Study of Mechanical Properties on AA5052, SS304 and S553 Sheet by Incremental Forming

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Abstract **– An increase in demand for the development of new product and its manufacturing techniques which adopts certain attributes to sustain in the market. Single point incremental forming (SPIF) is a Flexible and innovative technique in manufacturing of small batch sheet parts to the required shape. The process is carried out at room temperature (cold forming) and requires a CNC machining centre, a spherical tip tool and a simple support to fix the sheet being formed. Aim of the current study is to investigate material formability, thickness distribution and hardness of Aluminium AA5052, Steel S553 and Stainless Steel SS304 sheet metal. In this Study the effects of process variables like tool path profile, tool rotation speed, wall inclination angle and feed rate on the formability was investigated by experiments. From the experiments it is found that Formability is reduced due to increase in wall angle and tool run out. During studies Geometric accuracy of the parts manufactured was been studied and comparisons made between the CAD files and the actual manufactured parts.**

Key words: **Aluminium Alloy, Stainless Steel, Machine Tool, Sheet Metal, Forming, Bevel Protractor and Digital dial gauge.**

I. INTRODUCTION

In recent years there is increasing demand for the development of manufacturing technologies that are able to meet the market requirement, that is it should be also adaptable for new product development so that introduction of new products in the market can be achieved easily [1]. Increased use of Computer Aided Design (CAD) programs makes complex product designs possible, which in turn helps in making more complex prototypes [3]. At the same time, growing markets require frequent design changes, shorter lead time, and tighter budgets [3]. In short, prototyping must be faster, better, and less expensive [2]. A sheet metal product usually produced by using dies and punches with respect to size and shape of product are applicable only for mass production because the cost involved in dies and punches is high.

Incremental sheet forming (ISF) is a metal forming process which rose to standing at the beginning of the 1990s, unlike many other sheet metals forming process, incremental forming does not require any dedicated dies or punches to form a complex shape [2]. The process of incremental sheet forming has been seen as a more cost efficient alternative process when compared to conventional sheet pressing processes. The flexibility of the process is mainly related to the fact that incremental forming does not require a dedicated die and punch when compared to other forming process. With this technology a new product can be produced from CAD model to finished product. The ISF process supports the preference for low-volume, high value applications. The field of application concerning ISF processes is greatly increased as a result of its ability to create asymmetrical parts out of a large variety of metals [4].

From the literature review it is found that the researchers have focused much on the different shapes, sheet thickness, and material with varying the process variables in incremental forming. From literature review following conclusions are obtained [6]. Few researchers focus their attention towards wall angle and step depth Increment forming has not been performed on Stainless Steel 304 alloy sheet. So this research work has been focused on the incremental forming of frustrated square pyramid by varying the process variables in Stainless Steel 304 alloy sheet. In this Section Formability of sheet metal parts by varying various process parameters, spring back effect on Incremental sheet forming and Geometric accuracy of Incremental Sheet Metal products are reviewed. Research related to new tool path strategies and Finite Element Analysis (FEA) in ISF is studied [4]. From review paper basic steps involved in Incremental forming and also various parameter like Tool diameter, Tool path, Wall angle, Tool rotation speed, Feed rate, Friction between Tool and Work piece and Depth of Increment which affects the formability and Dimensional Accuracy are studied.

1.1 Steps Involved In Incremental Forming

i. Computer numerically controlled (CNC) machine
ii. Forming tool which deforms the sheet metal to form the desired shape
iii. Sheet metal work piece
iv. A fixture which clamps the metal blank securely
v. CAD/ CAM software for generation of G and M codes

II. EXPERIMENTAL WORK

In this section step involved in experimental work carried during this phase was discussed along with specification about the type of material used for work piece and tool.

2.1 Material Selection

Aluminium alloy 5052 contains nominally 2.5% magnesium and 0.25% chromium. It is the highest strength alloy in non heat treatable grades.It has good workability, medium static strength, high fatigue strength, good weldability and very good corrosion resistance. It has the low density and excellent thermal conductivity common to all aluminium alloys. It is commonly used in sheet, plate and Tube form.

2.2 Development of Incremental Forming Tool

The main purpose of the incremental forming tools is to deform the sheet metal to required form using CNC Milling machine. For this research three different tools are made with hemispherical tip radius of 8mm, 10mm, and 12mm. In this section type of tool material used for forming and it mechanical and chemical properties are studied.

The forming tool was to produce a region of highly localized stresses on the sheet metal and thus produce the formed shapes by localized plastic deformation. It was decided to use a tool having circular cross-section and a hemispherical tip for the project.

2.3 Development of Incremental Forming Fixture

In this section first type of material required for Fixture and their properties are explained. Then the component of fixture with two dimensional (2D), Three Dimensional (3D) and Actual component are explained with neat diagram. Requirement of fixture is to hold the work piece and withstand the force acting during forming.

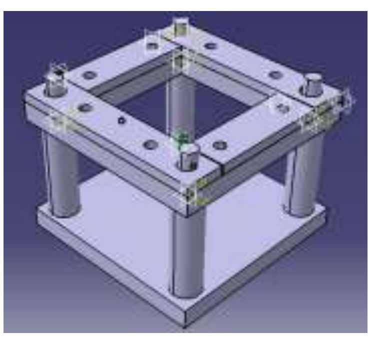

Fig 2.1 Three dimensional (3D) view Fixture arrangement

Fig 2.2 Experimental setup during Machining Condition

The objective of building the experimental set up was to perform experiments. Several components and Machining centre are required to perform process. In order to obtain continuous tool path movement in sheet metal, CNC (Computer Numerical Control) machining centre are used.

2.4 Experimental Conditions

Experiment was carried out in a SS304 sheet metal of 1mm thickness. Experiment was carried out for frustrated square pyramid of size 90mmx90mm and depth 50mm.Sheet metal of 200mm x 200mm was prepared and laser etching was done from literature review.

Table 2.1 Experimental Conditions for SS304 and AA5052 alloy of 1mm sheet

EXP NO	Spindle speed (RPM)	Feed rate (mm/min)	Step depth (mm)	Tool diameter (mm)	Tool path	Wall angle (DEG)	Material
1	1000	1500	0.2	12	OD to ID	20	SS304
2	2000	1500	0.2	12	OD to ID	20	SS304
3	2000	1500	0.1	12	OD to ID	50	SS304
4	2000	1500	0.2	12	OD to ID	40	AA5052
5	2000	1500	0.2	12	OD to ID	50	AA5052
6	2000	1500	0.1	12	OD to ID	55	AA5052

2.5 Material Characterization

In sheet metal processes, the Forming Limit Curve (FLC) is usually employed to evaluate the onset of a visible strain concentration. The Circle Grid Analysis (CGA) utilized for obtaining the material forming limits involved laser etching a grid with pattern of 5mm diameter circles (before deformation), shown in Fig 2.3. Then each circle's deformation is measured using Flexible rulers as those shown in Fig 2.4. These flexible rulers are made by taking photo copy of nataraj scale on OHP sheet in 1:1 scale ratio.

Fig 2.3 Etching Plate

Fig 2.4 Flexible Ruler

III. RESULT AND DISCUSSION

From the formed component various parameter are measured using height gauge, bevel Protractor and Digital dial gauge. Table 3.1 & 3.2 shows the various parameters measured from formed component. Figure 3.1 shows the five different formed components on aluminium 1 mm thick sheet metal and Figure 3.2 & 3.3 shows the 5 component formed on stainless steel 1 mm sheet metal. Formula used to measure actual thickness is shown

$$t_f = t_i\,(\sin 90\text{-}\$)$$

Where tf and ti are final and intial thickness, $ is wall inclination angle.

Table 3.1 Output parameter measured From AA5052 sheet metal

Exp no	Wall thickness (mm)	Forming angle(Deg)	Height formed (mm)	Actual thickness	% of Error (Formed angle
1	0.52	58	49.2	0.5	3.33
2	0.42	63.5	49.5	0.422	2.307
3	0.52	59	46.59	0.5	1.667

Table 3.2 Output parameter measured From SS304 sheet metal

Exp no	Wall thickness (mm)	Forming angle(Deg)	Height formed (mm)	Actual thickness	% of Error (Formed angle
1	0.52	58	49.2	0.5	3.33
2	0.42	63.5	49.5	0.422	2.307
3	0.52	59	46.59	0.5	1.667

Table 3.3 Output parameter measured From Steel sheet metal

Exp no	Wall thickness (mm)	Forming angle(Deg)	Height formed (mm)	Actual thickness	% of Error (Formed angle
1	0.52	58	49.2	0.5	3.33
2	0.42	63.5	49.5	0.422	2.307

Fig 3.1 Formed Components of AA5052 Sheet Metal

Table 3.4 Experimental Conditions for AA5052

Ex p no	Wall thickness (mm)	Forming angle(Deg)	Height formed (mm)	Actual thickness	% of Error (Formed angle
1	0.52	58	49.2	0.5	3.33
2	0.42	63.5	49.5	0.422	2.307
3	0.52	59	46.59	0.5	1.667

Table 3.5 Experimental Conditions for Stainless Steel SS304

Ex p no	Wall thickness (mm)	Forming angle(Deg)	Height formed (mm)	Actual thickness	% of Error (Formed angle
1	0.52	58	49.2	0.5	3.33
2	0.42	63.5	49.5	0.422	2.307
3	0.52	59	46.59	0.5	1.667

Table 3.6 Experimental Conditions for Steel

Ex p no	Wall thickness (mm)	Forming angle(Deg)	Height formed (mm)	Actual thickness	% of Error (Formed angle
1	0.52	58	49.2	0.5	3.33
2	0.42	63.5	49.5	0.422	2.307

Table 3.7 Measured strains from component with wall angle 45° and 50°

Percentage of Minor Starin	Percentage of Major Starin	Percentage of Minor Strain	Percentage of Major Starin
0	83	0	92
0	90	0	93
0	84	0	95
0	86	0	94

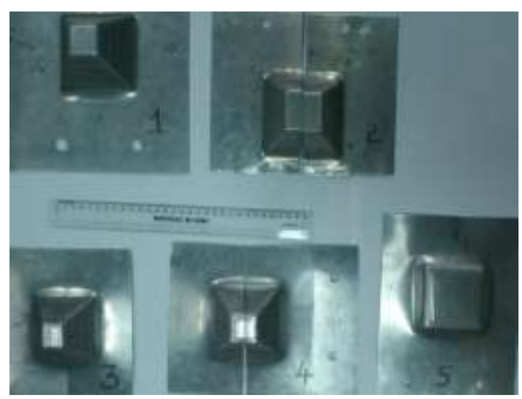

Fig 3.2 Formed Components of SS304 Sheet Metal

From the table 3.1 experiment no 2 and 3 wall angle increases from 45° to 50° which causes decrease in wall thickness of 0.10mm. Similarly for the experiments 1 &2, 2 &3 from table 3.2 when wall angle varies from 45° to 50°. This is due to the increase in wall angle; area under deformation is less when compared with fewer angles.

3.1 FLD Results

After experiments are conducted major and minor axis of the deformed circle are measured by using flexible ruler. For each formed component 20 circles were measured and thickness was measured at particular circle using digital dial gauge. Some of the measure values are tabulated in Table 3.2. FLD for all the experiment are shown in Figure 3.4

Table 3.8 some of measured strain from formed components

Sl No	Thickness of Sheet Metal	Percentage of Major Strain	Percentage of Minor Strain
1	0.49	76	52
2	0.45	82	60
3	0.45	84	54
4	0.42	80	56
5	0.4	85	59
6	0.38	77	63
7	0.36	78	55

Strain for wall angle of 45° and 50° are tabulated in Table 3.4. Due to reduce tool movement area when increase in wall angle. More material elongation takes place when wall angle increases, so that higher surface strains are formed.

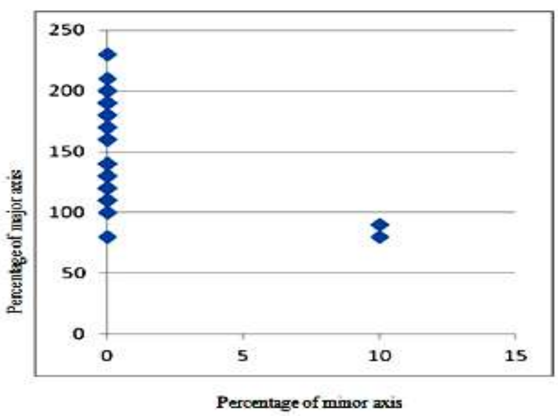

Fig 3.3 FLD for the all experiments

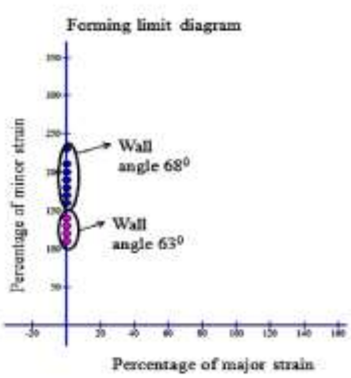

Fig 3.4 Forming Limit Diagram for IFP

3.2 Micro Hardness Results

When the sheet metal deformed to required shape both plastic and elastic deformation takes place, because of this plastic deformation strain hardening effect take place. Due to strain hardening, hardness of the deformed material will be varied. With the help of micro Vickers hardness testing machine hardness is measured. From the measured value hardness of the component before deformation is 86.9 HV and after deformation is 96 HV. From the results due to strain hardening hardens of the deformed component is increased. Fig 3.5 shows that GUI micro machining**.**

Fig 3.5 Hardness measurement

3.3 Prediction of Spring Back For Various Tool Path

From the experiment 3 and 4 from table 3.1, experiments sample height and wall angle are measured using the height gauge and bevel protractor. From this Sample following inference are obtained which are tabulated in Table 3.9

Table 3.9 Inferences from the experiments

Exp. No.	Tool Path	Actual Height (mm)	Height Formed (mm)	Actual wall angle (Deg)	Wall angle formed (Deg)	Spring Back ratio
1	Outer to Inner	50	47	40	38	0.95
2	Outer to Inner	50	48	45	40	0.92
3	Outer to Inner	50	48.5	60	50	0.90
4	Outer to Inner	50	40	40	38	0.91
5	Outer to Inner	50	35	42	35	0.91

From the results obtained spring back ratio is calculated. The spring back ratio is defined as the final angle after spring back divided by the initial stamping angle. From both the tool path movement Spring back Ratio is high in ZigZag Tool Movement and Low in Outer to Inner tool movement. Various cross sectional profile obtained using different tool path movement is shown in Figure 3.6.

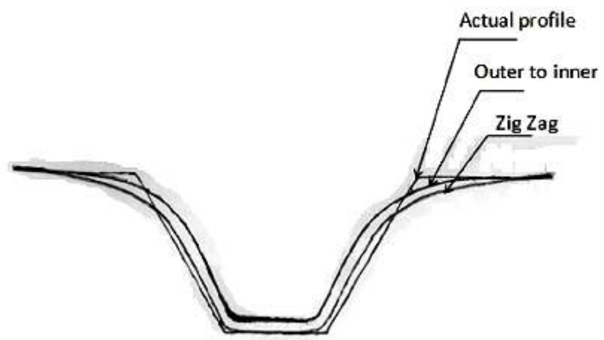

Fig 3.6 Profile obtained from various tool path profile

Spring back effect is low in Zig Zag tool movement because uniform tool path over the entire Area of 90mm x 90mm which causes uniform deformation over entire area whereas in outer to inner tool movement take place upto certain distance. In zig zag tool path movement thickness distribution is not uniform.

3.4 Thickness Distribution for Various Tool Path Profile And For Various Wall Angle

Thickness distribution varies for different tool path was calculated by using digital vernier caliper. Thickness of the component was measured for every 3mm distance by taking centre as zero and one side in positive value and other side by negative valve. Thickness distribution for outer to inner tool path and Zig Zag is shown in Figure 3.7 and 3.8. From figure that zig zag tool path shows uneven thickness distribution

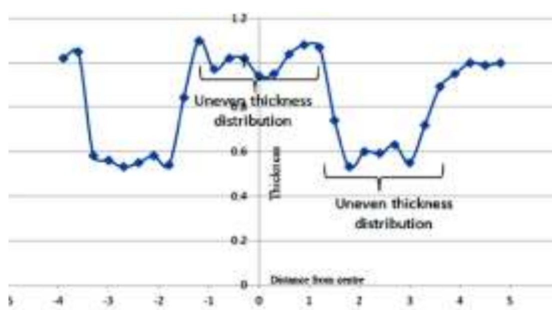

Fig 3.7 Thickness distribution for AA5052 with Outer to Inner tool movement and angle of 40°

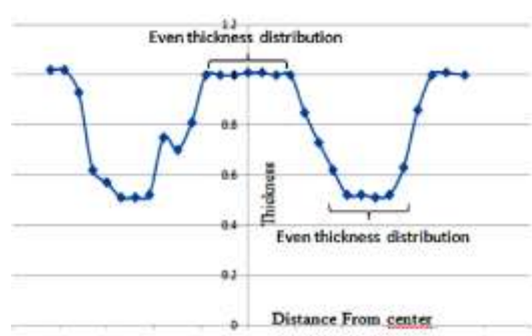

Fig 3.8 Thickness distribution for AA5052 with Outer to Inner tool movement and angle of 45°

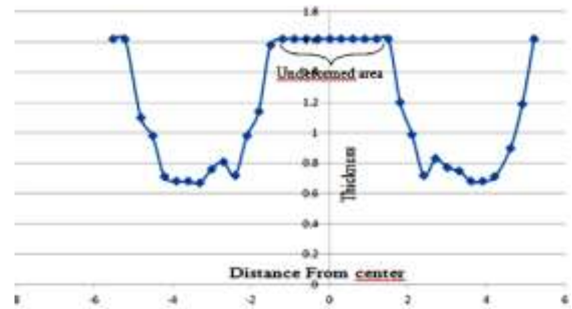

Fig 3.9 Thickness Distribution for AA5052 with Outer to Inner tool movement and angle of 50°

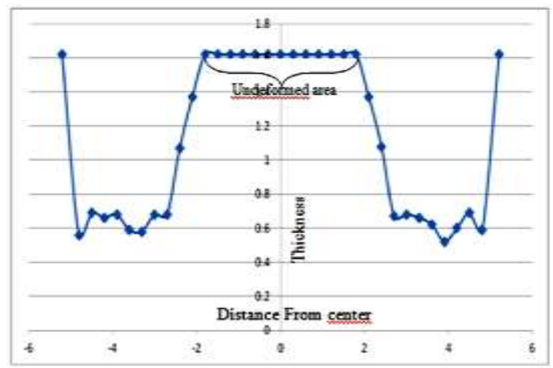

Figure 3.10 Thickness distribution for SS304 with Outer to Inner tool movement and angle of 45°

Thickness distribution for wall angle 40°, 45° and 50° are shown in Figure 3.9, 3.10 and 3.11. From this figure there is no difference between these graphs. Only difference seen is increase in wall angle reduction in wall thickness and increase in undeformed area.

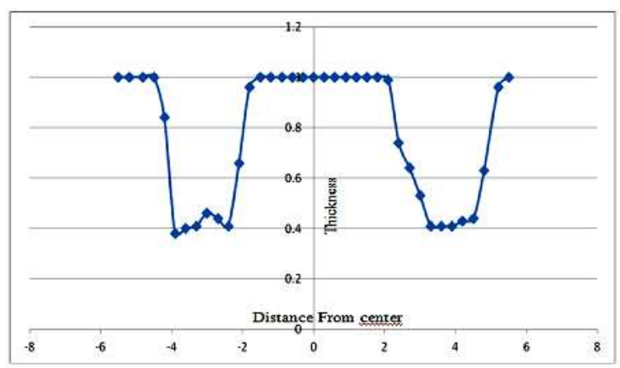

Fig 3.11 Thickness distribution for SS304 with Outer to Inner tool movement and angle of 50°

5.7 Failure Components

Figure 3.12 shows some of the failure components during forming process. These components were failed in the initial stage of the forming process this is due to the increase in wall angle, increase in the tool runout, etc., In the failure component zig zag and horizontal crack were created.

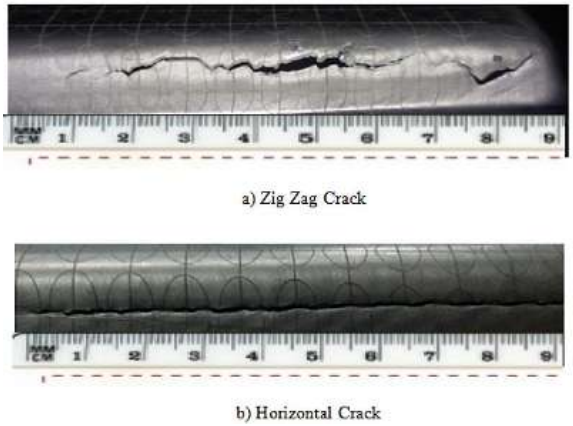

Fig 3.12 Failure components during the IFP

IV. CONCLUSION

From the literature review the incremental forming process has been understood well. Based on the literature review, FLD experiments have been performed over the AA5052, SS304, steel S355 and it has been plotted. For preliminary work, Incremental forming process has been performed for pyramid shape. The summary of the results obtained from the project work has been given below.

1. Incremental forming experiments were performed by varying materials like Stainless Steel SS304, Steel S355 and AA5052 aluminium alloy sheet.
2. Out of 8 experiments, 6 experiments were completed successfully without any failure due to the usage of coolant were as other 2 experiments failed at initial stage due to wall inclination angle and tool runout.
3. Incremental forming experiment failed due to the formation chips during rubbing action between tool and work piece. High pressure coolant were used to carry away the chips to avoid Failure
4. From the experiments geometric accuracy is high in outer to inner tool movement when compared to zig zag tool movement.
5. Wall thickness decreases with increase in wall angle
6. From the experiment component with feed rate of 500 mm/min, spindle speed of 1500 rpm, step size of 0.1, wall angle of 50° and tool radius of 12mm is formed well.

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