (from Cupping test with Wall angle of 45º)

$\varepsilon_{major} + \varepsilon_{minor} = 0.3039$ (from Cupping test with Wall angle of 50º)

REFERENCE

[1] Narayanasamy R. and Sathiyanarayanan C., Formability of HSLA and EDDQ steels of tube products of India, *Indian Journal of Engineering and Material Science,* 12 (2005) 141-150.

[2] Kopac J and Kampus, Incremental sheet metal forming on CNC milling machine tool, *J. Mater. Process. Technol*. 162-163 (2005) 622-628.

[3] Myoung-sup Shim and Jiong-jin park, The formability of aluminium sheet in incremental forming, *J. Mater. Process. Technol*., 113 (2001) 654-658.

[4] Matteo Strano, Technological Representation of Forming Limits for Negative Incremental Forming of Thin Aluminum Sheets, *J. Mater. Process. Technol*. 7, No 2 (2005) 122-129.

[5] Hiroki Takano, Kimiyoshi Kitazawa, Teruyu Kigoto, Incremental forming of nonuniform sheet metal: Possibility of cold recycling process of sheet metal waste, *Int.j. mach tool manu*. 48 (2008) 477–482.

[6] ToshiyukiObikawa, ShunsukeSatou, TomomiHakutani, Dieless incremental micro-forming of miniature shell objects of aluminum foils, *Int.j. mach tool manu.,* 49 (2009) 906–915.

[7] Yasunori Saotome and Takeshi Okamomoto, An in-situ incremental microforming system for three-dimensional shell structures of foil materials, *J. Mater. Process. Technol*., 113 (2001) 636-640.

[8] Kim and Park, Effect of process parameters on formability in incremental forming of sheet metal, *J. Mater. Process. Technol*., 130 (2002) 42–46.

[9] Park J.J. and Kim Y.H., Fundamental studies on the incremental sheet metal forming technique, *J. Mater. Process. Technol*. 140 (2003) 447 -453.

[10] Kim T.T. and Yang D.Y., Iimprovement of formability for the incremental sheet metal forming process, *Int.j.mech.sci*. 42 (2000) 1271-1286.