Experimental Investigation of AA5052 in Single Point Incremental Forming Using Dynamic Tool Condition

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Abstract

Recent advancements in CAE have made it possible to create several new sheet metals forming techniques that are best based on more traditional technology. The goal of the current work is to conduct an experimental investigation of the behaviour of 1.5 mm thick aluminium alloy AA5052 H-32 during single point incremental forming in terms of major strain, minor strain and calculated thickness. An optical measuring device uses a circle grid to indicate the measurement area to estimate strain. The full factorial approach was used for the experiment design. Using Autodesk Fusion 360, it is possible to significantly generate the necessary tool paths and shape. For the experimental work, a truncated square pyramid geometry with a 60-degree angle was chosen.

Keywords
SPIF, Circle Grid, Spindle Speed, Thickness, Strains and ANOVA.

1. Introduction
Single point incremental forming (SPIF) is a cutting-edge method for producing small batches of sheet parts quickly and profitably. Because SPIF is a die-less process, it may create parts with a wide variety of thicknesses and symmetrical and non-symmetrical geometries. The automotive sector, the aerospace industry, home appliances, and many more industries use sheet metal shaping. Additionally, it is simple and affordable to manufacture the needed components. Numerous researchers are attempting to satisfy client demands utilizing diverse manufacturing techniques without compromising product quality. It should be noted that any adjustments must be made easily for a new design or concept, and that newly established manufacturing methods must be able to produce necessary parts for the chosen material. Because of its versatility in part formation, incremental sheet forming (ISF) is the production technique most used in the automotive and aerospace sectors. It is possible to direct the movements of the Tool using a three-axis CNC/VMC machine. To limit the degree of freedom in the X and Y directions, the fixture should be designed accordingly. Even so, the downward indentation made by the tool should allow the clamped sheet to move freely in the Z direction. Any CAM software is used to generate tool paths. There is a variety of software, including ARTCAM, FUSION 360, Inventor, and others. In this project, we want to use Fusion 360 to generate Tool paths and construct a CAD model of the necessary shape. In this study, a tool path is generated according to our process parameter using a 3D contour tool path.

Jeswiet. et al. (2005) Four fundamental components make up incremental sheet forming: Sheet metal blanks, blank holders, single point forming tools, and CNC motions are listed in that order. the fundamental Initial Unformed Blank Cone (one pass) rotating cylinder First Blank rotating cylinder shaped cone Shear developing Figure 1. shows typical spinning elements; F is the metal forming force, v is the tool feed, and is the spindle rpm. single forming tool whose motion is typically defined in terms of Cartesian coordinates, with tool motion in the horizontal sheet plane denoted by the x- and y-axes and the vertical z-axis serving as the direction of deformation. There are novel methods available today that allow sheet metal to be locally plastically deformed, allowing for genuinely flexible manufacture of intricate sheet metal components. This can be accomplished either through the manufacturing of usable rapid prototypes in a

day or using small batch lots with short lead times. The new techniques are appealing because any facility with a three-axis CNC mill can manufacture sheet metal using them. Due to their outstanding corrosion resistance and high strength to weight ratio without affecting vehicle quality, aluminum alloys like the 5XXX series play a significant role in the automotive sector.
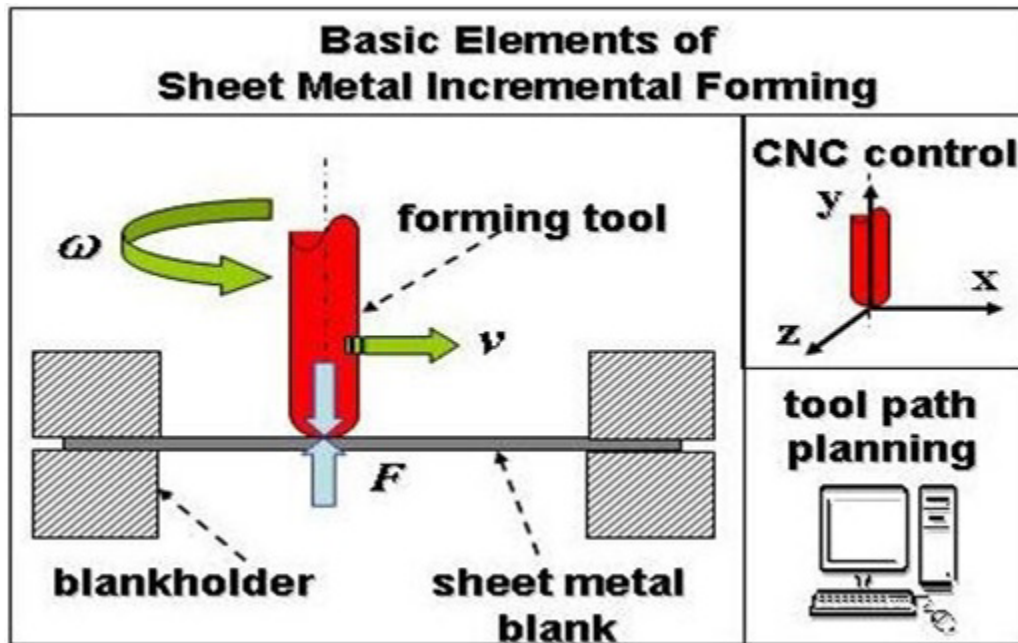

Figure 1. Basic elements of SPIF (Jeswiet. J et al.2015)

1.1 Objectives
The 1.5mm thick AA5052 H-32 material was chosen. These materials are used extensively in the automotive sector to create marine, aircraft, buildings, general sheet metal construction, gasoline lines and tanks, flooring panels, rivets, and wire. They both have strong formability qualities. The outcome of this effort includes responses like strain and thickness. AA5052 H-32 Alloy's impact on forming behaviours will be investigated.

- Study of several parameters, such as Step depth, Spindle Speed, and Feed rate, which will have an impact on single point incremental forming.
- To conduct experimental research of the dynamic tool condition of the forming tool on AA5052 H-32 alloy.
- To optimize process parameters for SPIF process.

2. Literature Review
There was a lot of work done that was research-focused during the SPIF process. To investigate the practicality of the SPIF method, Hardik et al. (2015). Set up on a 3-axis CNC machine, a single point incremental forming tool was built. An accurate shape was then created from a CAD model that was created using CAD-CAM software.To create tool paths for the same, CAD-CAM was widely used. The surface roughness of the developed component was measured using the Mitutoyo SJ201 surface roughness tester.A higher value of roughness along the tool path is caused by the tool markings that were created on the sheet during the forming process. After the component had been produced, its thickness was measured using a digital venire caliper. They discovered that the thickness was less than the sheet's undeformed thickness and was evenly distributed over the wall. While the thickness at the wall was reduced because of the sheet stretching during deformation, the thickness distribution was unified due to the constant incremental axial depth of the Tool utilized during forming.

Erika et al. (2016). The effect of the tool strain path on the formability of AA7075-O sheet and localized thinning in single point incremental forming was researched. The effects of tool trajectory along the generated sheet's wall and their effects on dimensional accuracy were established through trials and the creation of numerical models for analysis.

With consequences for dimensional accuracy, computer models and experiments were used to estimate the tool path's effect on cumulative strain along the generated sheet's wall. They concluded that three distinct regions bending, thinning, and steady state. combine to form thickness fluctuation along the wall of the truncated cone. Using a finite element model, the properties of the thinning area, as well as its position and size, are investigated. A model of the development of thickness reduction indicates that most of the dilution takes place beneath the Tool. Then comes a period of drastic thinning, followed by a time where thickness is steady.To determine what triggers the excessive thinning region to appear after the bend region has been extended to the beginning of the steady state zone, more investigation is required. to increase fracture depth. Accordingly, the researcher deduced that a reduction in step depth and tool diameter results in a greater fracture depth.

Honarpishch et al. (2018). discussed employing response surface methods for multi-response optimization of single point incremental forming of an Al 1050 Cu bimetal with a hyperbolic shape. Four input variables tool diameter, rotational speed, step down, and sheet arrangement and two output variables fracture depth and wall thickness variation were used in the DOE Table on which the experimental procedures were based. Then, using experimental data, the RSM prediction model and multi objective optimization were run, and finite element analysis was used to assess the forming force, stress distribution, and wall thickness using predetermined optimal parameters. The final stage of the process involved evaluating the main effect and interaction impact from the ANOVA.

Baruah et al. (2017). studied analyses the significant Changing factors for the performance characteristics in incremental sheet forming. To maximize formability and reduce roughness in three different dimensions, including rolling, transverse, and angular, they used Taguchi's L9 orthogonal array to achieve the best parameters. The results of the Grey relational analyses and the ANOVA showed that the lubrication had the largest contributing factor along the various rolling directions, feed rate had the lowest contribution, vertical step down had the second-highest contribution, and speed had the third-highest contribution.

Cavaler et al. (2010). studied In SPIF of AISI 304L stainless steel, the impact of process variables and tool coating is investigated. A decrease in surface roughness is observed as step depth is increased. Additionally, untreated tools showed greater surface roughness than coated tools.

Malwad et al (2014) conducted experiments with various forming angles and shown that greater wall angles can maintain more thickness decrease and that smaller wall angles may achieve uniform thickness distribution. Utilizing the widely used AA8011, they investigated the deformation process. In addition to this research, the findings on the impact of wall angle, step down, tool diameter on formability, and thickness distribution over wall angle were provided.

Vikas, and Kumar et al. (2019) It is a new sheet metal prototype technique with a low machine and tool investment cost. investigated how the SPIF process's forming forces were affected by the sheet's thickness, step size, tool diameter, tool shape, spindle speed, wall angle, and feed rate. It was determined that increasing the sheet thickness, step size, tool diameter, wall angle, and spindle speed results in an increase in forming force.

Hamilton et al. (2010) deliberated the effect of high feed rates and spindle speeds on thickness distribution is studied. A mathematical model is generated to expect the orange peel effect in ISF using measured roughness values and using forming parameters.

Jawale et al. (2016) studied Lubrication study for Single Point Incremental Forming of Copper, several available lubricants were analyzed to find out the most significant one which is suiTable for incremental forming resulting good surface finish. And also, its effects on other parameters like forming angle, fracture strains etc were investigated. They concluded that mineral oil is the best suited and economical available lubricant giving good surface finish response.

Bhattacharya et al. (2011) formability is significantly impacted by tool diameter, sheet thickness, and their interactions. Additionally, the study suggests that formability Behavior in the Table range is not considerably impacted. During the investigation, feed rate and step depth were taken into account. Furthermore, the surface roughness study indicates that step depth, tool diameter, and wall angle are the most important significant factors.

3. Methods

The equipment and supplies used in the experiment for this work for the current experimental effort, which is depicted in Figure 2 and Figure 3.the commercially significant aluminum alloy AA5052 H-32 is utilized most influencing parameters were selected which have major impact on Thickness. Strain measurement was done by using Circle grid analysis method. By using Rapid-I vision measurement device, the strain measurement has been done. Considering the selected influencing parameters, Design of Experiments has been done by using Full factorial where Major strain, Minor Strain, and Calculated Thickness as the response factors (Figure 2 and 3).
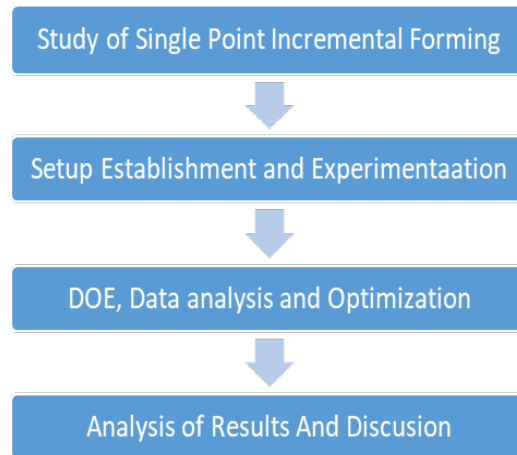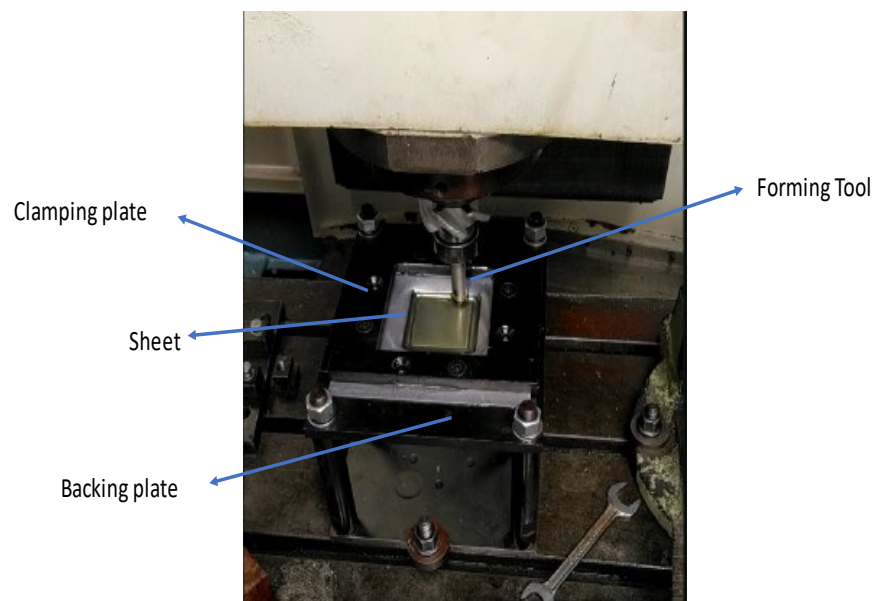

Figure 2. Flowchart of Process Methodology

Figure 3. Experimental setup

3.1 Process Parameter

Tests were conducted utilizing a standard VMC-PVM-40 equipped with a FANUC controller and contour tool path designed using G-code. The tool route began close to the sheet's edge that was clamped, and it continued the thickness

variation in single point incremental formation from an outward to an inward strain path. The following settings were utilized.

- Sheet Thickness = 1.5 mm
- Tool Diameter =10 mm
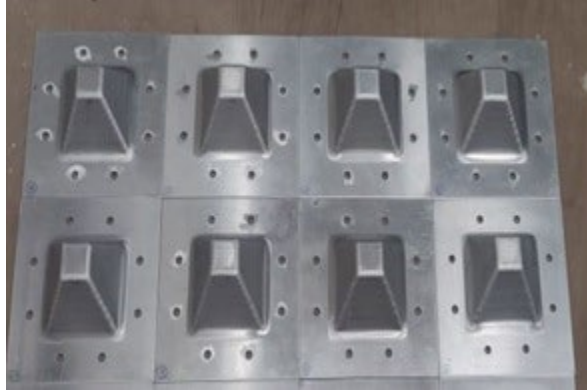- Wall angle=60 degree
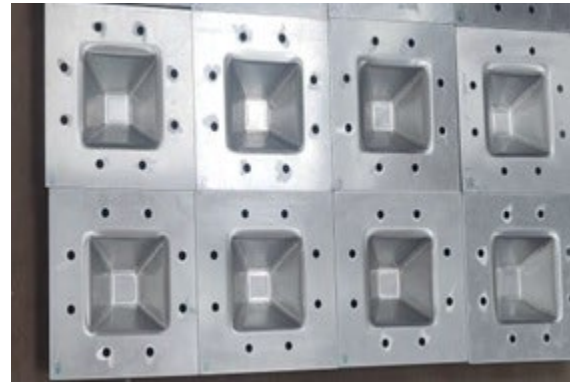

Figure 4. Bottom view of formed by SPIF

Figure 5.Top view of Formed by SPIF

With step depths of 0.5 mm and 1 mm, spindle speeds of 1500 rpm and 1200 rpm, and feed rates of 1500 mm/min and 1000 mm/min, eight pyramids were created. To reduce friction Throughout the process, 85W-140 oil lubricant was continuously used. To increase measurement accuracy, strain and thickness were measured at the same position on the produced geometry.the strain and thickness of the formed component were confirmed using the average value. The formed parts as per design of experiment with the help of process parameters as shown in above Figure 4 and Figure 5.

3.2 Material and Methods
On any CNC-operated milling machine, single point incremental forming can be done exactly. Due to their high stiffness, large speed and easy to program the tool path milling machines are preferred and are available in different designs, which differ in working volume, maximum feed rate, maximum load, stiffness, and cost prices. SPIF fixture was fixed on the bed of the machine and the zero setting would be done. AA5052, 1.5 mm In order to complete this task, the VMC-PVM-40 with a FANUC controller was employed, as illustrated in Figure 6. Experiments were carried out using the thick sheet material. Due to their high specific strengths, aluminum alloys are widely used in the automotive and aerospace industries. They have good formability, strength, weldability, strong corrosion resistance, and good fatigue resistance. The blanks were sized to 175 mm 175 mm and subsequently marked using laser engraving. Most researchers have utilized screen printing to stamp circular grids on the sheet's reverse side prior to forming. To plot formation limit stresses and thickness strains, we used experimental procedures to laser-engrave circular grids on the reverse of each sheet. For economic reasons, we chose circular grids of 5 mm diameter that are touching and are marked over the surface area of 160 mm 160 mm on one side of the blanks. Normally (Figure 6 and 7), circle diameter is restricted to a maximum of 3 mm.After the SPIF procedure, these circles enlarge into ellipses. The experiment used a truncated square pyramid. (Table 1 and Table 2).

Table 1. Chemical composition of the blank material

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
AA5052 H-32	0. 120	0. 300	0. 005	0. 095	2. 463	0. 191	0. 001	0. 015

Table 2. Mechanical properties

Property	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Density (g/cm³)	Melting point (°C)	Modulus of Elasticity (GPa)	Thermal expansion(/k)

AA5052 H-32	240	193	10.4	2.63	605	70	$23.7*10^{-6}$

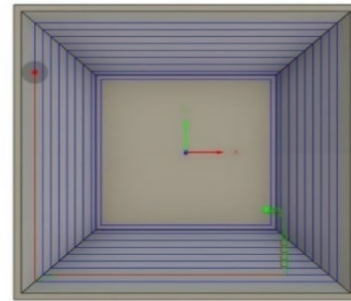Figure 6.CNC Milling machine   Figure 7. Tool path

3.3 Tool Path Generation

A three axis CNC/VMC machine can be used to direct the Tool's movements. To limit the degree of freedom in the X and Y directions, the fixture should be designed accordingly. Even so, the downward indentation made by the tool should allow the clamped sheet to move freely in the Z direction. Any CAM software is used to generate the tool path. Software options include ARTCAM, FUSION 360, Inventor, and others. As demonstrated in Figure 7. we want to use Fusion 360 to generate tool paths and a CAD model of the appropriate shape. In this study, a tool path is generated in accordance with our process parameter using a 3D contour tool path. For the experimental work, a 60-degree truncated square pyramid geometry was chosen. Using the AUTODESK FUSION 360 software and tool path generation in accordance with our process specifications, a CAD model with the necessary angle and depth was created. The produced tool path was then put through additional processing to provide G and M codes for the Fanuc controller. The Compact Flash card used to store this programmed was then inserted into the VMC device.

3.4 Strain and Thickness Measurement

Stretching often occurs during single point incremental formation, and this stretching effect causes all the circles that are within the forming area to get longer.After the SPIF procedure, circles with a 5 mm starting diameter were lengthened and took on an elliptical form.Because of the material's isotropic composition, it stretched evenly in all directions.The center line and the sheet's rolling direction were used to carry out the measurement for these elongated circles as marked.Rapid-I vision measurement was utilized to measure the major and minor diameter of these ellipses that were generated during incremental formation as shown in Figure 9 and Figure 10.As mentioned by M. M. Ghadmode et al. (2019). the main strain and minor strain were determined using the following equation (1), (2) and (3).Major strains were represented on the vertical axis, while minor strains were plotted on the horizontal axis as shown in Figure 8.

- $\varepsilon = \ln\frac{Ln}{Lo}$ .... (1)
- $R: \varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 0$ .... (2)
- $\varepsilon_3 = \frac{dt}{t}$ .... (3)

dt = Change in thickness   t = original thickness
ε= strain   R= Volume Consistencyε_1= Major strain
Ln=major or minor diameter of ellipseε_2=Minor strain
Lo =original diameter of circle ε_3=Thickness strain
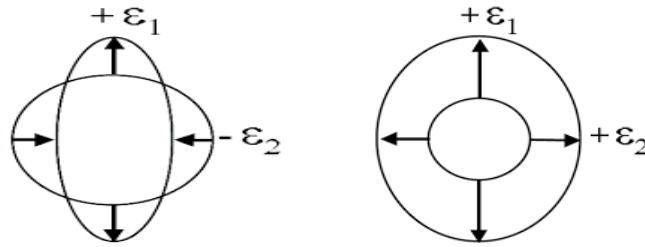
Figure 8.circles deform to become ellipse

Figure 9. Circle after deformation

Figure 10. Rapid -I vision Measurement

4. Data Collection

With respective run order Full factorial. The value of strain and Thickness is selected at responses. Given Table shows measured value of after forming with respective experimental run order are as following Table 3.

Table 3. Experimental run order with measured response

Sr. No.	Process Parameter			Responses Parameters		
	Step depth (mm)	Spindle Speed (rpm)	Feed rate (mm/min)	Major strain	Minor strain	Calculated thickness (mm)
1	0.5	1500	1500	0.668	0.046	0.430
2	0.5	1200	1000	0.744	0.064	0.288
3	1	1200	1000	0.698	0.055	0.369
4	1	1500	1000	0.621	0.045	0.501
5	1	1200	1500	0.677	0.054	0.404
6	0.5	1500	1000	0.654	0.039	0.460
7	1	1500	1500	0.573	0.026	0.602
8	0.5	1200	1500	0.669	0.051	0.420

5. Results and Discussion

5.1 Numerical Results

Analysis of variance (ANOVA) was used to determine how process characteristics affected a selection of responses. The analysis was performed using Minitab 17. The major process parameters influencing the responses have been determined using the F test value at a 95 percent confidence level. Therefore, a parameter is only considered important if its probability value is less than 0.05. The P value evaluates each parameter's statistical significance. The next step

is to determine percentage contribution, which shows how important a parameter is in relation to other parameters in reducing variation (Table 4-6).

Table 4. ANOVA for Major Stain

Source	DF	SS	MS	F-Value	P-Value
Step depth(mm)	1	0.003423	0.003423	4.40	0.104
Spindle speed (rpm)	1	0.009312	0.009312	11.96	0.026
Feed rate (mm/min)	1	0.002103	0.002123	2.70	0.176
Error	4	0.003115	0.000779		
Total	7	0.017952			

Table 5. ANOVA for Minor Stain

Source	DF	SS	MS	F-Value	P-Value
Step depth(mm)	1	0.000050	0.000050	0.88	0.402
Spindle speed (rpm)	1	0.000571	0.000571	10.09	0.034
Feed rate (mm/min)	1	0.000097	0.000097	1.72	0.266
Error	4	0.000226	0.000234		
Total	7	0.000945			

Table 6. ANOVA for Calculated Thickness

Source	DF	SS	MS	F-Value	P-Value
Step depth(mm)	1	0.009669	0.009669	3.65	0.129
Spindle speed (rpm)	1	0.032614	0.032614	12.32	0.025
Feed rate (mm/min)	1	0.006987	0.006987	2.64	0.180
Error	4	0.010591	0.002648		
Total	7	0.059860			

5.2 Graphical Results

Each major factor's impact on the output response is depicted in the main effect plot for major strain, minor strain and thickness variation. Spindle speed has the greatest impact on major strain, major strain, and calculated thickness.
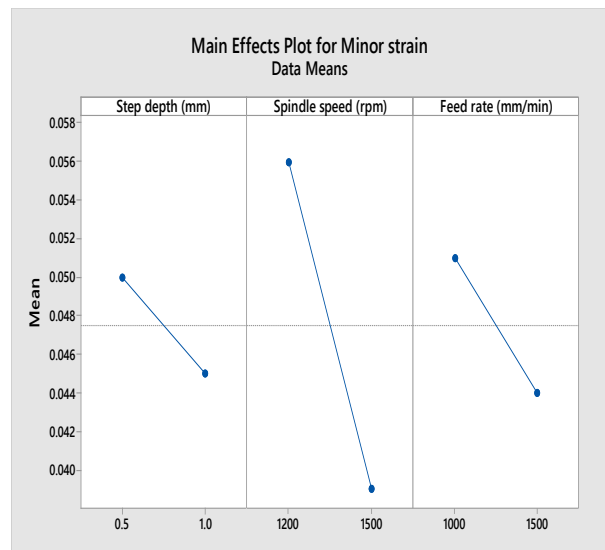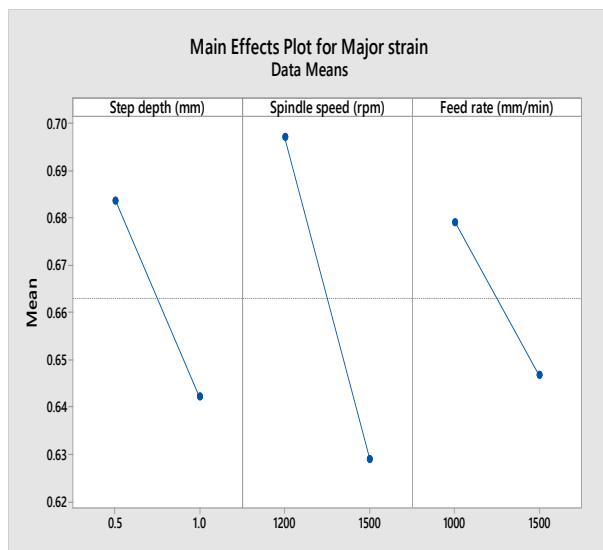
Figure 11. Main Effects plot for Major strain   Figure 12. Main Effects plot for Minor strain
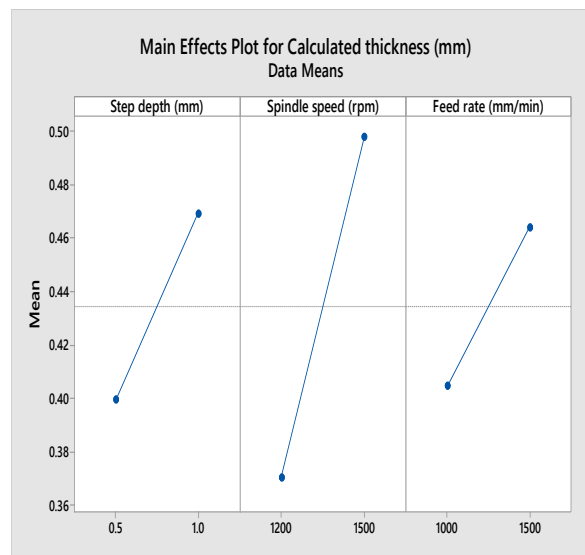

Figure 13. Main Effects plot for Calculated Thickness

The primary effect plots for the major strain and minor strain are shown in Figure 11 and Figure 12. Major strain has been seen to increase when the step depth is decreased and decrease when the step depth is increased. The spindle speed and feed rate show the same phenomenon. Tables 4 and 5 present the results of an ANOVA for major strain and minor strain, respectively, where spindle speed is the most significant factor.

The calculated thickness's primary effect plot is shown in Figure 13. It was shown that calculated thickness reduces with decreasing step depth and increases with rising step depth. The spindle speed and feed rate follow a similar pattern. Table 6 shows the ANOVA for the computed thickness, with spindle speed being the most significant variable.

6. Conclusion
The following conclusions were drawn from the present investigation are above graphical representation:
Step depth, spindle speed and feed rate are the influential parameters affecting major strain, minor strain, and thickness of sheet in single point incremental forming. Present contributions of process parameters to the major strain, minor strain and calculated thickness of sheet were made assuming other process parameters as constant.
As Step depth increases the value of major strain, minor strain decreases, and thickness increases respectively.
With increase in value of Spindle speed and feed rate, the value of major strain and minor strain decreases, while thickness increases.
Thus, Spindle speed has the larger influence on output response i.e major strain, minor strain and calculated thickness.

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