SURFACE ROUGHNESS EVALUATION OF AA 3003 ALLOY IN SINGLE POINT INCREMENTAL FORMING TECHNIQUE

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Abstract- Single point Incremental forming (SPIF) is an innovative manufacturing process in the area of sheet metal forming process. The technicality of this process is to form a desired shape without dedicated dies and especially advantageous for low volume production or customized parts or rapid prototyping. The present study aims to find the significance of input variables on the surface roughness of the formed part. Six process variables with two levels are considered for deformation of AA3003-O alloy. The experimental runs conducted according to Design of experiment (DOE) Taguchi L_8 orthogonal array. The nano scale surface roughness is measured by using atomic force microscopy (AFM). The input process variables considered for the present study taken as Step down size, Feed rate of tool, RPM, thickness of metal, wall angle and lubricant. Finally, the taguchi methodology is used for the statistical analysis followed by ANOVA to find the interaction of process variables. The response study indicates that the Step down size and wall angle as the most significant input variables.

KEYWORDS: SPIF, Surface Roughness, Process Variables, Taguchi methodology, ANOVA

1. INTRODUCTION

Incremental sheet metal forming is a developing forming process of sheet material without the use of dies which is a feasible solution for the rapid prototyping and the manufacturing of small batch sheet parts. Single point incremental forming (SPIF) is one of the ISMF process in which blank is formed without support at the back of blank. The process is carried out at room temperature and requires a CNC machining centre. Extensive research has been carried out in the field of ISMF but that does not provide an adequate solution such as formability of sheet metal, tool path generation, force prediction, FE simulation etc. the smoothness of formed part matters the process capability, in this regard, the experiments followed by statistical analysis of ISMF are carried on thin AA3003-O with input variables to find the significance of them in surface roughness Sa of formed part. Therefore, the main controlling parameter in this technique is the rate of deformation at any point on the sheet [1-5]. The preliminary study on SPCC steel material having similar properties as DC04 has been formed through incremental punching with varying forming angles without supports at the bottom. The formed parts have springback error and dimensional inaccuracy at the edges [6]. A large number of research works have been reported for the optimization of formability as well as surface roughness, analyzing and controlling the influencing process parameters. The challenges for the accuracy of ISMF are quality surface of final part and formability of the work material to its maximum limit without breakage. A comparative analysis between the analytical and the experimental surface roughness of pyramid frusta made of AA7075 aluminium sheet which describes a predictional model for the evaluation of process parameters amplitudes [7] followed by the effects of working parameters on the external surface roughening, orange peel effect, observed in single point incremental forming (SPIF) to estimate models to categorize the extent of orange peel roughening based on visual inspection and on surface roughness measurements [8]. The experimental research on the surface quality of the medical implants (partial resurfacing of the femoral condylar surface of the knee) obtained by

SPIF followed by mathematical models that define different roughness parameters and highlights the factors that influence it [9]. The effects of input variables on the dimensional accuracy, surface roughness, and microstructure of parts of carbon steel (DC01), stainless steel (304), and aluminum (A1050) has been statistically processed by using the ANOVA technique [10]. A mathematical prediction to optimize both the wall angle and surface roughness for the material Al5052 alloy sheets in relation with parameters using three-layer back propagation neural network and genetic algorithm [11]. The prediction of minimal surface roughness by means of Grey Relational Analysis (GRA) on aluminium IS grade 19000 by the application of lubricant [14].The statistical analysis of ISF on SS304 material with varying tool diameter with process parameters (e.g. feed rate, speed of spindle, wall angle, and step depth increment) found that significance of step depth on surface roughness was63.56% [15]. The regression analysis predicts wall angle contributes 69%, step depth 27%, Spindle speed 3% and tool diameter 1% on surface roughness [16].

2. MACHINE, TOOL AND MATERIALS

2.1 Incremental Sheet Forming Machine

The SPIF process is carried out on MIKROTOOLS DT-110, a CNC vertical milling machine with 0.1 micron accuracy shown in Figure 1. This machine is chosen for the experimentations due to close dimensional control. The following is the specification of the machine.

Table size: 810×400 mm

Travel: x-axis:200 mm, y-axis:100 mm and z-axis:100 mm

Spindle speed: 0 -3000 rpm

Feed rate: 1 - 2000 mm/min

AA3003-O	Composition (%)					
	Al	Si	Fe	Cu	Mg	Zr
	98.12	0.628	0.705	0.05	1.2	0.05

Position accuracy: +/- 1 micron/100mm

Vibration isolation: 4-point heavy duty passive dampers.

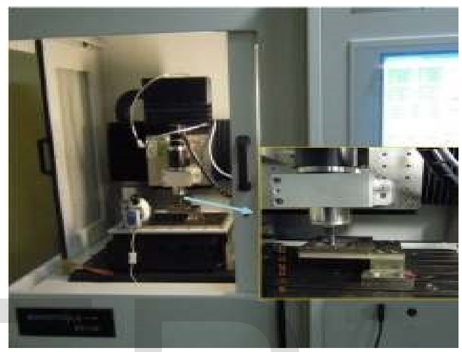

Fig 1: the incremental sheet metal forming set-up on MIKROTOOLS DT-110

2.2Tool

A 50 mm mild steel rod of 7mm diameter rod is used for making the tool. The one end of tool is grooved in such a way that half of a 6mm diameter stainless steel bearing ball inserted on it. The bearing ball is taken for its high wear and thermal properties. On the other hand, once the bearing ball wears out after long run, it will be easily replaced. The tool are shown in figure 2

Fig 2: Tool used for SPIF

2.3 Material

The SPIF is more suitable for the sheets having low thicknesses. The miniaturization trend always finds part with high quality; therefore, commercially available AA 3003-O sheet of 0.2 and 0.4 mm thickness is taken for the study. The scan electron microscopy (SEM) is used for the chemical composition. The results are given in table1.

Table 1: Chemical compositions (%) of AA 3003-O

The ultimate tensile strength test is carried out in "INSTRON" Series IX Automated Materials Testing System with crosshead speed of 5mm/min at 30⁰C with 50% humidity. The sample is prepared as per American society for testing's and materials (ASTM) standard E8. The mechanical properties are given in table2.

Table 2: Mechanical properties of Aluminium AA3003-O

Material	3003-O
Ultimate tensile strength	130 MPa
Yield strength	125 MPa
Density	2.73 g/cm^3
% Elongation	18
Poisson ratio	0.33
Melting point	655^{0}C

3. EXPERIMENTAL INVESTIGATION

The present work is to predict Sa of the formed part which is processed by using single point incremental forming. The investigation is to show the significance of process parameters on the roughness of the product. The influences of input variables such as step depth (Δ), feed rate ( ), spindle speed ( ), sheet thickness ( ), wall angle ( ) and lubricant ( ) is considered for the analysis. The ranges of individual parameters are shown in table 3.

Table 3: Extreme values of the experimental plane

Input Variable	Δz (mm)	f (mm)	R	T (mm)	θ (°)	L
Lower Level	0.1	20	500	0.2	15	MoS_2 Grease
Higher level	0.7	100	2000	0.4	45	Graphite Powder

Taguchi method is adopted for analysis in the present study. This method uses a special set of arrays called orthogonal arrays (OA). The OA method lies in choosing the level combinations of the input design variables for each experiment. The L_8 orthogonal array is meant for understanding the effect of 6 independent factors each having 2 factor level values (table 4).

Table 4: the taguchi design L_8 for Experiments

EXP. No.	Δz (mm)	f (mm)		R (mm)	θ (°)	L
1	0.1	20	500	0.2	15	MoS_2 Grease
2	0.1	20	500	0.4	45	Graphite Powder
3	0.1	100	2000	0.2	15	Graphite Powder
4	0.1	100	2000	0.4	45	MoS_2 Grease
5	0.7	20	2000	0.2	45	MoS_2 Grease
6	0.7	20	2000	0.4	15	Graphite Powder
7	0.7	100	500	0.2	45	Graphite Powder
8	0.7	100	500	0.4	15	MoS_2 Grease

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In the present study, surface roughness Sa measured directly and to account for waviness is used. The 5*5 mm section of deformed part from square pyramidal frusta (fig. 3) is measured precisely through digital verniercaliper, marked and cutting carefully by cutter without damaging the formed area and treated as samples.

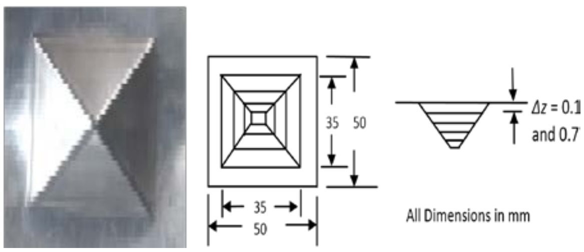


Fig 3: The formed Square Pyramidal frusta with their dimensions

The roughness Sa is measures through atomic force measurement (AFM) technique. The highly precise machinery NT-MDT, solver-4 having magnification of 58X to 578X is used for measuring the Sa, in which a probe scan the specified area at a time. The test data of Sa with coded factors are presented in Table 5. The signal to noise (SN) ratio for the surface roughness is evaluated by using equation 1. Higher the Sa value indicates rougher surface of part. The low Sa indicates the smooth surface of final product. So smaller is best consideration approach for the roughness follows in the analysis.

The Signal to noise ratio for roughness as

$$S/N\ of\ Sa = -10 \log \frac{1}{n} \sum_{i=1}^{n} y_{ij}^2 \qquad \text{......1}$$

Where; n is number of replications,

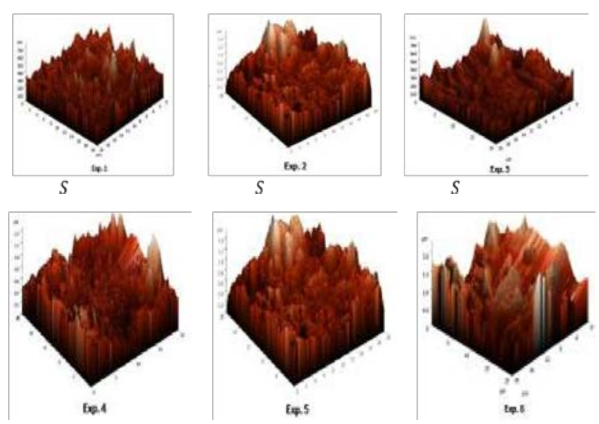
y_{ij} is observed response value.

Table 5: Coded factors and Responses of Sa

EXP. No.	Δz (mm)	f (mm)	R	T (mm)	θ $(°)$	L	Response Sa
1	1	1	1	1	1	1	57.232
2	1	1	1	2	2	2	64.562
3	1	2	2	1	1	2	58.156
4	1	2	2	2	2	1	69.744
5	2	1	2	2	1	1	107.621
6	2	1	2	1	2	2	85.058
7	2	2	1	2	1	2	109.831
8	2	2	1	1	2	1	93.755

4. RESULT AND DISCUSSION

The 3D micrographs generated by AFM test for all the experiments are presented in figure 3 (a-h). The test result indicates the amount of sampling which includes the maximum pick, minimum pick, pick to pick (Sy), ten point heights average (Sz), root mean square (Sq) and average roughness (Sa) of the scanned area. Since the study concentrates to find the significance of above mentioned input variables on Sa, only the average roughness Sa is indicated in table 5.



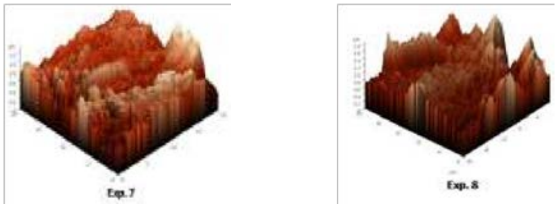


Fig 4: 3-D AFM image of formed part for each experiment with their 1_2value

Table 6 corresponds to the S/N responses for roughness Sa. With reference to the maximum signal to noise ratio, the input parameters to improve surface quality of final part is Δ =0.1 mm, = 20mm/min, = 2000, = 0.4 mm, = 45⁰ and = Graphite Powder.

Table 6: Response Table for S/N Ratios: Smaller is better

Level	*Δz*	*f*	*R*	*T*	*θ*	*L*
1	**-35.88**	**-37.65**	-37.90	-37.97	**-37.12**	-38.03
2	-39.87	-38.10	**-37.85**	**-37.78**	-38.63	**-37.73**
Delta	3.99	0.46	0.65	0.20	1.51	0.30
Rank	1	3	6	5	2	4

ANOVA is the tool to provide conformity information about the system. It states the percentage influence of process parameters in numeric terms, the relative influence of parameters. ANOVA is preferable and statistically valid information for collective influences of factors that are excluded (error) in the study. Table76 shows the ANOVA for Sa.

Table 7: Analysis of Variance for S/N ratio

Source	DF	Seq SS	Adj MS	F	P	Significance
Δz	1	31.8892	31.8892	13485.45	**0.005**	Yes
f	1	0.4195	0.4195	177.38	**0.048**	Yes
R	1	0.0056	0.0056	2.39	0.366	No
T	1	0.0787	0.0787	33.26	0.109	No
θ	1	4.5651	4.5651	1930.51	**0.014**	Yes
L	1	0.1802	0.1802	76.18	0.073	No
Residual Error	1	0.0024	0.0024			
Total	7	37.1406				

The statistical analysis with 95% confidence level is carried out by using Minitab 17.0.1 version. The significance of input variable on Sa is confirmed by p value. If $p \leq 0.05$, it indicates the significance of the individual parameter which affect the Sa. Considering the cases with P value,

Table 6 indicates that the significant input variables for the ISMF of AA3003-O is Δ (P=0.005), (P=0.048) and (P=0.014). The % contribution of significant input variables is presented in table 8.

Table 8: Contribution (%) of significant input variables

Input Variable	P	Significance	Contribution (%)
Δz	0.005	Yes	**85.86**
f	0.048	Yes	**1.12**
θ	0.014	Yes	**12.29**

Response surface of surface roughness (Sa) versus significant parameters (e.g. step depth, feed rate and wall angle is presented in figure 5 (a-c).

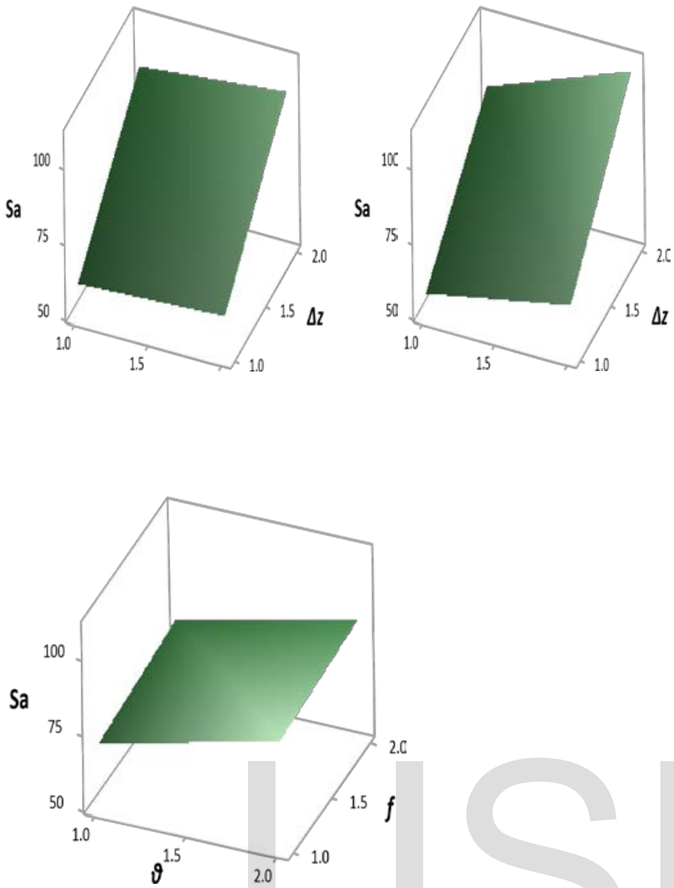


Fig 5: Response surface of surface roughness (Sa) values

5. CONCLUSION

The experimental analysis is carried out to investigate the significance of input variables on surface quality of formed part which was made by Al3003-O material through SPIF. Total six input variable are considered for the investigation whereas surface roughness Sa as the output parameter. Taguchi L_8 orthogonal array is taken as design of experiment. ANOVA is done to identify the significance of factors for the surface roughness Sa. Based on the results and discussions, the following conclusions are made:

- The statistical analysis conform that step depth, feed rate and wall angle is significantly affects Sa.
- The statistical analysis conform that step depth contributes 85.86%, feed rate 1.12% and wall angle 12.29% on Sa.
- The Sa is improved by keeping lower step down size as 0.1mm, low feed rate as 20 mm/min and low wall angle as 15^0 respectively.

This paper reveals the significance of responses of individual input variables on the Sa. The interaction of process parameters are not calculated in the present study. Successively, The statistical analysis for interaction will be calculated. Definitely, interaction plots explore the significance of parameters on Sa.

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