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Single Point Incremental Forming (SPIF) of Aluminum Alloy AA 1050: Experimental evaluation of the effect of process parameters on surface roughness

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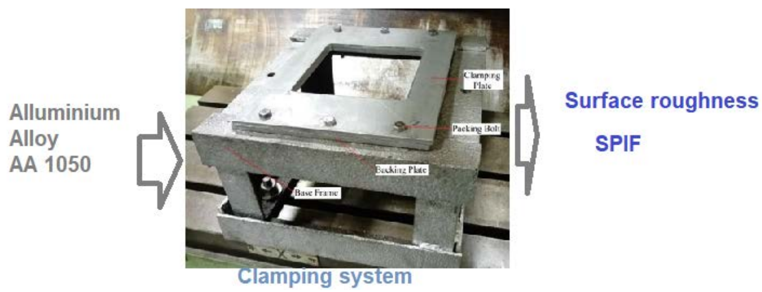
ABSTRACT

The work on single point incremental forming of Aluminium alloy (AA1050) performed experimentally have been included in this report. The impact of process variables including tool shape, tool size, step size, and feed was examined on the surface roughness Aluminium alloy AA1050. The experimental analysis was conducted utilizing the Response Surface Methodology (RSM) and the relevance of process parameters was determined using analysis of variance (ANOVA). The tool's form was found to have the biggest impact on surface roughness. The surface roughness is also greatly influenced by the tool size and step size. Higher feed rates can be used without degrading surface quality since feed has the least impact on surface roughness.



Keywords: Single point Incremental Forming, AA 1050, Surface Roughness, metal surface, metal compression,

INTRODUCTION

Single point incremental forming (SPIF) is a novel metal forming process that has many advantages over conventional forming such as flexibility, lower tooling cost and short tooling development time. It is suited for low volume production runs. Incremental sheet forming (ISF) is also known as die less incremental forming since it does not require dedicated dies to form the part. This die-less nature provides competitive advantage for low production runs. Surface finish of the formed components, among other factors, is a key factor in determining whether ISF is suitable as a manufacturing method. ISF is a desirable option for creating components for low volume production because of the direct generation of physical parts from the CAD model using NC part programme with little demand of part specific tooling.[1]

Several studies on surface roughness in SPIF have been conducted.[2-4] However, ISF has not yet been accepted fully in industries. More research work is being carried out in industrial and educational sectors in order to deploy the process for industrial applications. Using Aluminium 3003-O as the work material, the effect of flat end and hemispherical tool shapes on the profile accuracy of a U-shaped channel was examined by Ziran et al. (2009).[2] They found that hemispherical tools lack the profile precision that flat end tools have. The orange peel effect, which increases forming time and surface roughness on Al 3003-H14, was studied by Hamilton and Jesweit (2010).[3] They concluded that the peel effect increases as step size increases. They also observed that spindle speed has no significant impact on the peel effect. Ambrogio et al. (2011) studied the suitability of ISF at very high feed rates to reduce processing time.[4] They looked into the hypothesis that poorer surface quality is caused by bigger tool step sizes using the work materials AA 1050-O, AA6082-T6, and AA5754. Additionally, they came to the conclusion that a smaller tool punch produces better geometric accuracy. In their 2013 study, Cawley et al. investigated the effects of parabolic and angled tool shapes on the formability and surface polish of 1.59mm thick Al 3003-O sheet.[5] They noticed that surface polish grows as the parabolic coefficient grows. They saw some pitting, which was more prevalent when the beginning contact area was smaller. In SPIF, the effect of process parameters on accuracy and surface roughness was investigated by Radu and Cristea in 2013.[6] They came to the conclusion that a large tool diameter has a favourable

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impact on surface polish and a detrimental impact on accuracy. They also observed that high feed rate results in smoother surface finish. Echrif and Hrairi (2014) investigated the influence of process parameters on surface finish of the formed component.[7] They discovered that a small step size and big forming tool size generate a very fine, soft surface, but a high step depth produces a highly rough surface and causes waviness. Kumar et al. (2015) studied the effect of ellipsoidal and hemispherical tool shapes on surface finish.[8] The researchers came to the conclusion that ellipsoidal tool shapes produce superior surface finishes than hemispherical tool shapes. Ibrahim (2016) used finite element analysis to compare different tool profiles.[9] It was discovered that modifying the forming tool's shape for a certain sheet thickness can help prevent the formation of wall and corner folds around the forming tool. Depending on the figure and area of contact, changes to the tool profile have an impact on SPIF's formability.

From the literature review, it can be concluded that many researchers have investigated the effect of tool size, step size and feed in SPIF. However, very few research works have been reported on the influence of tool shape in SPIF till date. In the present paper, the influence of step size, tool size, tool shape and feed on the surface roughness of formed component in SPIF has been investigated. Box Behnken technique - Response surface methodology has been used to design the experiments. Finally, ANOVA has been done to analyze the results.

Experimental Work

The CNC milling machine used in the present work was M/S Batliboi-Dart. A clamping system was created to retain the sheet. The clamping plate, base frame, backing plate, nuts, and bolts are the primary components of the clamping system. The clamping system is depicted in Figure 1.

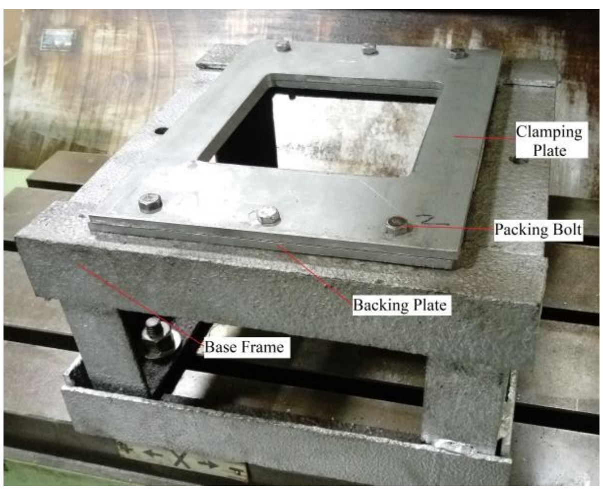

Figure 1 Clamping System

The base frame was manufactured using mild steel. Clamping and backing plates were made using Aluminium. High Speed Steel (HSS-M2) material was chosen as a tool. Table 1 lists the physicochemical characteristics of HSS-M2.

Table 1. Physical Properties of HSS-M2

Density	8138 kg/m3
Machinability	65 % of 1% Carbon steel
Melting Point	4680 ºC
Thermal Conductivity	41.5 W/m/K
Modulus of Elasticity	190-210 GPa
Specific Gravity	8.15

Experimental Design

Three tool shapes - ellipsoidal, hemispherical, and flat-end were taken into consideration in the current work. Three levels of each factor viz. tool size, step size and feed were taken. Box Behnken technique-RSM was used to design the experiments. Total 51 experiments were conducted as calculated by RSM. The process parameters and their levels are given in table 2.

Table 2. Levels of Process Parameters

Parameter	Levels		
Tool Shape	Hemispherical	Ellipsoidal	Flat-End
Tool Size (mm)	6	9	12
Step Size (mm)	0.2	0.4	0.6
Feed (mm/min)	1000	2000	3000

Measurement of Surface Roughness

Surface roughness is an important aspect of the surface quality. Improving the surface finish can aid in making ISF industrially acceptable.

In the present work, surface roughness of the formed components was measured using Mitutoyo SJ-310 ISO 1997 surface quality tester. Before measuring, the produced sections were trimmed to the surface area on which surface roughness was to be determined. After cutting, acetone was used to clean the chopped pieces and remove any remaining oil if any had been present. Roughness measurements were performed for a component in three different places, and their average value was taken into account. A cut sample is shown in Figure 2.

Figure 2 Sample for Surface Roughness Measurement

ANOVA FOR SURFACE ROUGHNESS

The surface roughness ANOVA is displayed in Table 3.

Table 3 ANOVA for surface roughness

Source	Sumof Square	df	Mean Square	F-Value	p-Value	Remarks
B -Feed	0.0249	1	0.0249	20	< 0.0001	Significant
C-Tool Size	0.569	1	0.569	454.56	< 0.0001	Significant
D-Tool Shape	3.490	2	1.750	1392.940	< 0.0001	Significant
CD	8.760E-3	2	4.38E-03	3.490	0.04	
A^2	7.690E-3	1	7.69E-03	6.130	0.0176	
B^2	9.180E-3	1	9.18E-03	7.320	0.01	
C^2	0.0299	1	0.0299	23.669	< 0.0001	
Residual	0.05	40	1.25E-03			
Lack of Fit	0.033	28	1.19E-03	0.8399	0.661	Not Significant
Pure Error	0.017	12	1.41E-03			
Corrected Total	4.560	50				

The analysis is performed with a 95% level of confidence.
Adjusted R2 = 0.9862 Predicted R2 = 0.9822

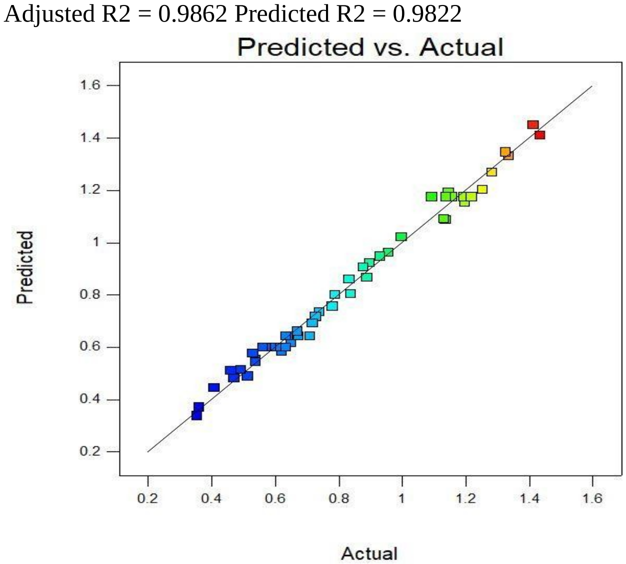

Figure 3 Predicted vs. Actual Values for Surface roughness.

It can be observed from the ANOVA that all the parameters are significant. The F values indicate that tool shape is the most significant factor followed by tool size, step size and feed. The value of predicted R2 is in good agreement with the R2 adjusted.

The expected vs. real surface roughness map is shown in Figure 3. They almost move in a straight line. This suggests that the mistake rate is small.

RESULTS AND DISCUSSION

Figure 4 shows the perturbation plots for the three tool shapes

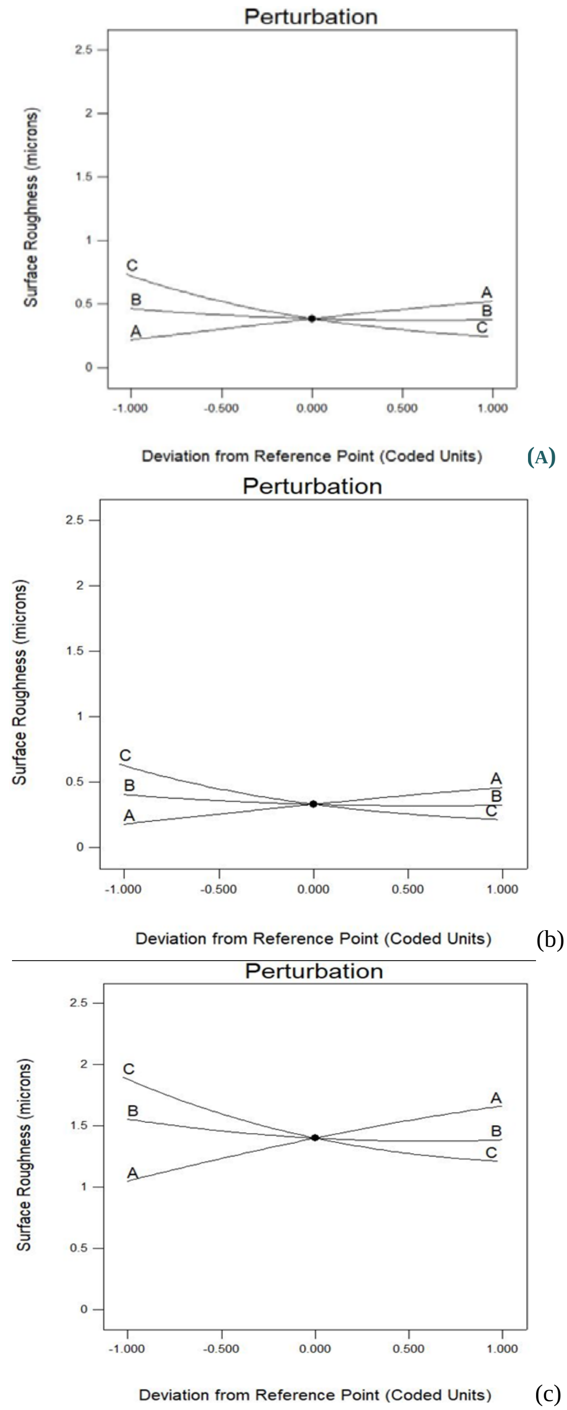

Figure 4. Perturbation Plots (a) Hemispherical Tool (b) Ellipsoidal Tool (c) Flat-End Tool

The above charts show that every tool form exhibits the same pattern. The Ellipsoidal tool provides the best surface polish, whereas the Flat-end tool provides the poorest.[10] The intermediary is the hemispherical tool. The ellipsoidal tool's wall stays in contact with the component's deformed wall for a little bit longer than the hemispherical tool does.[11] This causes a rubbing action on the surface of the deformed wall, which lessens the waviness and decreases surface roughness. Additionally, the ellipsoidal tool's surface roughness is reduced since its scallop height is smaller than that of a hemispherical tool. Due to the largest tool-tip contact area with these types of tools, flat-end tools provide the worst surface finishes.[12,13]

Figures 5 and 6 depict how the process parameters affect surface quality for ellipsoidal tool shapes. The plots for the additional two forms exhibit a similar pattern.

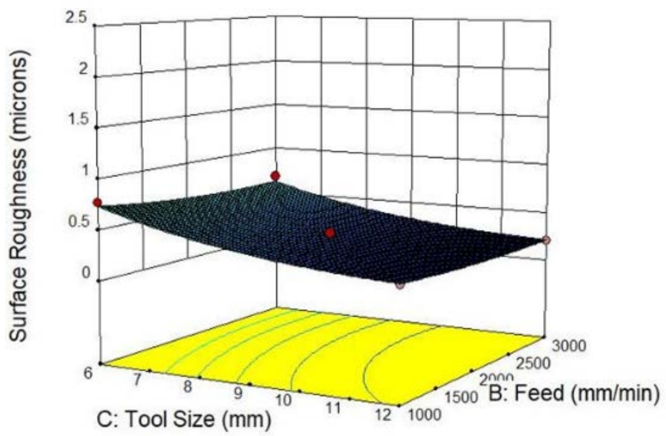

Figure 5. Effect of Step Size and Feed on Surface

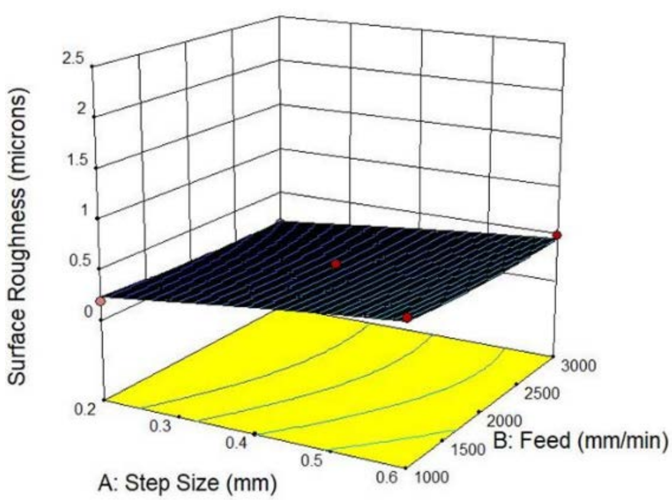

Figure 6. Effect of Tool Size and Feed on Surface Roughness

It is evident that as tool size increases, surface roughness reduces. The result of feed is the same. However, compared to the impact of tool size, the influence of feed on surface roughness is much less pronounced. The fact that a small-sized tool produces more localized stress can be used to explain why surface roughness decreases as tool size increases. As a result, the plastic deformation and subsequent material displacement are increased. This causes an undesirable surface finish. When bigger sized tool is used, the surface formed in the first contour is rubbed by the tool in the consecutive contour, and hence a better surface finish is obtained.[14,15]

The effect of the step size is the reverse. In other words, surface roughness rises as step size increases. This is so that fewer forming cycles are required when the step size is increased. When using big step sizes, the tool is not in touch with the sheet for a relatively long region between two succeeding contours, preventing deformation. This makes the surface rougher, resulting in a component with worse surface quality.[16–20]

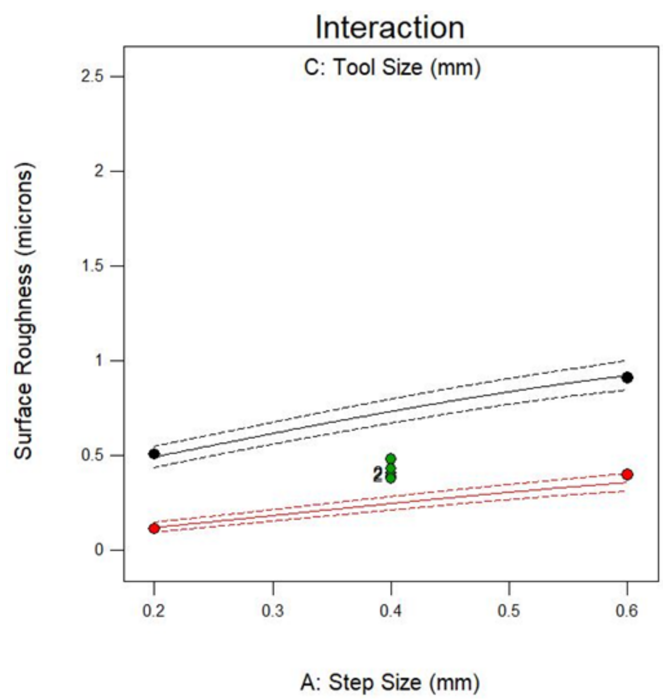

Figure 7 Impact of Tool Size and Step Size on Surface Roughness

Feed is maintained constant at 2000 mm/min to account for the interaction between step size and tool size (Fig. 7). Tool sizes of 6mm and 9mm are represented by the red and black lines, respectively. The lines aren't quite parallel to one another. This shows that step size has an impact on surface roughness when tool size is altered.[21]

Conclusion

The effect of process variables, including tool shape, step size, feed and tool size on surface quality was examined in the current work. We looked at three tool shapes: hemispherical, elliptical, and flat end. The study leads to the following conclusions:

The ANOVA shows that tool form is the most important variable. Tool size has the most impact on surface roughness among the numerical variables. Surface roughness is also influenced by step size, however the impact is less noticeable than it is with tool size. Surface roughness is least affected by feed.

The surface roughness gets progressively less as the tool size grows. The same factors that affect feed also affect surface roughness, although the impact is essentially nonexistent. As step size grows, surface roughness also grows. Therefore, using a smaller step size is required to achieve a greater surface polish. The ellipsoidal tool has the least surface roughness of the three tool forms. Using flat end tools yields the most surface roughness. Therefore, choosing the right tool form is essential to achieving great surface quality. The size of the tool and the size of the steps should be considered as well because they have a big impact on the surface quality.

It is necessary to design a flexible sheet metal forming process since customer requirements are becoming more variable. Due to its property of part independent tooling, incremental sheet metal forming might be beneficial to the sheet metal industry. The surface quality can be increased by looking at additional tool shapes. Additionally, the study may be expanded to include additional materials such as polymers, magnesium, and copper. It may also be investigated to combine incremental sheet metal forming with traditional forming techniques in order to shorten the forming process and increase geometric precision.

Nomenclature

Symbol	Meaning	Unit
A	Step Size	mm
B	Feed	mm/min
C	Tool Size	mm
D	Tool Shape	-

Conflict of Interest

Authors declare no conflict of interest is there for publication of this work.

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