EFFECT OF TOOL PROFILE ON SINGLE POINT INCREMENTAL FORMING PROCESS

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Abstract : Single point incremental forming (SPIF) process is different from conventional forming process, it is a die less forming process performed using non-cutting edge tool moving along the circumferential surface of the product that is to be formed. The process investigation has been carried out on AA2024. The input parameters such as step size, wall angle, tool speed, feed rate and tool type were brought under study to see their effect on the response variables such as surface roughness, wall thickness. Better surface finish was observed for hemispherical end tool, and specific trend of varying thickness of the formed product was observed

***IndexTerms* – SPIF, Surface roughness, Wall thickness.**

I. INTRODUCTION

The single point incremental forming process is die less forming process which is suitable for small batch type production and for rapid prototyping. As is conventional forming process die and punch is used to form the sheet, design of die and punch for particular product of batch type production is costly affair. In SPIF process customized products with complex shapes can be prepared without the need of die and punch assembly. A non-cutting edge tool with round bottom tipis used to deform the sheet metal blank. The tool travels the circumferential tool path generated by the CAM software for particular shape of the product. While following the tool path the tool causes the localized plastic deformation in the sheet blank to form the sheet. This process is generally carried out on vertical machining centers. Working principle of SPIF is shown in the fig.1. The sheet is clamped in XY plane in the fixture. The tool moves in desired axes to create the desired part. The performance of SPIF process is affected significantly by the process parameters (step size, wall angle, tool speed, and feed rate), shape of the product and tool shape (hemispherical end, ball end, flat end)

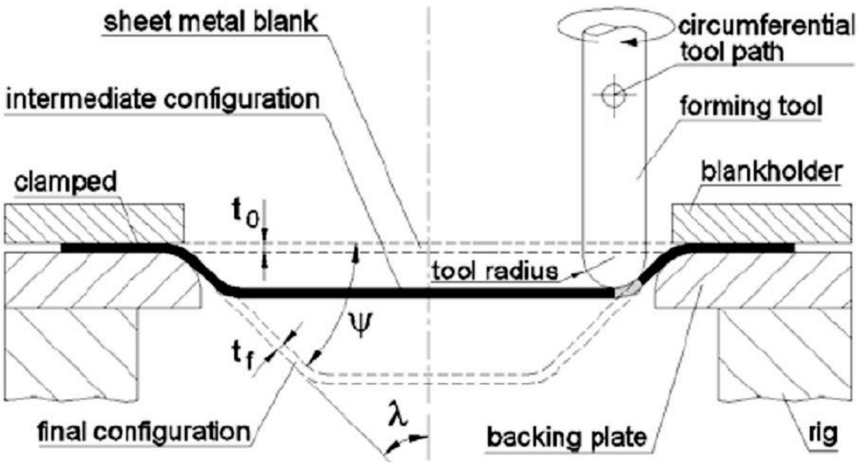

fig. 1: SPIF working principle [1]

Many researchers have investigated the SPIF process for betterment of the performance characteristics. Subramanian and Kumar [2] performed SPIF on SS 304 sheets using hemispherical tool. Formability of sheet was better at lower feed rates. Lower step depth showed increased formability. Thickness of the formed component was found to be non-uniform. Maximum 50% thickness reduction was observed. Mulay et al. [3] spindle speed has very less effect on surface roughness and formability. Increased spindle speed increases frictional heat which resulted in higher formability. Maximum forming wall angle was observed to b 85.40^o. Naranjo et al. [4] heated support was used for sheet to perform SPIF process on TiAl4V alloy. Increase in temperature increased the formability. The force required top form the sheet was found less due to heated sheet. The forming temperature didn't have major impact on the surface finish of the components. Maqbool and Bambach [5] studied the effect of different tool diameter. Better geometrical accuracy was obtained for small tool diameters and step size. Singh and Agrawal [6] process simulation was done on ABAQUS and results were compared to actual experimentations carried out. The spring back was observed to be reduced with increase in bent wall thickness. Skjoedt et al. [7] performed SPIF process using dummy sheet. It increased the surface finish but the formability of the component was observed to be reduced. Use of dummy sheet increased the required forming force.

II. EXPERIMENTAL WORK

2.1 Material selection

The material used as the work-piece to carry out the SPIF experimentation will be Aluminum alloy 2024. AA2024 is high-strength aluminum alloys known for its high strength and excellent fatigue resistance. % of elongation of material is about 20 to 25%.

The following table shows the chemical composition of the workpiece material AA2024.

Table no. 1: composition of AA2024

Weight (%)	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other	Al
Min.			3.80	0.30	1.20					94.7
Max.	0.50	0.50	4.90	0.90	1.80	0.10	0.25	0.15	0.05	90.85

2.1 Tool and setup development

The experiments were carried out on vertical machining center having siemens 8282D basic controller. Fig 2 shows the experimental setup developed to carry out the process. The sheet that is to be formed is clamped between the plates.

fig. 2: experimental setup

The tool type was one of the varying process parameter to understand its effect on the response variables. Three types of tool profiles were brought under studies which are hemispherical end tool, ball end tool and flat end tool. The dimensions of the end tip were kept same that is 10 mm, only the shapes of the tool were varied. The fig 3 shows the different tool profiles developed to carry out experimentation.

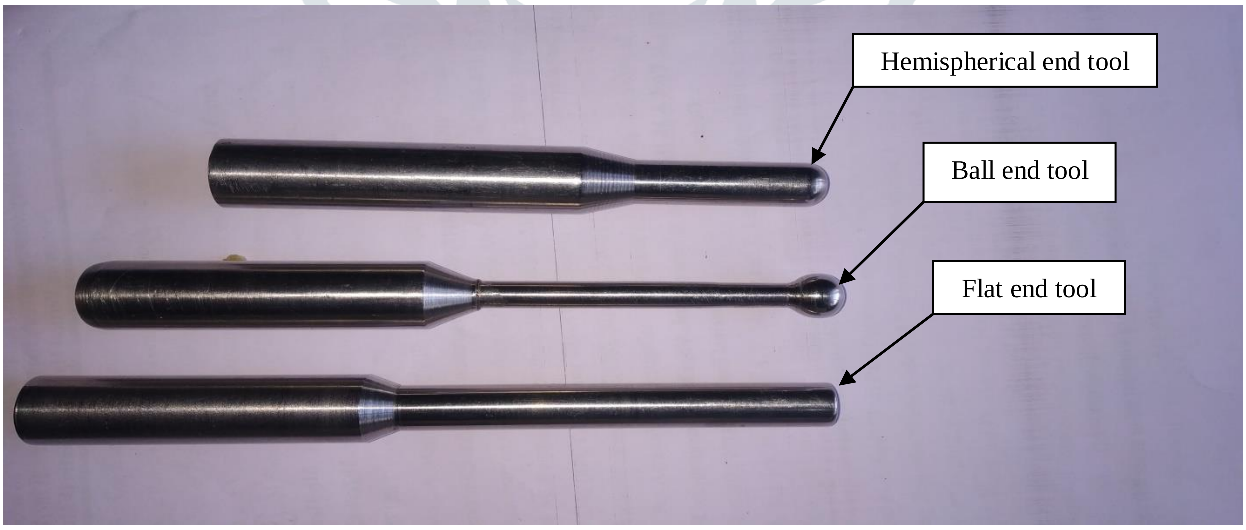

fig. 3: tools with three different profiles

2.2 Tool path generation

Modeling of the product and generation of the tool path is done using UG-NX 10 software. Fig below shows the product shape and the tool path being generated accordingly. This generated tool path is extracted in the form G-codes suitable with the controller of the machine on which SPIF process is to be performed. The shape of the product selected to carry out the experimental investigation is square pyramidal type. Different type of customized product shape can be considered and the tool path can be generated using CAM software's.

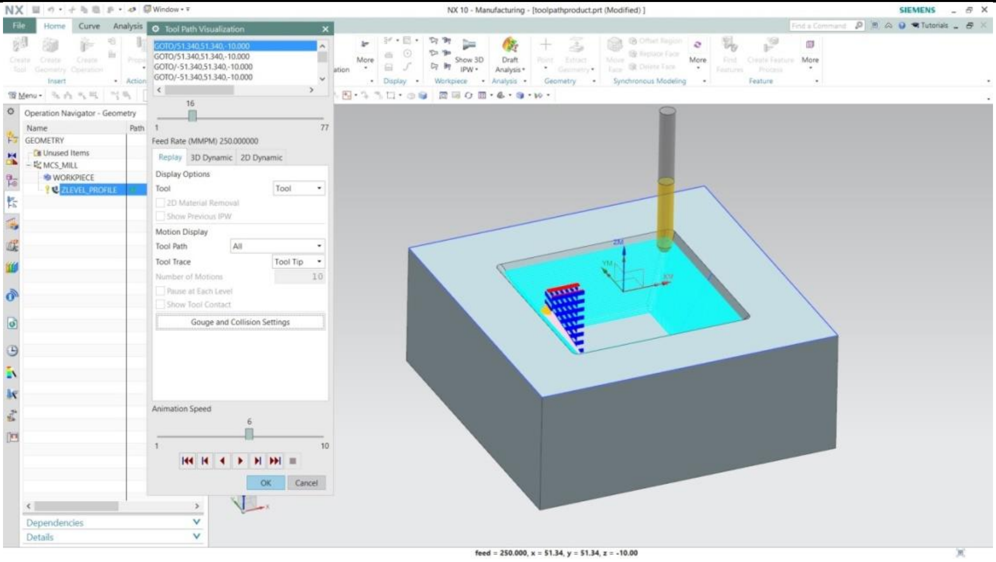

fig. 4: tool path generation using UGNX 10

III. DESIGN OF EXPERIMENT

Design of experiments (DOE) is a systematic method to determine the individual and interactive relationship between factors affecting a process and the output of that process. The most commonly used terms in the DOE methodology include controllable and uncontrollable input factors. Controllable input factors are those input parameters that can be modified in an experiment or process. Uncontrollable input factors are those parameters that cannot be changed. Following are the process parameters and there levels decided to perform the SPIF process and see their effect on the response variables.

table no. 1: parameters with levels

Process Parameters	Level 1	Level 2	Level 3
Wall angle (degree)	60	70	80
Step Size (mm)	0.5	1	-
Tool Speed (rpm)	1000	1500	2000
Feed Rate (mm/min)	300	600	900
Tool Type	H	B	F

Tool Type: H :- Hemispherical end Tool
B :- Ball end Tool
F :- Flat end

Orthogonal arrays provide a best set of well balanced (minimum) experiments. The number of rows of an orthogonal array represents the requisite number of experiments. L18 orthogonal array is formed using these process parameters and there levels in Minitab software.

3.1 Experimentation

The fig below shows the 18 incrementally formed components by varying the process parameters and there levels according to the orthogonal array

fig. 5: incrementally formed components

IV. RESULTS AND DISCUSSION

The experimentations were carried out according to set of L18 orthogonal array. The following table shows surface roughness and the thickness of the components measured.

table no. 5.1 : results

Expt. No.	Process Parameters					Response variables	
	Step Size (mm)	Wall angle (degree)	Tool Speed (rpm)	Feed Rate (mm/min)	Tool Type	Roughness (μm)	Thickness (mm)
1	0.5	60	1000	300	H	1.53	0.638
2	0.5	60	1500	600	B	1.54	0.63
3	0.5	60	2000	900	F	6.14	0.596
4	0.5	70	1000	300	B	2.11	0.673
5	0.5	70	1500	600	F	5.04	0.655
6	05	70	2000	900	H	1.19	0.658
7	0.5	80	1000	600	H	1.25	0.65
8	0.5	80	1500	900	B	1.11	0.6
9	0.5	80	2000	300	F	4.92	0.613
10	1	60	1000	900	F	5.74	0.573
11	1	60	1500	300	H	2.07	0.613
12	1	60	2000	600	B	1.88	0.618
13	1	70	1000	900	F	4.67	0.65
14	1	70	1500	900	H	2.12	0.626
15	1	70	2000	300	B	1.15	0.54
16	1	80	1000	900	B	2	0.658
17	1	80	1500	300	F	6.19	0.68
18	1	80	2000	600	H	1.34	0.601

4.1 Thickness analysis of formed part

Thickness is measured using micrometer having least count of 0.01mm. Reading were taken using following formula

$$\text{Thickness} = \text{Main Scale reading} + (\text{Least Count} \times \text{Thimble reading})$$

Thickness readings were measured at 0mm, 25mm and 50mm distance from top of the formed part. The average of the 3 readings is reported as the thickness of the formed part.

Thickness distributions for the formed part were plotted on graph with respect to the depth of measurement for different wall angles.

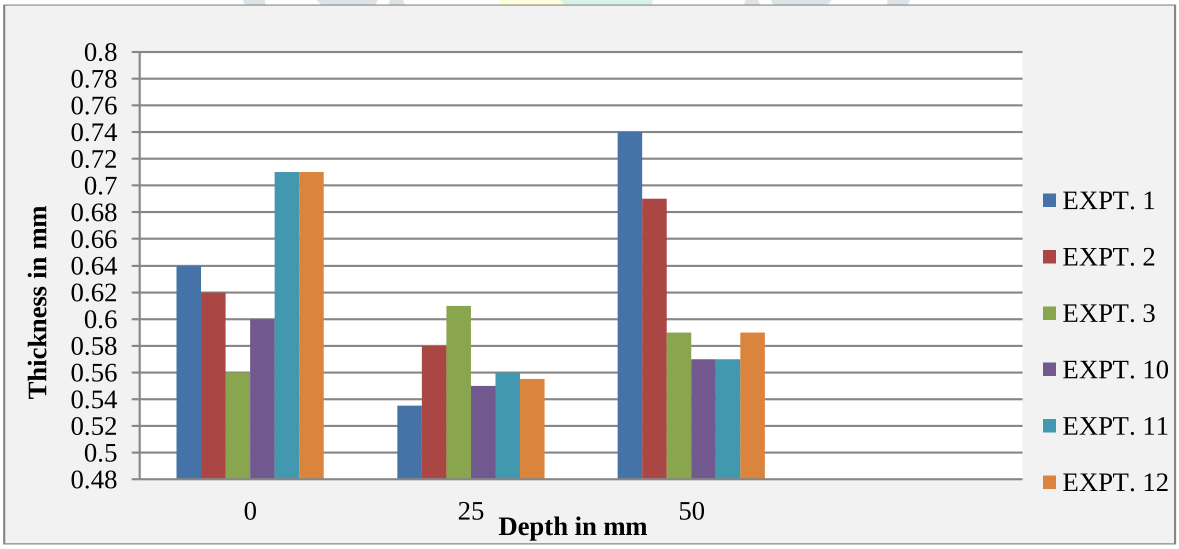

fig. 6: thickness distribution for 60° wall angle

The above graph is the plot of the thickness distribution of the parts with 60^0 wall angle as one of the parameter according orthogonal array. The thickness distribution was observed to be varying with the depth of the component and at the mid portion it was found to be the minimum as compared to the thickness at top and bottom of the component

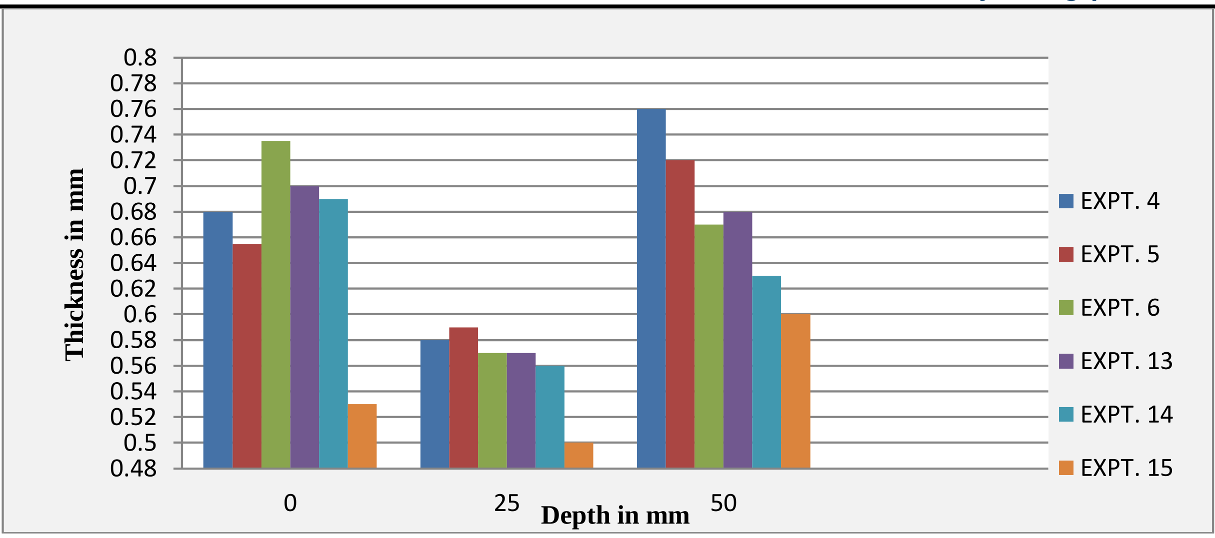

fig. 7: thickness distribution for 70^o wall angle

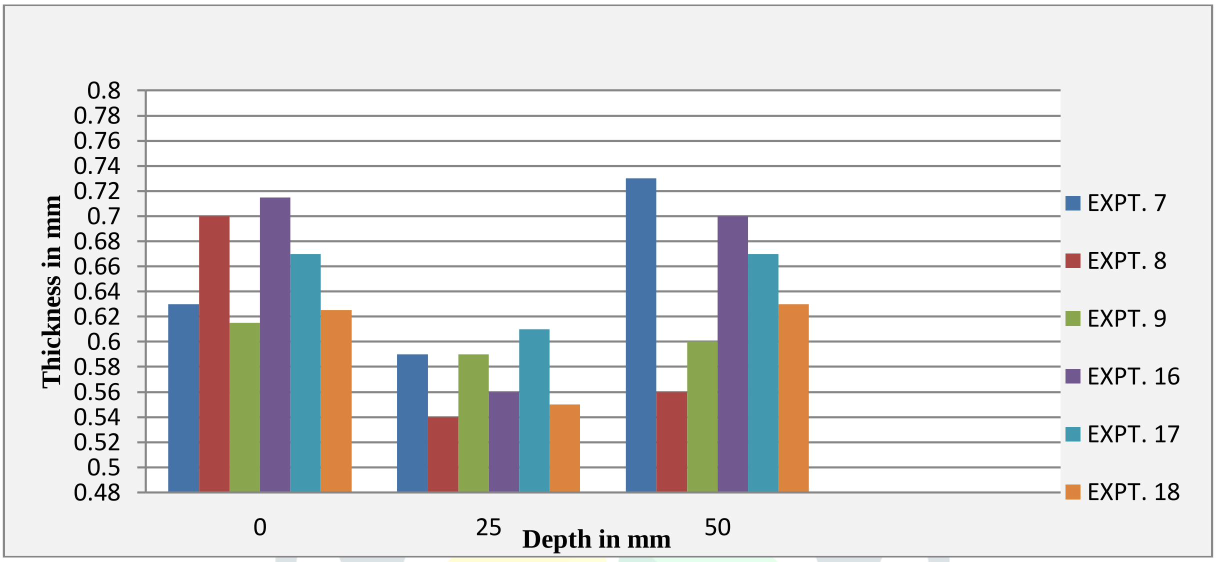

fig. 8: thickness distribution for 80^o wall angle

From the plots of thickness graph with respect to depth of the component an particular trend of thickness variation is observed. The thickness reduction also depends on the clamping of the sheet between the fixture plates. If the clamping force is less the material flow takes place easily and the combined effect of bending and shear deformation is observed which result in less thickness reduction of the material during the incremental forming process. If the clamping force is more the material flow through the fixture plate is less and moreover the effect of shear deformation is observed is significantly high thus the thickness reduction is more in such case.

4.2 Roughness analysis of formed part

Surface roughness is one of the most important response variables to check the compatibility of the process to manufacture any product. Taylor Hobson roughness tester was used to measure the roughness of the incrementally formed component. The result table shows the reading for surface roughness for each of the experiment performed according to array. To maintain the accuracy of the roughness value the readings were taken 3 times and the average of the three readings is reported as the surface roughness of the component.

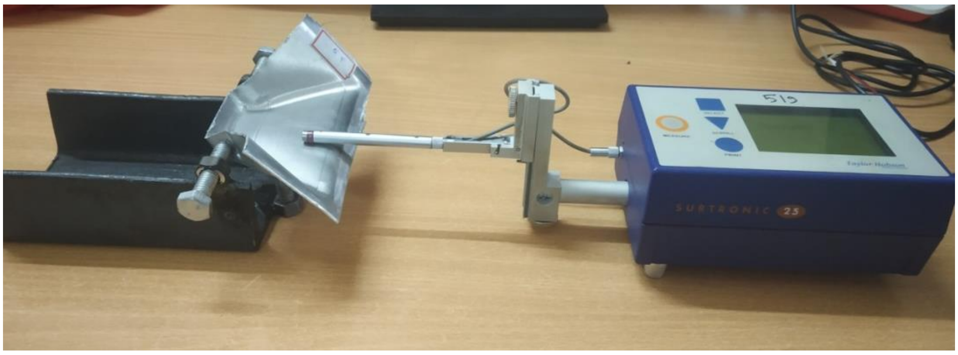

fig. 9: Taylor Hobson roughness tester

Type of tool profile widely affects the surface roughness of the component in single point incremental forming process. Different tool profile shows different surface contact with the forming sheet surface. Hemispherical tool and ball end type tool has similar type of contact i.e. the curved surface of the end tip. Whereas the flat end tool has the chamfered corner at its tip so with each incremental step depth it takes step marks are observed is the reason why the flat end tool shows higher surface roughness value.

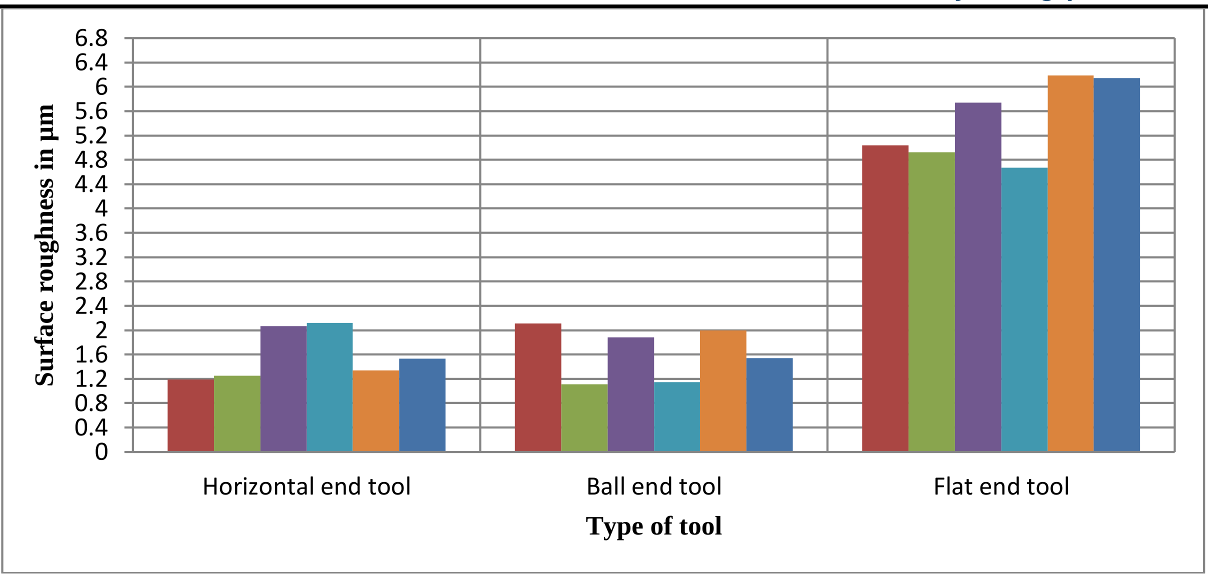

fig. 10: roughness distribution for different tool type

The above fig shows the plot of roughness value with respect to different tool profiles. The flat end tool has delivered high roughness as compared to hemispherical and ball end tool

V CONCLUSION

Varying thickness is observed with the depth of the component. Maximum thickness reduction is observed at center of the component, which is the critical area while performing the SPIF process. On an average 40% thickness is observed of the 1mm AA2024 sheet.

Tool Shape plays an important role in surface roughness. Hemispherical and ball end tool gives the desirable low surface roughness value. Step size also affects the roughness of the part, good surface finish was observed for 0.5mm step size.

IV. ACKNOWLEDGMENT

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