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# An Experimental Investigation on the Single Point Incremental Forming Of Aluminium Alloy

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Abstract— **Incremental Sheet Forming (ISF) is an innovative forming approach for sheet materials. This process has been promising a flexible, and inexpensive way to form sheet products. The present work be going to be focuses on the attention of single point incremental forming (SPIF) process of a Aluminium alloy. Which have important industrial applications with a high ratio of weight/strength. SPIF test be going to carry out with different tool dimensions, while simultaneously changing the feed rate. In this work the thickness reduction, formability, strain distribution over the sheet surface will studied.**
**In addition, To know the forming condition. Finite element analysis of Incremental sheet metal forming simulation will have been carried at by using LS-DYNA software finally comparison work is going to do for both experimental and simulation work.**

**Keywords—: Incremental forming; FEM simulation, Process parameters; CNC machine.**

## I. Introduction

Conventional sheet metal forming processes require large batch sizes (mass production) because these processes require large energy costs and very high investment in equipment and tooling (i.e. machine-tools, moulds, dies, jigs and fixtures). Single Point Incremental Forming (SPIF) is a new metal forming process with a high potential economic payoff for rapid prototyping applications suitable for flexible and small quantity production fulfilling this gap in metal forming processes.

Nowadays, the need of improving both processes and components has matched with the need of weight reduction. This is particularly crucial for Aluminium alloys that possess poor formability. Recently, Aluminium alloys have received increasing interests in the automotive industry as potential structural materials due to their low mass density that allows significant weight reduction and, consequently, fuel savings. Aluminium is one of the lightest structural metal. In addition to its low specific weight, it offers excellent mechanical properties compared with other metallic materials. Other advantages of Aluminium alloys for structural applications include good properties at elevated temperatures (compared to plastics and polymer matrix composites), fatigue strength, dimensional stability, dent resistance, machinability, corrosion resistance and aesthetic appeal. Therefore, there has been a growing interest in using Aluminium alloys for load bearing and structural components. Aluminium alloy components have traditionally been produced using die-casting. However, press forming has become a promising alternative because of environmental issue with casting, and because better material properties can be obtained by press forming. To enable such applications, it is essential to be able to predict the press forming of these materials and the process parameters that allow the part to be formed without rupture or defects induced by the forming process.

*Process of incremental sheet metal forming*

This is a process where sheet metal is formed with a small force and no press is needed. A piece of sheet metal it's chucked all around with a special chuck (Fig. 1.2). The tool is guided with an NC computer program, which defines the trajectory along which the tool should move. The trajectory along which the tool should move is defined directly from a model made in CAD. Tool can also rotate which causes local deformation and the creation of a desired shape by deepening the sheet metal.

Single Point Incremental Forming (SPIF) gives a new important contribute to incremental forming processes like Spinning and stretch expanding which is the capability of produce non-axisymmetric parts.

In single point incremental forming there is no support for the tool and there is only support for work-piece between the two ends. The blank sheet is clamped in a universal stationary blank holder and the forming tool describes the contour of thedesired geometry controlled by a regular CNC machine (Figure1).

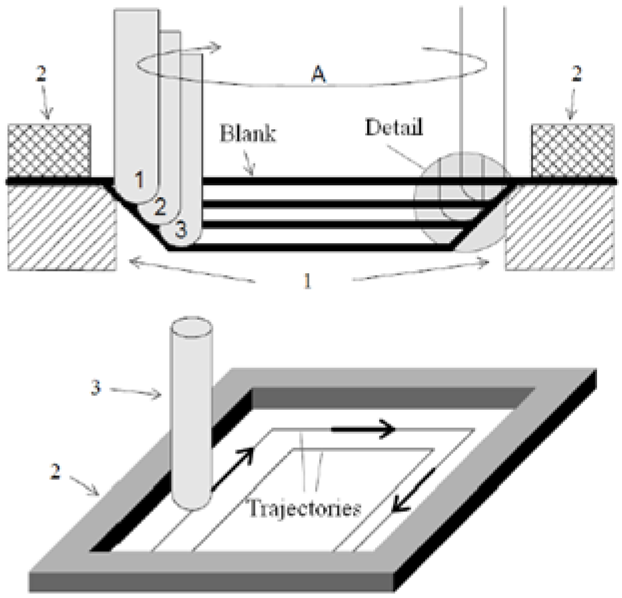



Figure 1 Schematic representation of a cross section view of SPIF process

Figure 2 Process of incremental forming

## II. Material and Methodology

**EXPERIMENTAL WORK**

*Grid Marking*

To study the strain behaviour in incremental sheet metal forming it is important to have grid marking on the surface of the cup. For this grid marking the screen printing method was selected. By using screen printing method butted 5mm diameter circular grid is formed. The grid pattern is printed directly onto the metal sheet using a suitable ink which is resistant to the metal forming process.

*Chemical Etching*

For this chemical etching 12v battery was selected and sodium hydroxide was selected (NaOH). In this method the work piece is connected with anode and plan sheet is connected with cathode. For chemical etching 100gms of NaOH is mixed with 500ml of water. The anode and cathode plates are dipped in to electrolyte. After 20min the plate are taken out cleaned by using turpentine oil. The schematic of chemical etching process is shown in figure 3

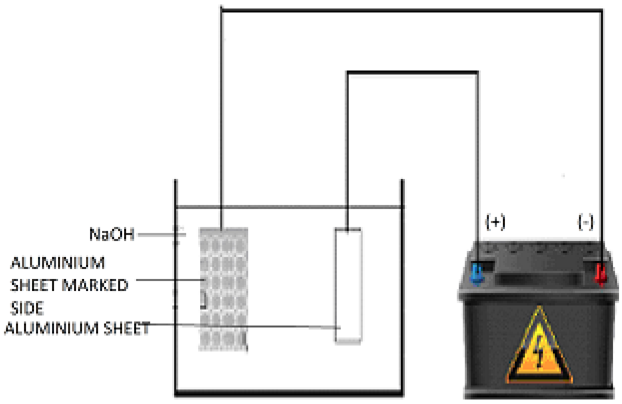



Figure3: Chemical Etching Process

*Design and Fabrication of Fixture*

Figure 4: Fixture

In the incremental sheet metal forming, to get the desired part fixture is essential, which is used as a supporting tool for the work piece. Without the support of a fixture the desired shapes cannot be formed. CATIA model of this (assembled and parts of fixture) are shown in Fig 4.

*Design and Fabrication of Tool*

To get the desired shape component, tool is necessary, it plays a key role for making any component shapes of sheet metal forming. Different types of materials can be used for making the tool like tool steel, mild steel, stainless steel etc.

For this work the material used for making tool is stainless steel. The height of the tool is 95mm, diameter of the shank is 12mm and ball point of the tool diameter which will be on the edge is (8,10,12 mm), it is fixed to the collate which is finally inserted into the tool holder. The CATIA model and fabricated tool is shown in Figs 5

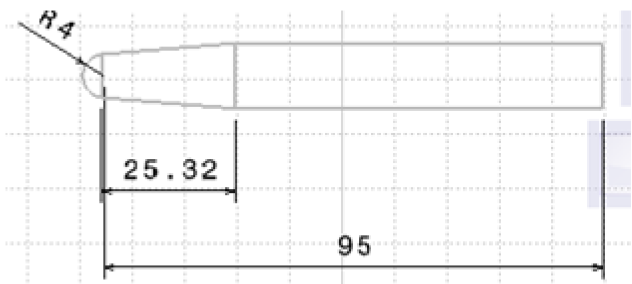



Figure 5 : CATIA Model of Tool

*Machine Selection*

Machines available to produce component shapes are industrial robot, water jet technology, CNC milling machines. Generally many of the industries prefer CNC milling machine due to easy in operation, fast change in parameters and tool path.

Machine selected for this experiment is CNC vertical milling machine, which has specifications like: Control system-FANUC oi MATE MC, X, Y and Z-axis are 450mm, 350mm and 350mm.Table size is 600×350mm, Positional Accuracy-0.01mm, Repeatability-0.05mm. CNC Milling Machine is shown in Fig 6

Figure 6: CNC Milling Machine

*Tool Path*

Intial tool is moved axially and is directed to move along linear path, after every one cycle, the tool is moved axially. These movements are called (Δz) axial feed, (Δx) radial feed and feed rate. This is continued until frustum of cone shape is obtained. Same thing is repeated for squre pyramid (Fig 3.28) and hexagonal pyramid also except instead of circular movement tool is moved in straight line. In CNC machines tool paths are directed by part programs.

**Experimental Setup**

Single point incremental sheet metal forming, also known as dieless forming, is a new and innovative method of sheet metal forming. The sheet metal is formed in a complicated unsymmetrical shape without dedicated die

The rod-shape forming tool with a smooth hemispherical head of 5mm diameter was clamped into the spindle of the milling machine. The sheet metal was fixed and positioned with the upper blank holder, which was pressed onto the lower blank holder in which the simple die was placed. The whole support tool was inserted and fixed onto the worktable of the milling machine. While the tool presses and locally deforms the sheet directly under the tool head with a very small value of deformation, the blank holder and fixture remain fixed during the entire forming process. The tool follows to the predetermined tool path and gradually forms the sheet metal in a series of incremental steps until the final depth is reached. In this we consider different parameter rotational of spindle, axial feedrate, X, Y feedrateThe steps of single incremental sheet metal forming are shown in Fig 7. They are defined as Δx, Δz and h, representing increment in x and z direction and finite forming depth, respectively.

Figure 7: Experiment Setup

For conducting experiment the selected parameter are shown in table 1 Cups having shape of frustum of square pyramid were formed using the part program. A part from the change in the parameters two major conditions were considered namely tool with and without rotation.

Table 3.1: ISMF Process Parameters

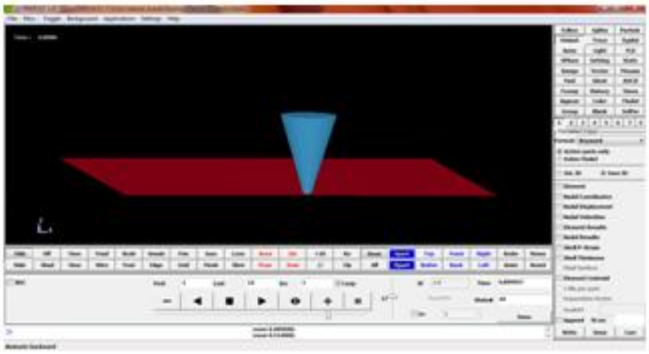
| | |
|---|---|
| Forming depth (mm) | 35 |
| Rotational speed (rpm) | 0 |
| Feed Rate (X,Y) (mm/min) | 100,300 and 500 |
| Tool diameter (mm) | 8,10 and 12 |
| Tool path | Clock wise direction |
| Axial feed (Z) (mm) | 1,2 and 3 |

## III. Results and Tables

The knowledge about deformations of the sheet metal is very important to design appropriate tools and select appropriate parameters. It is necessary to define the critical areas and failure zone. In this section, results obtained from FE analysis, strain distribution and comparison of major and minor strain at critical areas are compared with forming limit diagram.

*Finite Element Analysis Of Ismf Of Frustum Square Prism*

Finite element analysis was done for frustum of square pyramid using Hyper mesh for pre-processing and LS-DYNA for analysis and post processing. Forming limit diagram with colour contours of the cup formed with 1/4th of its height is shown in figure 8.



Simulation Of Incremental Sheet Metal Forming In Ls-Dyna

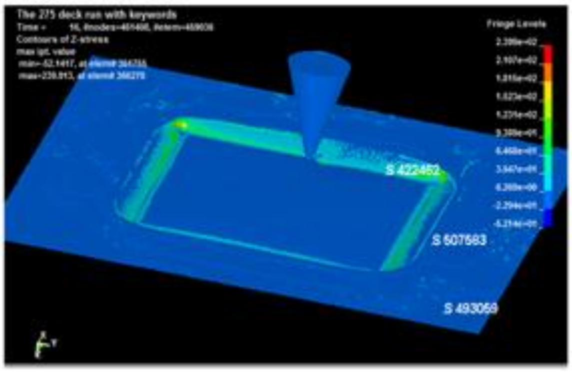



Figure.8 Stress Distribution

Three points are selected on the wall surface to study the strain behaviour of the process. Major strain and minor strain value of those three points are compared with forming limit curve in figure 9. All three points are positioned very close to major strain. It is observed that the elements are undergoing plane strain deformation.

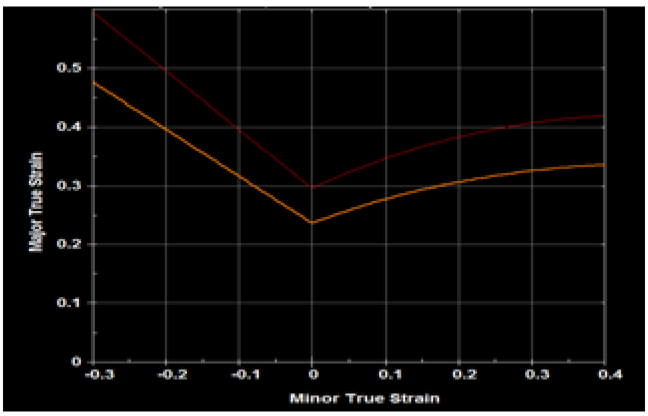



Figure 9: Forming Limit Curve Obtained from FEA

Experimental Result

Cups were formed under different conditions using CNC machining center. Three points were selected on wall surface similar to finite element model and the major and minor strains were measured using Mylar tape (figures 10). Measured strain were compared with forming limit curve.

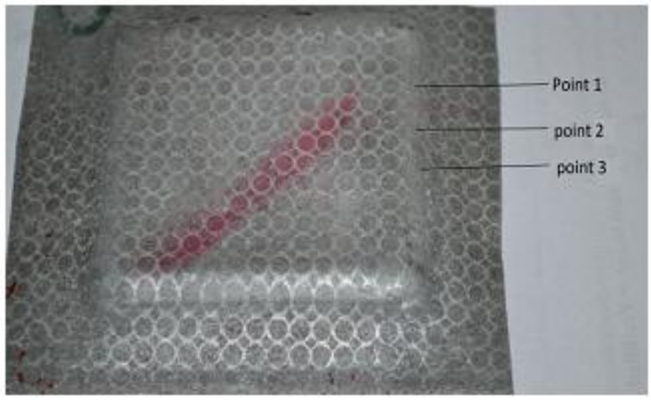



Figure 10: Locations of Strain Measurement on Side Wall of Cup

Major and Minor strain of the selective element measured from the wall of the cup are included in the forming limit diagram (FLD). All three values below FLC, two values are on major strain axis. Locations of major and minor strain included in FLDs in figure 11 & 4.9 are matching closely. Prediction based on FEA is very close to experimental results.

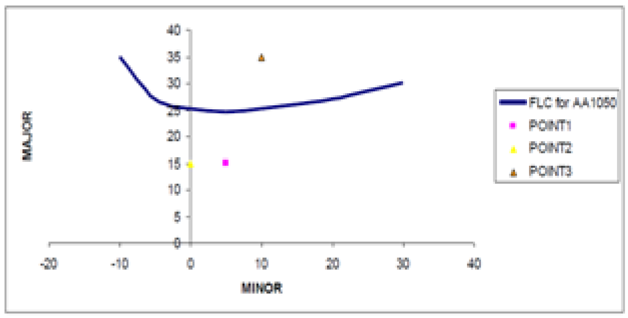



Figure 11: Comparison of Major and Minor Strain with FLC

Figure 12 shows the comparison of experimental and FE values of major and minor strains measured from the wall of fully formed cup along with standard FLC. Major strain measured from FEA lies on stretching side and experimental value lies on drawing side. But both the values are in danger zone.

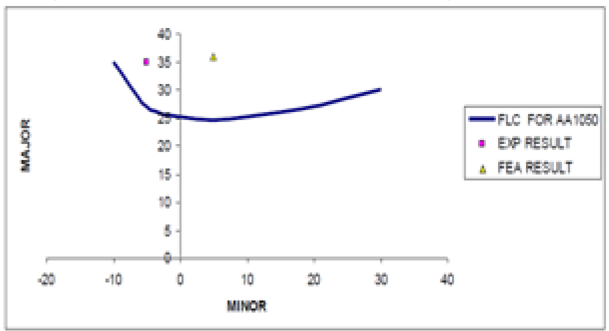



Figure 12: Comparison of Experimental and FEA Results ofMajor and Minor Strain

Comparison Of Strain Behaviour Under Different Conditions

Cups were formed under three major conditions namely axial feed rate, planar feed rate and different tool dimensions. Were varied and cups were formed. Four locations were identified for the strains are presented in table 4.1. Discussion on strain behaviour is discussed in the following sections.

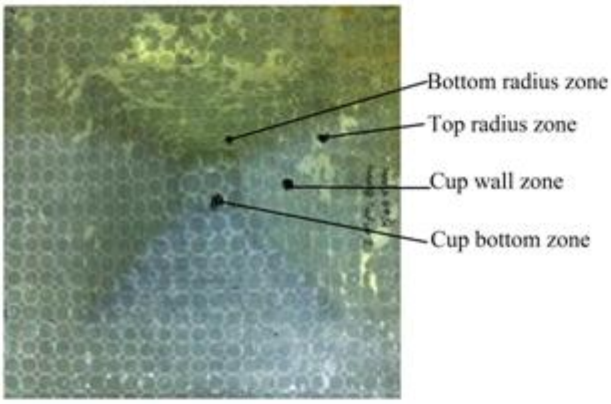



Figure.4.7: Formed of Frustum of Square Pyramid with StrainMeasurement Locations

Behaviour of Strain – 8mm Diameter Tool

Major and minor strain measured from the cup formed with rotating tool without lubrication is illustrated in figure 13.

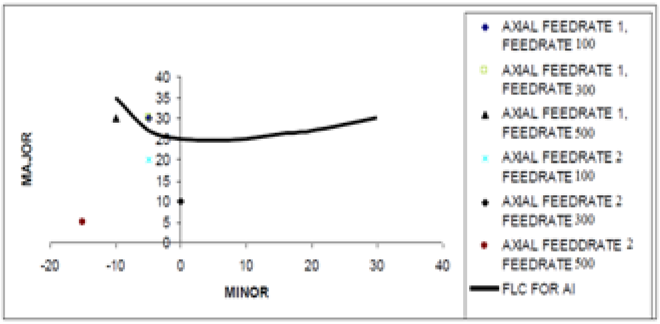



Figure 13: Comparison of Strain

It is observed that with axial feed of 1mm; feed rate 100 and 300 mm/rev, the strain values are in danger zone (above FLC), whereas for the feed rate 500 mm/rev, the strain below FLC. When the axial feed rate is changed to 2mm all the strain values are moved to safe region. Particularly for axial feed rate of 2 mm and feed rate of 200 mm/rev the element undergoing higher values of minor strain.

Behaviour of Strain – 10mm Diameter Tool

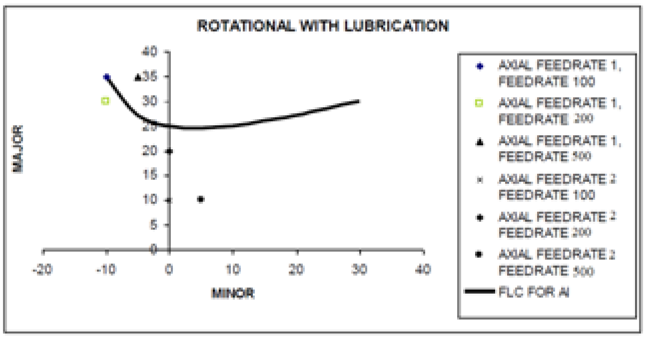



Figure 14: Comparison of Strain

Comparison of major and minor strain induced in the part formed by rotating tool under lubricating condition is shown in figure 14. Overall it is observed the induced strain values are either above FLC or plane strain axis. Strain induced by axial feed rate 2mm; feed rate 500 and 200 mm/rev are very safe than other conditions.

**IV Conclusions**

As it has been observed, incremental sheet forming process is a very promising manufacturing process which stillrequires further optimization. The effect of process parameterslike advancing speed, forming force and forming strategy inthe characteristics of the parts (thickness, geometrical accuracy, roughness) has been studied, showing the possibility to optimizethe quality of the formed parts by an accurate control ofthe process parameters. Finally, a simple FEM process model isbeing developed in order to predict the behaviour of the sheetduring forming process.

The results of the study can be summarized as follows:

(1) The formability increases as the feed rate decreases.
(2) With the configurations of the sheet used in the experiment, the best formability was obtained with 8mm tool.
(3) Higher depth can achieve with less axial feed rate.

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