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EFFECT OF PROCESS PARAMETERS AND WALL ANGLE ON QUALITY AND ACCURACY OF FEATURES MANUFACTURED BY SINGLE POINT INCREMENTAL FORMING

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Abstract - Incremental Forming is one of the most widely employed metal forming technique for manufacturing of complex shaped sheet metal parts in a small scale and customized fashion. The technique has advantages in terms of cost effectiveness, improved material formability due to application of localized plastic deformation, low forming forces etc. However, quality and dimensional accuracy, which are key factors in analyzing the effectiveness of any manufacturing process, are reported to be on the lower side for products manufactured by this method. In present study, an attempt has been made to understand the effect of process parameters on surface roughness (R_a) and angular accuracy (E_a) of the components manufactured by Single Point Incremental Forming (SPIF) technique on Aluminium 5052 alloy sheets having a thickness of 0.5 mm. The experiments have been designed using Taguchi's L9 standard orthogonal array by considering three parameters viz. incremental depth, tool rotational speed and tool feed rate. All experiments have been carried out at three different wall angle conditions, viz. 50°, 55° and 60°. It has been understood from the analysis of the results that incremental depth has the most significant effect on surface roughness. However, in the case of angular accuracy, it has been observed that, irrespective of the wall angle, feed rate of the tool also contributes along with incremental depth. It has also been inferred that wall angle of the target feature also influences the extent of surface quality and angular accuracy of the formed component to some extent.

Keywords: Incremental Forming, Feature distortion, Surface roughness, Angular error.

I. Introduction

Single Point Incremental Forming (SPIF) is a type of metal forming process in which 3D components can be formed without the use of dedicated dies. The metal in the case of SPIF is plastically deformed progressively in a layer by layer fashion using a CNC controlled system using a simple shaped tool. The process, therefore advocates high level of flexibility due to the relatively simple system that it requires to fabricate complex shaped features and also facilitates enhanced formability [1].

Despite the advantages, one of the major factors that limits the usage of the process is the geometrical inaccuracies that occur in the products fabricated by this method. Many research works have been reported on study on effect of process parameters on surface quality and profile error in features generated by SPIF [2 - 4]. However, studies pertaining to the angular inaccuracies the SPIF products have been found to be very few. Further, as the wall angle need not be same for all products, it is important to study how the effect of process parameters on the inaccuracies under different values of wall angles as well. In this work, an attempt has been made to study the effect of process parameters on surface roughness and angular error of features fabricated with different wall angles using SPIF.

II. Experimental Plan And Procedure

The experimentations have been carried out on AA5052 Aluminium – Magnesium alloy sheets having thickness of 0.5 mm. Hemispherical ended EN8 material tools with 8mm diameter have been used to form the sheet. The target feature has been set as a conical frustum with 30 mm top diameter and 10 mm depth. Contour tool path strategy as discussed in [5] has been employed for carrying out experimentations.

Three process based parameters viz. depth increment, rotational speed of the tool and feed rate of the tool have been selected for experimentations. All the parameters have been considered at three different levels. Table 1 shows the parameter levels that have been employed for experimentation.

Table 1

Parameters and Levels employed

Parameter	Unit	Levels
Depth increment	mm	0.2, 0.3, 0.4
Rotational speed	rpm	600, 900, 1200
Feed rate	mm/min	20, 400, 600

The experiments have been designed using Taguchi's L9 orthogonal array, which consists of 9 experiments. All 9 experiments are carried out under three different conditions of wall angles, viz. 50°, 55° and 60°. The experimentations were performed on a CNC milling machine. All experiments have been performed twice. Selected photographs of the formed components are shown in Fig. 1.

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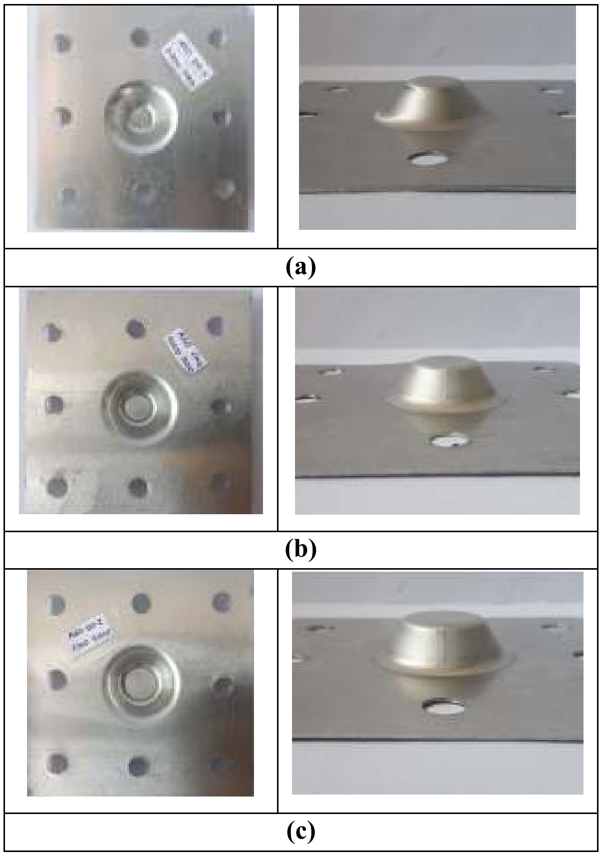


Fig. 1. Photographs of specimens formed with a wall angle of (a) 50°, (b) 55°, (c) 60°

After completion of the experimentation, the formed part is thoroughly cleaned and measurements are taken for surface roughness (R_a) and angular error (E_a). Surface roughness has been measured using Mitutoyo's SJ400 probe based surface roughness tester. The measurements have been taken at 6 different locations and the observations are averaged to obtain the final reading. In the case of measurement of angular error, the difference in achieved wall angle and target wall angle has been calculated. The achieved wall angle has been measured using a Coordinate Measurement Machine. Main effects for each parameter has been calculated and plotted graphically for analysis.

III. Results And Discussion

III. I. Effect of process parameters on Surface Roughness

Fig. 2(a – c) shows the main effect plots for surface roughness under different conditions of process parameters and wall angle. It can be clearly seen that roughness is most influenced by the depth increment and the response is found to be increasing with increase in the level of parameter. As the process is done by contour tool path strategy, if the gap between the layers that have been considered for tool movement is high, the surface formed will have pronounced unevenness. Similar trends can be seen for all wall angles considered. However, it is worth noting that the roughness value is lower for intermediate wall angle condition and the intensity of roughness is relatively high conditions of high wall angle.

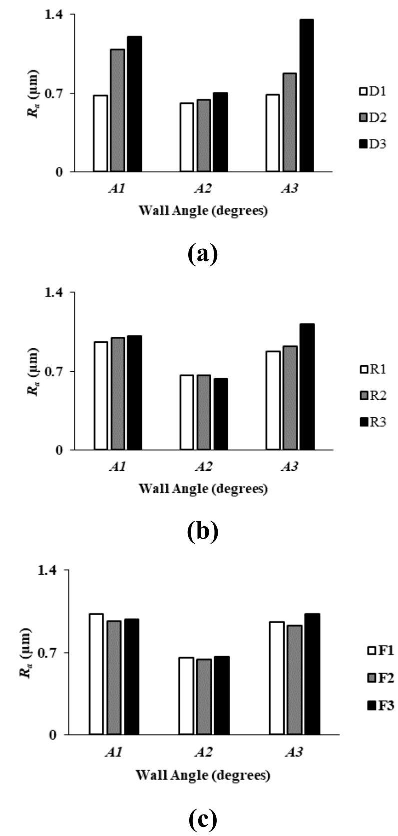
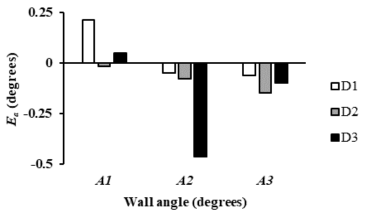


Fig. 2. Main Effect Plots for Surface Roughness (R_a) with variation of (a) Depth increment, (b) Tool Rotational speed, (c) Tool Feed rate

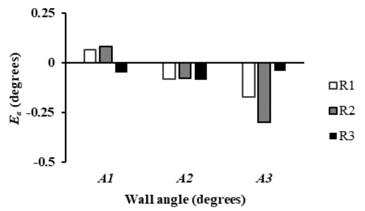
It can also be inferred from Fig. 2(b & c) that tool rotational speed and feed rate have negligible effect on quality of the formed component. However, as found in the case of variation of depth increment, it can be understood that irrespective of the value of rotational speed or feed rate, the surface roughness tend to reduce with initially with increase in wall angle and again start to increase. From these observations, it can be understood that selection of optimum parameter combination for SPIF also depends on the wall angle of the target feature.

III. II. Effect of process parameters on Angular Error

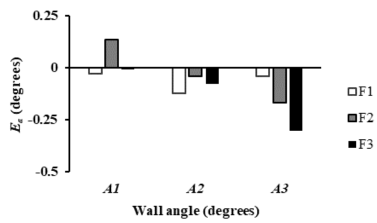
From Fig. 3(a – c), which shows the main effect plots for angular error measured under different conditions of process parameter levels and wall angles. A positive value for Ea suggests that the product is over-formed and a negative value indicates the case of generation of an under-formed product.



(a)



(b)



(c)

Fig. 3. Main Effect Plots for Angular Error (E_a) with variation of (a) Depth increment, (b) Tool Rotational speed, (c) Tool Feed rate

It can be seen from the graphs that variation of all three parameters does not show any specific trend for obtained values of angular error. However, it is worth noting that depth increment and feed rate have a relatively high influence on the response. At the same time, it is worth noting that, rather than the process parameters, the wall angle plays a crucial role in the extent of angular error that it may be involved in the formed product. It can be understood from the plots that when the wall angle is small, the sheet has been over-formed for majority of the process parameter conditions considered for experimentation. At the same time, with increase in wall angle, the angular error has been found to be on the negative side for all parameter conditions. This implies that products where under-formed under such conditions.

Hence, it can be inferred from these observations that the deformation induced by the tool on to the sheet has been effectively transferred in the case of forming of features with low wall angle. However, at high wall angle conditions, the sheets have not been deformed to the required extent, showing the occurrence of springback. Therefore, application of any strategy for compensating the angular error critically depends on the wall angle of the target feature.

IV. Conclusions

Experimental investigations have been carried out to analyze the effect of process parameters in SPIF and wall angle of the target feature on surface roughness and angular error in products formed on AA 5052 alloy sheets. It has been understood that depth increment is the most influential parameter in the case of surface roughness of formed products. For angular error, even though not showing any specific trend, depth increment and feed rate have been found to be influential. However, it has been understood that wall angle also plays an important role in the level of surface quality and angular error in the formed component. It has been observed that a higher wall angle results in higher surface roughness as well as angular error. Hence, it is important to identify the optimum parameter combination for minimizing surface roughness or for employing tool compensation strategies by considering the wall angle of the target feature as well.

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