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RESEARCH ARTICLE

EFFECT OF PROCESS PARAMETERS ON THE GEOMETRIC ACCURACY OF THE AA1050 ALLOY DURING THE ICREMENTAL FORMING PROCESS

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ABSTRACT

The purpose of this study is to investigate the effects of process parameters (tool diameters, wall angle and step size) on geometric accuracy during forming pyramid shape using computer numerical control (CNC) milling machine. Taguchi orthogonal array (L9) was used to design the experimental work and the results were analyzed using ANOVA package in Minitab 2017. The results shows that geometric accuracy increase as tool diameter and step size are decrease while it increase with wall angle increase. Two type of error was found sheet bending error (eb) and spring back error (es). Tool diameter have the highest effect on geometric accuracy followed by wall angle and step size.

KEYWORDS

Incremental sheet forming (ISF), Geometric accuracy, ANOVA, Taguchi, process parameters.

1. INTRODUCTION

Incremental Sheets Forming (ISF) Technique is an emerging forming process ideal for quick prototypes and production of a small batch. In the ISF process, sheets metal are gradually formed in a three-dimensional shape designed using the general configuration tool in the computer numerical control (CNC). In this process, small parts of the products are formed and the area of local deformation travels through the whole product until the final form is obtained. During the use of that process, parts to be formed are formed directly from the CAD data without the need for special tools. Therefore, incremental forming process is a promising process on a large scale to produce small and custom-made payments, unlike traditional processes like deep -drawing and stamping. The forming tool generally follow the pre -designed tool path to incrementally deforms the material through a series of contours till the desired final shape is obtained. The incremental sheets forming techniques (ISF) can be divided to two groups: the single points incremental forming (SPIF) and two point incremental forming (TPIF), as well known as positive and negative forming, respectively. Single points incremental forming (SPIF) is a good solution for the quick and cheap prototyping and small batch production [1]. The reason why this process is flexible, no die is used in comparison to other forming process. Therefore, the cost of tools as well as dies can be avoided in addition reducing forming time. The process begins with the clamped of a flat plate on the CNC machine table. This process is used to form symmetrical and asymmetrical parts with different thickness ranging from 100 micrometers to several millimeters. The second type of process is called TPIF because the sheet blank is formed under the influence of two points of contact whether the other point is a positive or negative die [2]. During incremental forming process, it can be noticed some deviations related to the parts produced geometry. The first sources of deviation is over formability at small walls angle and low formability on large walls angle because when walls angle is lower in range (30° to 60°) there is an increase in formability. At high forming angle between (60° to 80°), low formability is produced due to high spring back [3]. It has been shown that the geometric accuracy of the final outcome of the path generated, the tool path plays an important roles. Thus, the tool path can be used to enhance the accuracy of the parts in the SPIF. However, to improve whole part accuracy, it must take into account behaviors of each individual parameter and any possible interaction between parameters [4]. The simplest system for measuring the geometric error caused by incremental forming is based on the use of laboratory devices Among them, the most utilised are:

- Laser scanners based on a laser beam triangulation that enables point clouds to be obtained. A suitable code can be used to manage this cloud to restore the true surface. The system is very quick, needs no contact with the ground, but it is costly and needs surface therapy to guarantee an appropriate opacity: only in this case can the laser beam be used. [5];
- probe systems based on the use of machines capable of measuring the space point coordinates. The accuracy is not very big, but it's not costly;

CMM systems: they are probably the most advanced state of the art in the measurement field [5]. These machines guarantee high accuracy but, on the other side, they are costly, involve the correct placement of the portion in the cube and, lastly, sometimes the plotting method is not very quick. Geometrical error is the difference between the obtained profile and the designed profile. There are three type of geometrical error may be found in the final product, sheet bending (e_b) in the area nearing to the clamping edge, sheet lifting including springback (e_s) and pillow effect (e_p) at the part base the final depth becomes smaller than the actual one [6]. Figure 1 shows the different geometrical error. There is another classification of geometrical errors found after finishing process [7]:-

Clamped accuracy: is defined relative to the geometry of the part when still clamped within the blank holder of the frame.

Unclamped accuracy: is defined relative to the part when it has been released from the blank holder.

Final accuracy: is defined relative to the part when it has been cutout from the unwanted material of blank or when cut to measure the thickness of sheet.

So, the springback is the main source of process inaccuracy and consists of local springback (during process) and global springback (after removal of clamping)

2. LITERATURE SURVEY

Geometrical accuracy in incremental forming process products remains once of the greatest challenge for academic investigator and users. Julian

Allwood, et al. [7] concluded that the geometrical accuracy specification in industrial use for sheet metal components are usually about ± 0.2 *mm* along the total part surface, while the geometrical error for incremental forming process is about ± 3 *mm.* Julian Allwood, et al. [8] summed the geometrical accuracy in the incremental process in three parts, (1) measured accuracy when the part is still clamped, (2) measured accuracy when the part is unclamped, and (3) measured accuracy when cut off unwanted part from the blank. Improving the geometry accuracy of the part when it is still clamped is the primary objective of this research. F.Micari, et al. [8] divided the part accuracy in three types in ISF into as shown in Figure 2: (1) near the main base where plastic deformation begins (sheet bending), (2) after forming tool is lifted (sheet spring back), and (3) at the basis of the product part base (pillow effect). He also discussed the effect of process parameters on geometrical accuracy, as well as presented some strategies to improve engineering accuracy and discussion. G. Ambrogio, et al. [9] studies the effect of some relevant process variables (tool diameter and tool pitch) on geometrical accuracy through FEM model. Geometrical error has been measured numerically and experimentally and compared with the actual one. AA1050-O with dimension (240mm × 240 mm×1mm) was used. Tool with hemispherical head has been considered to produce pyramid shape. Laser- scanning technique was used to examine the deformed geometry of the experimental part. The results obtained from this study are an excellent overlapping between the results of FEM, laser-scanning and the actual one with better results as 3.53mm when used D_{tool}=12mm and tool pitch=1mm and worst one as 6.70 mm when used D_{tool}=18mm and tool pitch=2.5mm. Ambrogio et al. [10] investigated the influence of process variables (diameter of the tools, step size down, forming wall angle, sheets thickness and the final depth) on geometrical accuracy during forming truncated cone through statistical analysis.

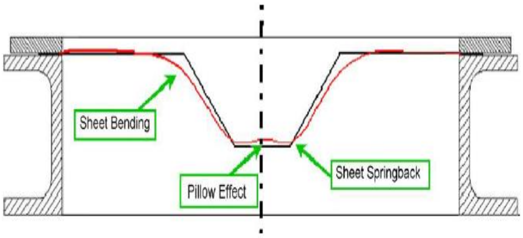

Figure 1: Different geometrical error. [6]

It was concluded that sheet thickness and final depth had a significant effect on geometrical error measured at corners, while the tool diameter has a big influence on the geometric error resulting from the pillow effect. Khamis Essa & Peter Hartley [11] studied the effects of add a backplate, kinematic tool and modified the toolpath on the geometrical accuracy using FE model. It was clear that the use of back plate can be minimized the sheet bending error in the tool contact area and use of kinematic tool can reduced the springback error and extend tool path can be eliminate the pillow effect at sheet base. Carlos Guzmán et al. [12] investigate the geometrical deviation in the slop transition area by simulating pyramid shape at two different depths and slopes using finite element method. Noted that the springback has a small effect on the geometrical accuracy of the angle transition area because the plastic deformation is small in that zone. In order to obtain the required geometry, it was recommended that the tool path can be designed to look at these elastic strain. Layth F. Shakir, et al. [13] measured the influence of forming angle on the dimensional accuracy (depth error) of the formed part. Helical (spiral) toolpath (HTP) was used to form a pyramid shape with three different wall angles while keep the other process parameters constant. It was observed that lower angles give higher precision, Helical tool path (HTP) could be described as the "optimal" tool path to achieve higher geometrical accuracy, the vertical pitch has a major effect on product accuracy and thickness and using the backing plate will reduce bending and springback at upper base. Jagtap and Kumar [14] studied the influence of the four essential process parameters (preform tool radius, preforming, wall angle and tool radius compensation) on formed parts accuracy in incremental forming process along with stretch forming. Designed the experiment using Taguchi analysis and kept the tool size constant in all experiment it was concluded that geometrical error is highly effected by tool offset followed by wall angle and the lastly preforming with contribution percentage as (44%,36% and 14%) for tool offset, wall angle and preforming respectively. Geometric accuracy is not affected by preform tool radius.

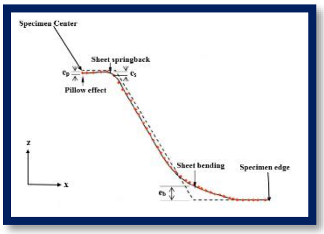

Figure 2: Type of geometrical errors. [3]

2.1 Research Objective

This article aims to get the best understanding of the effect of some process parameters like (wall angle, tool diameters and pitch step down) with a different sheet thickness on geometrical accuracy of product through a single point incremental forming (SPIF), which has the main influence on inaccuracy of parts and defects of products. Accuracy of forming parts is studied to suggest how to reduce geometrical error.

3. EXPERIMENTAL SET UP

The experimental work is done on the "KM-80D" three-axis CNC machines with maximum space 500×8000×500 mm³. The maximum feed rate is 10000mm/min. The forming tools with a diameter of 8, 10, 12 mm are used. The step depth size of 0.2, 0.4 and 0.6 mm are used, and wall angle are 45º, 50º and 55º.Before starting the forming experiment, the blank is lubricated with the machinery oil for better surface finish. The incremental forming process set up is shown in Figurer 2. The sheet metal blank 300 × 300 mm is tightly clamped with screws at four sides to prevent movement during forming process. The tool with hemispherical end is used during the process. All the tools are made from surface hardened tool steel (hardness 59 HRC). The present work is carried out on pyramid with dimensions (90×90) mm² and constant depth 40 mm. The tool travels along the contour on the sheet surface as shown in Figure 3. After completion of each contour, the tool moves down to a depth equal to the step depth and follow the next contour.

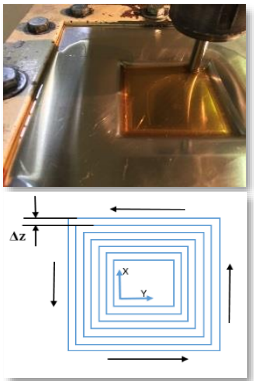

Figure 3 : Incremental sheet forming with tool path

4. MATERIAL PROPERTIES

AA1050 aluminum alloy sheet with thicknesses 1mm and 1.5 mm are used, which is commonly used in the electrical and chemical industries, because it has corrosion resistance, high electrical conductivity and workability. The chemical composition of the work piece is shown in Table 1.

Table 1. Chemical Composition

Material	Value
Al%	99.58
Mg%	0.0003
Si%	0.0440
Cu%	0.0234
Fe%	0.280
Mn%	0.0033
Ti%	0.0300
V%	0.0109
Zn%	0.0099

5. DESIGN OF EXPERIMENTS

A systematic approach is necessary to plan and condition experiments so that useful results can be obtained. In this case, the experiments are planned using the Taguchi method so that the minimum test trials are performed. Appropriate data collection can lead to more effective conclusions. Experimental design helps to reduce the total number of experiments to be conducted and obtain a regular distribution of data across the range of controllable factors to investigate. Also, the creation of relationship between different inputs variables become easier. The experiments are designed using three process parameters (tool diameter, wall angle and step size) with three different level for two different sheet metal thickness.

5.1 Geometry Measurement

For geometry measurement, Coordinate Measuring Machine (CMM) Renishaw/Cyclone series 2 was used. Geometrical error is the differences between the obtained profile by CMM and the designed profile. There are three type of geometrical error may be found in the final product, sheet bending (e_b) in the area nearing to the clamping edge, sheet lifting including springback (e_s) and pillow effect (e_p) at the part base the final depth becomes smaller than the actual one. [12].

6. RESULTS AND DISCUSSION

The geometric error can be described as the difference between the CAD model and the actual one. To illustrate the influence of process parameter used on final part accuracy, a comparison will be made between measured one and ideal one. The geometric errors which was measured experimentally are clarified in table 2.

Table 2: The results of experimental for geometrical error

Exp. number	Tool Diameters (mm)	Wall Angle (º)	Step Size (mm)	e_b(mm)	e_s(mm)
1	8	45	0.2	4.0	0.5000
2	8	50	0.4	4.1	0.4100
3	8	55	0.6	4.3	0.3820
4	10	45	0.4	4.6	0.6300
5	10	50	0.6	4.3	0.4558
6	10	55	0.2	4.1	0.3667
7	12	45	0.6	4.9	0.7594
8	12	50	0.2	4.7	0.6200
9	12	55	0.4	4.3	0.4630

From figures (4 and 5) it can be seen that geometrical error decreased as tool diameter decreased. The minimum value is obtained when 8mm tool diameter was used and it equal to (4.133 mm) and the higher value equal to (4.633 mm) when 12mm tool diameter was used. The reason is that the stresses are concentrated in a limited area of the sheet metal, which means that when using a small tool diameter, the deformation will focus on a small area, thus improving geometrical accuracy. In fact, in a given area, the sheet metal is deformed depending on the step size the tool does not distort the entire area, but it moves to a small sheet area, so the deformation becomes somewhat like the ladder. The greater the size of the step, the greater the stretch of the metal and the greater the thinning. For this reason, the geometrical error increase as step size increase as shown in figures (4 and 5) and table 3. When the size of step increase from 0.2mm to 0.6 mm, the geometrical error increased from (4.267mm) to (4.5mm) and from (0.4956mm) to (0.5324mm) for e_b and e_s respectively. These results for the influence at tool diameter and step size on geometric accuracy are in agreement with that obtained by Ambrogio et al. [10]. The wall angle has a great effect on the dimensional accuracy. From figure (4), it can be seen that the geometrical error decrease as the wall angle increase. Sheet bending error (e_b) decrease from (4.5mm) to (4.233mm) and springback error (e_s) decrease from (0.6298mm) to (0.4039mm) when wall angle change from 45° to 55°. Because increasing in wall angle lead to increase in amount of plastic deformation and this cause to decrease in geometrical error. These results are in agreement with that found by Jagtap and Kumar [15].

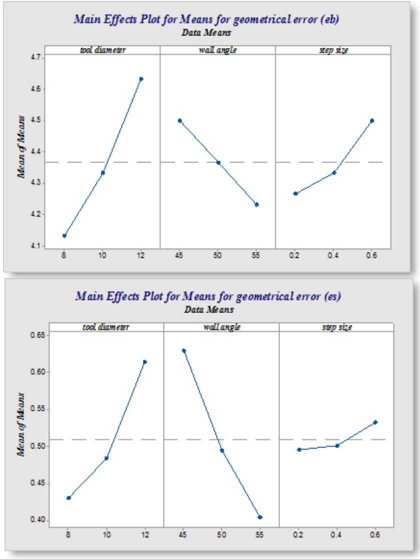

Figure 4: Mean effect plot for mean for geometrical error.

Table 3: The mean response for geometrical error.

Taguchi Analysis	e_b(mm)			e_s(mm)		
	Mean response			Mean response		
	Tool diameter	Wall angle	Size of Step	Tool diameter	Angle of Wall	Size of Step
Level 1	4.133	4.500	4.267	0.4307	0.6298	0.4956
Level 2	4.333	4.367	4.333	0.4842	0.4953	0.5010
Level 3	4.633	4.233	4.500	0.6141	0.4039	0.5324
Delta	0.500	0.267	0.233	0.1835	0.2259	0.0368
Rank	1	2	3	2	1	3

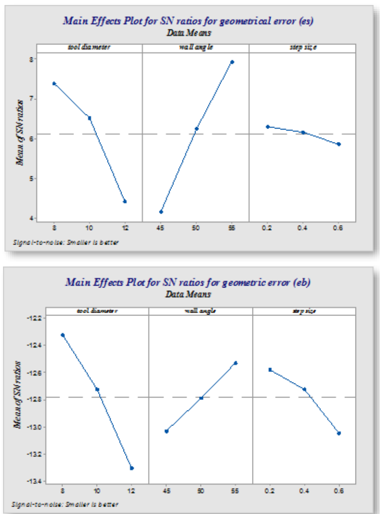

Figure 5: Mean effect plot for S/N for geometrical error.

The contribution value for each factors is illustrated in table 4. the tool diameter have the high contribution value as 51.35% followed by wall angle 14.41% and step size 11.71% for sheet bending error, while for springback error, wall angle have the higher contribution value as 55% followed by tool diameter as 37.92% while step size have very low effect (less than 10%). Although the backing plate is used to support the plate in all the experiments. Some deviations were noticed in the final products. In order to minimize this deviation we should reduce as much as possible the distance between the working area and the sheet edge. In this work the distance between the working area and the edge is 10 mm on each side.

Figures (6 to 8) show the comparison between measured profile and ideal profile.

Table 4: ANOVA results for geometrical error

	Source	DF	SS	MS	Contribution	P-value
e_b	Tool diameters(mm)	2	0.38000	0.19000	51.35%	0.305
	Wall angle (º)	2	0.10667	0.05333	14.41%	0.610
	Step size(mm)	2	0.08667	0.04333	11.71%	0.658
	Error	2	0.16667	0.08333	22.52%	
	Total	8	0.74000		100.00%	
e_s	**Source**	**DF**	**SS**	**MS**	**Contribution**	**P-value**
	Tool diameters(mm)	2	0.053414	0.026707	37.92%	0.125
	Wall angle (º)	2	0.077478	0.038739	55.00%	0.089
	Step size(mm)	2	0.002372	0.001186	1.68%	0.762
	Error	2	0.007601	0.003801	5.40%	
	Total	8	0.140865		100.00%	

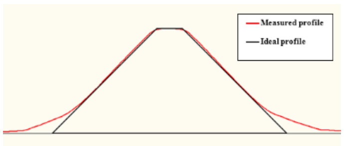

Figure 6: Deviation between measured and ideal model

(D=8mm, α=45°, Δz=0.2mm)

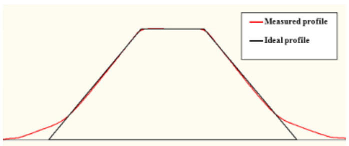

Figure 7: Deviation between measured and ideal model

(D=10mm, α=50°, Δz=0.6mm)

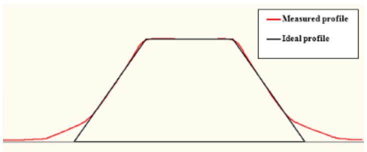

Figure 8: Deviation between measured and ideal model

(D=12mm, α=55°, Δz=0.4mm)

7. CONCLUSION

Best Geometric accuracy of the produced part can be achieved when using 8mm tool diameters, 55° wall angle and 0.2mm step size. The contribution ratio and the effect of process parameters on geometric accuracy (sheet bending error) are 51.35% for tool diameter, 14.41% for wall angle and 11.71% for step size, while for springback error are 37.92% for tool diameter, 55% for wall angle and 1.68% for step size. There is no difference in geometric accuracy when different sheet thickness was used.

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