Pilot Studies on Single Point Incremental Forming Process for Hyperbolic Brass Cups

A. Chennakesava Reddy

Abstract— Incremental sheet forming is a sheet metal forming technique wherein a sheet is formed into the final part by series of small incremental deformations. It is a relative new sheet forming process which offers the possibility of forming complex parts without dedicated dies using only a single point tool and a standard 3-axis CNC machine. This paper presents the preliminary studies on the finite element modelling of single point incremental sheet forming process for hyperbolic cups using 60-40 brass alloy. ABAQUS 6.14 software code was used for finite element analysis. Though the experimental strains obtained were within the allowable limits, the sheet fractured as the maximum equivalent stress induced was 548.3 MPa which exceeds ultimate tensile strength of brass that is 470 MPa.

Index Terms— Brass, single point incremental forming process, hyperbolic cups.

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1 INTRODUCTION

METAL forming is the backbone of modern manufacturing industry besides being a major industry in itself. Throughout the world, hundreds of million tons of metals go through metal forming processes every year. As much as 15–20% GDP of industrialized nations comes from metal forming industry. Single Point Incremental Forming (SPIF) is a sheet metal forming technique in which sheet is formed using a single, small tool as opposed to a large die. In SPIF, the tool makes a series of (x-y) contour passes around the periphery of the part, stepping down in the third (z) axis between each pass as shown in figure 1. The sheet is thus formed into the desired shape based on the tool path. Unlike conventional sheet metal forming techniques such as stamping or spinning, SPIF is able to form complex asymmetrical parts, without the need for a die.

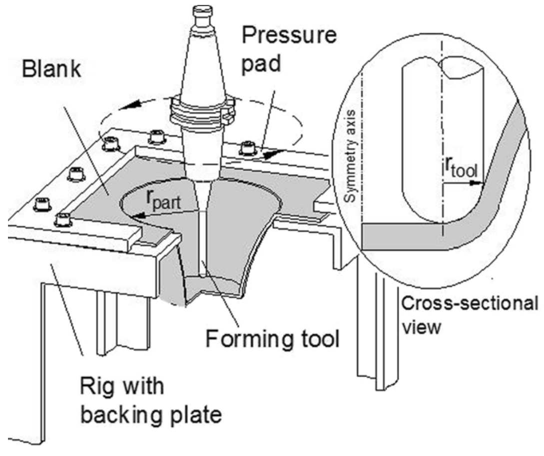

Fig. 1. Single point incremental forming process.

In a series of research on deep drawing process, a rich investigation have been carried out on warm deep drawing process to improve the super plastic properties of materials such as AA1050 alloy [1], [2], [3], [4], [5,] [6], AA2014 alloy [7], AA2017 alloy [8], AA2024 alloy [9], AA2219 alloy [10], AA2618 alloy [11], AA3003 alloy [12], AA5052 alloy [13], AA5049 alloy [14], AA5052 alloy [15], AA6061 alloy [16], Ti-Al-4V alloy [17], EDD steel [18], gas cylinder steel [19].

Unlike in the conventional sheet forming there are many parameters which affect the process mainly step depth, tool diameter, sheet thickness, friction coefficient, type of lubricant, tool path, increments along X&Y directions, spindle speed, feed rate, wall angle [20], [21].

Kopac et al. [22] given importance to the tool movement along the tool path, i.e tool path from center to the end of the sheet has good effect and also concluded that the optimal inclination of walls on the product are 45°, bigger angles may cause errors, cracks, and product failure.

Malwad et al. [25] described the deformation mechanism by variation of wall angles. Greater formability can be achieved in cups which have wall angle less than 75°. As the wall angle reduces shearing plays an important role in deformation and biaxial starching takes place at the corners so the sheet cracks at corners than sides. The numerical simulations of frustum of cone and pyramid with different slope angles were performed using LS-DYNA and analysed the formability.

Bagade et al. [23] has described the deformation behaviour and microstructure of EDD steels in incremental sheet forming. In which optimum wall angle are 73°, thickness is drastically reduced by 75% of sheet thickness and grain size decreased due to strains developed. Induced biaxial stretching causes failure in sheet.

Tisza, et al. [24] has stated that due to the special incremental nature of deformation process, significantly higher deformation can be achieved compared to conventional sheet metal forming processes and it also follows from its unique deformation characteristics that materials with lower formability in conventional forming may be manufactured in an economic way. Fiorotto, et al. [25] has stated that choosing an aluminium sheet as a diaphragm and using a vacuum bag wrinkle-free part have formed in an incremental fashion even though resin tends to accumulate.

The purpose of present project work was to estimate the formability of 60-40 Brass alloy to fabricate hyperbolic cups using single point incremental forming (SPIF) process.

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2 MATERIALS AND METHODS

60-40 brass sheet was used in this study of single point incremental sheet forming to fabricate hyperbolic cups. Brass is made of copper and zinc with compositions as given in Table 1. The mechanical properties of brass are given in Table 2.

TABLE 1
COMPOSITION OF STAINLESS STEEL 304

Cu	*Pb*	*Fe*	*Zn*	*Other*
62.5-66.5%	*0.8-1.4%*	*Max 0.1%*	*34%*	*8-11%*

TABLE 2
MECHANICAL PROPERTIES OF STAINLESS STEEL 304

Density	*8.2 g/cc*
Young's modulus	*470 MPa*
Tensile strength	*0.31*
Poisson's ratio	*102 GPa*

Plasticity data was obtained by conducting tensile test of 60-40 Brass, from which the data obtained is represented in figure 1. The obtained values were taken as material properties-plasticity for simulation of SPIF process.

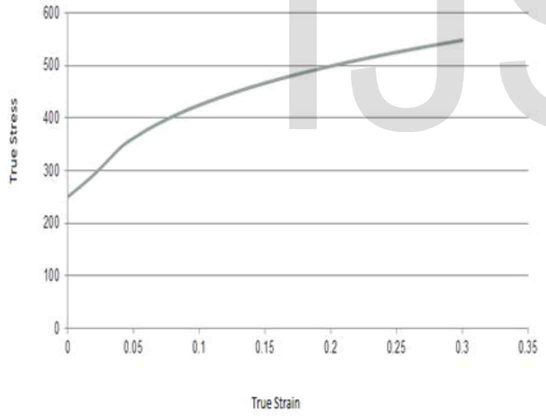


Fig. 1. True stress-strain curve of AA6082 alloy.

2.1 FEM Pre-processing

The finite element method (FEM) has become an important tool for the numerical solutions of engineering problems. It is the piecewise approximation of object where the object is divided into number of small elements, the integration of all such small elemental analysis finally give the solutions [27]. The finite element modelling of SPIF process was carried out using ABAQUS (6.14) software to fabricate hyperbolic cups. In geometric modelling a square sheet of dimensions 150 mm×150 mm and tool of cylindrical rod having hemispherical end 6 mm radius was created. The sheet and tool were modelled as deformable, analytical rigid body respectively and assembled together as shown in figure 2. In order to reduce the complexity of the model the other parts like tool holder, work holder were simulated by boundary conditions, hence this is a simplified model. Tool was given a reference point for governing tool motion. Contact was the interaction between tool and the sheet. Since the sheet undergoes the localised deformation at the contact, modelling of contact should be correct. The contact was modelled as frictional contact. Coefficient of friction was considered at different levels as 0.15.

Meshing is the process of discretizing the component. Here the sheet was meshed as shown in figure 3 with quad dominated S4R shell elements [27]. Element size has impact on computational time and results. Fine mesh gives the good results with greater computational time. Coarse mesh leads to inconsistent results, penetration and convergence problems during simulation process. A fine mesh of 2mm was generated for consistent results.

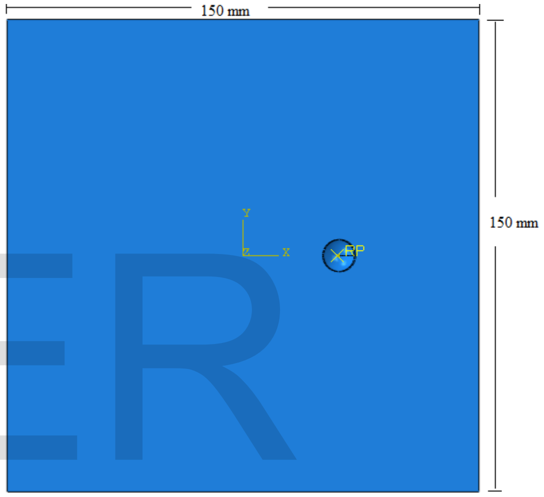


Fig. 2. Modeled sheet and Tool.

TABLE 3
NODES AND ELEMENTS

Element size	*2mm*
No. of Elements	*5777*
No. of Nodes	*5626*

A simplified model was created by eliminating tool holder and work holder, but they are simulated by the boundary conditions. Edges of the sheet are fixed and tool was given four degrees of freedom, three translatory along x, y, z directions and one rotational around tool axis as shown in figure 4. The motion of the tool was controlled by amplitude data in smooth step form.

2.2 Experimental Validation

Initially tool was placed at centre of the square sheet and made it as zero position. Tool was moved in a specified contour till it completed the specified path then tool takes a specific depth in downward direction and moves to a new point.

The tool path generated by the CAM package [28] for hyperbolic cup is as shown in the figure 5.

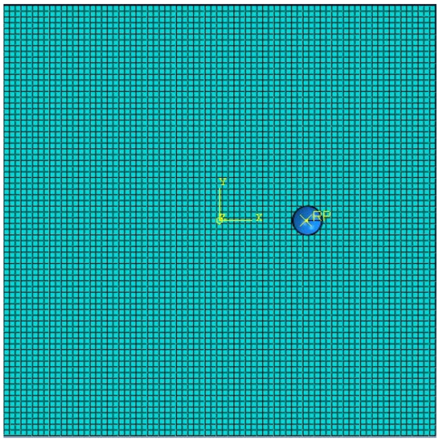


Fig. 3. Meshed sheet.

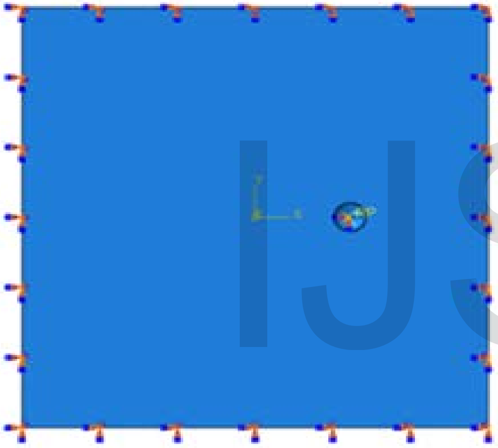


Fig. 4. Boundary conditions.

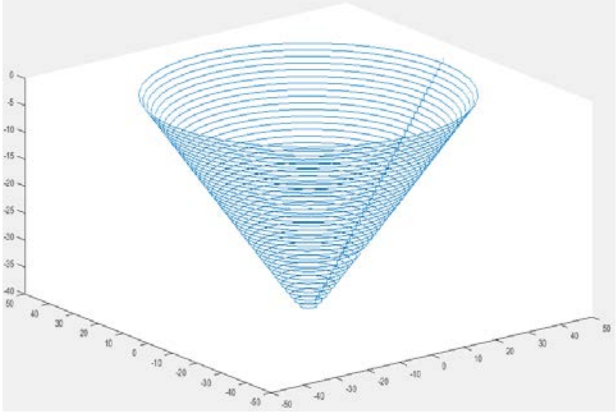


Fig. 5. Tool path generation.

Blank of 150mm × 150mm was cut from large sheet material using bench shear machine. Holes are made in the corners of the sheet using a drilling machine. Square patterns were drawn with 5 mm distance between them on back side of blank as shown in figure 6 for the purpose of extracting results from finished part. Blank is clamped to the blank holder and tool of 6mm diameter if fixed in tool holder. Tool was placed at one corner of sheet for hyperbolic cup. This was made zero position using inch mode in CNC machine. The part program was loaded and checked to eliminate errors. Program was run to start the machine (figure 7).

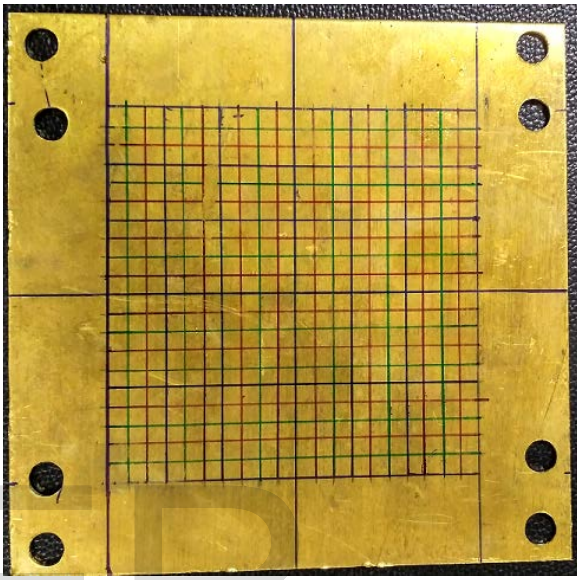


Fig. 6. Prepared sheet.

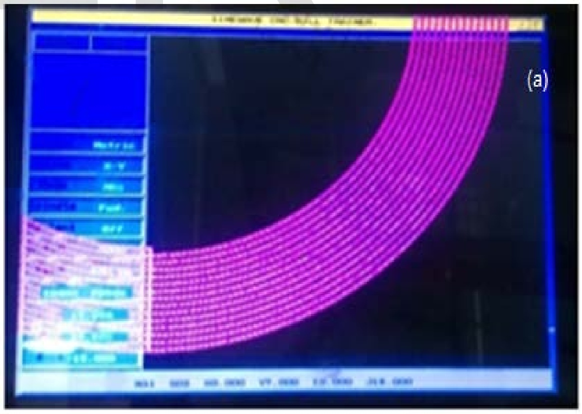


Fig. 7. Simulation of CNC program.

3 RESULTS AND DISCUSSION

The maximum equivalent stress induced in the hyperbolic cup is 548.3 MPa. Maximum equivalent stress is observed in the walls of cup as shown in figure 8. Maximum equivalent plastic strain obtained is 0.837, it is observed in walls of the last step of simulation as shown in figure 9.

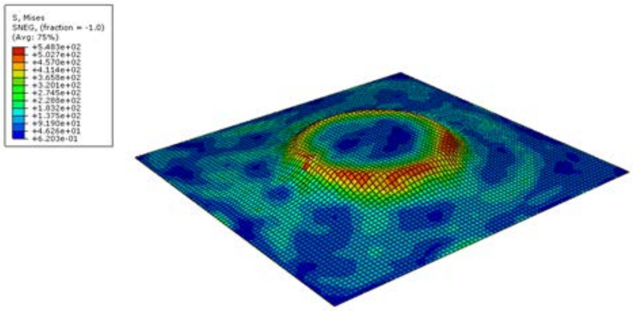


Fig. 8. Equivalent stress induced in sheet thickness.

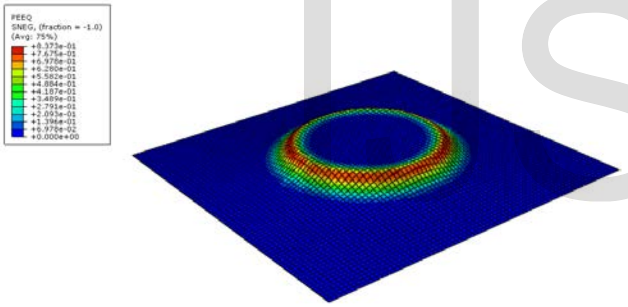
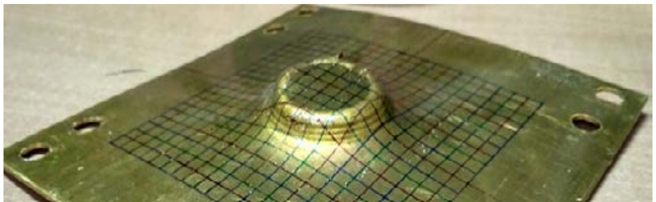


Fig. 9. Equivalent strain induced in (a) 1mm sheet and (b) 1.2mm sheet.

Validation of the simulation results was carried out by creating finite element grid of 5mm size on front and backside of the sheet material. The size of element was 2mm in case of simulation results. The stress and strain pattern obtained by the finite element method coincides with the pattern on the cups. From the experiments conducted on CNC machine to draw hyperbolic cup, fracture occurred at a depth of 12 mm as shown in figure 10. The maximum strain obtained was calculated from the pattern observed on the cup as shown in figure 10 which is found to be 0.75. Strains obtained from FEA represent the maximum values of rupture (figure 11). Though the experimental strains obtained were smaller than that of FEA and within allowable limits, the sheet was fractured because the maximum equivalent stress induced was 548.3 MPa which exceeds ultimate tensile strength of brass that is 470 MPa.



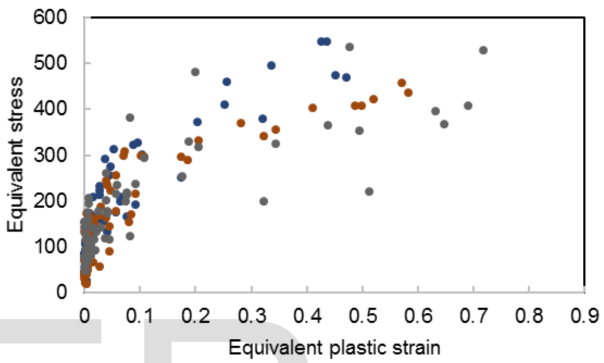


Fig. 11. Plot showing equivalent strain vs equivalent stress.

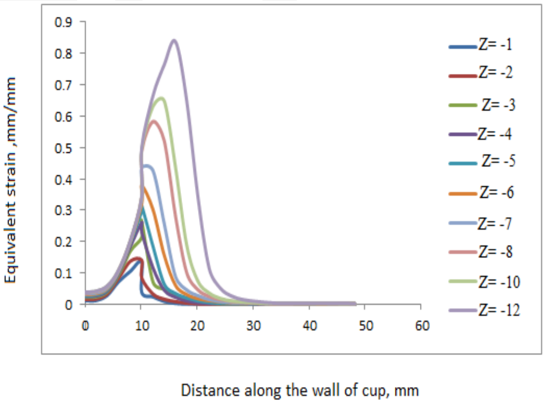


Fig. 12. Strain variation in the wall of the cup on 1mm thick sheet.

The strain variations are highly non-linear in the first stage and linear in the subsequent stages. The strain variation along the wall of hyperbolic cup at respective step depths is shown in figure 12. The thickness variation along the walls of hyperbolic cup is shown in figure 13. The majority of thickness reduction takes place in the walls of the cup but not in the flange or bottom of the cup. Figure 14 represents the formability diagram for hyperbolic cup. During initial stages of SPIF, the shear and compressive stresses were dominating the formability of hyperbolic cups of brass. At later stages of plastic deformation, the shear stress is highly predominant and uniaxial tension is less predominant resulting the fracture of sheet.

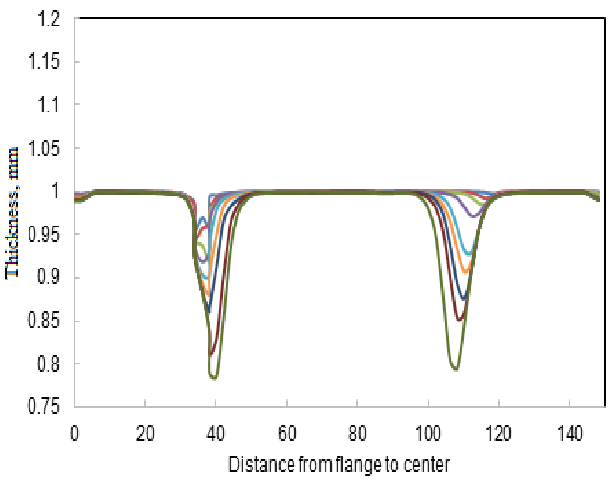


Fig. 13. Thickness variation along the walls of hyperbolic cup.

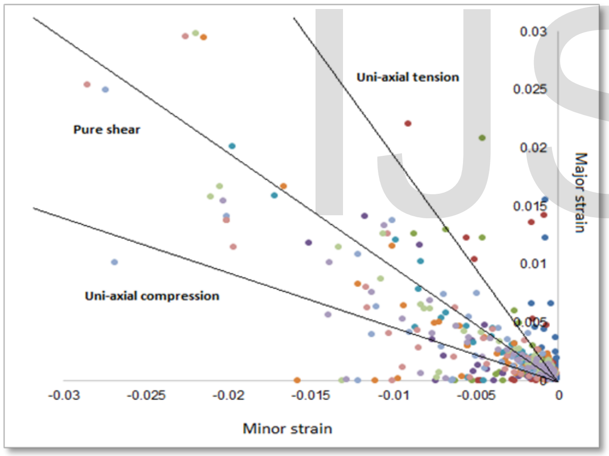


Fig. 14. Formability limit diagrams of (a) 1mm and (b) 1.2mm thick sheets.

4 CONCLUSION

In the present work, the finite element analysis and validation are successfully implemented for single point incremental forming process of brass sheet. Even though the experimental strains obtained were within the allowable limits, the sheet fractured. The maximum equivalent stress induced was 548.3 MPa which exceeds ultimate tensile strength (470 MPa) of brass. Another major parameter is the composition of brass 60-40, which contains 60% copper and 40% zinc. Though copper is ductile in nature, due to the addition of higher amount of zinc the ductility of material was reduced which made drawing of the cup difficult resulting in a fracture. So, this material is not viable to carry out Incremental deep drawing process.

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