

Fabrication of a Complicated Specimen with Two Point Incremental Forming Process

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Abstract: Manufacturing of complicated industrial components is one of the main challenges for mechanical engineers in sheet metal forming processes. Incremental sheet metal forming (ISMF) is used widely for forming complicated shapes by a single rotating tool. This paper examines the experimental investigation of two-point incremental forming of a complicated specimen made of AA3105 aluminum alloy. The part shape consists of positive and negative cavities and the shape complexity limits the manufacturing process to two-point incremental forming process (TPIF). In addition, the effects of selected process parameters such as forming depth in each increment of process, tool rotational speed and various forming patterns on thickness distribution and thinning percentage of specimen are investigated. The forming pattern includes the sequence of forming the cavities (Internal/External pattern and External/Internal pattern). The main finding of the study can be expressed that the thinning ratio of manufactured specimen is increased with an increase in the forming depth in each increment of TPIF. Also, the higher rotational speed leads to a reduction in the thinning of the fabricated specimen. The results prove that the use of Internal/External forming pattern leads to reduction in the thinning of the manufactured specimen.

Keywords: Forming Increment, Forming Pattern, Thickness Distribution, Two-Point Incremental Forming, Tool Rotational Speed

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Biographical notes: **Mehdi Safari** received his PhD in Mechanical Engineering from Isfahan University of Technology in 2013. He is currently Associate Professor at the Department of Mechanical Engineering, Arak University of Technology, Arak, Iran. His PhD thesis relates to forming of complicated shape parts by laser forming. His research interest includes manufacturing processes. **Jalal Joudaki** is the faculty member (assistant professor) of Arak University of Technology. He graduated from Iran University of Science and Technology (IUST) in 2016. His PhD thesis relates to the determination of residual stress profile while bending thick sheets. His area of interest is residual stress, manufacturing process, fatigue, finite element method.

1 INTRODUCTION

The incremental sheet metal forming (ISMF) process is an efficient manufacturing method for the fabrication of special parts with distinct profiles. This method can fabricate parts for rapid prototyping and due to elimination of die, it can provide higher flexibility in manufacturing of sheet metal parts. The number of samples decreased even to one specimen. Different parts with symmetric and non-symmetric geometrical profiles can be produced at considerably lower time and cost. The required equipment for forming is noticeably cheap in comparison to the similar manufacturing processes such as hydroforming process. In this process, the blank is clamped by a fixture from the lateral edges. Then, a hemispherical rotating tool pushes the blank and deforms it plastically to obtain the desired shape. The tool movement obeys different patterns like helical movement or constant height movement.

The ISMF process is very similar to the spinning process and flow forming process. The blank is fixed in the ISMF process but it rotates in the spinning and flow forming process. Due to the fixed position of the initial blank, the non-symmetric or asymmetric part profiles can be produced by independent movement of the forming tool in X, Y and Z directions. ISMF process can be divided into three different categories according to the type of tool and blank contact force, Single Point Incremental Forming (SPIF), Two Point Incremental Forming (TPIF) and Multi-Point Incremental Forming (MPIF). Most of the time, single point or two-point incremental forming is used for forming symmetric and non-symmetric profiles. In single point incremental forming (SPIF) process, the forming tool moves according to a G-Code program, no back up die exists and the desired shape will be obtained by plastic deformation of the blank along the vertical (Z) axis. The tool movement path has an important role in the ideal deformation of the blank. Springback is one of the main problems in ISMF process.

The two-point incremental forming process is a suitable process for the fabrication of parts with higher dimensional accuracy and less thickness reduction. However, the process operation is hard in comparison to single point incremental forming process. Several types of research have been published by researchers in recent years. Silva and Martins [1] studied the two-point incremental forming process with a partial die. The theoretical formulation and experimental measurements are combined to find the maximum height of forming. The geometrical tolerances of formed blanks by the two-point incremental forming process with partial die are higher than the parts formed by single point incremental forming process. During the unloading stage, the released elastic strain changes the final shape and makes it imprecise. Garcia-Romeu et al. [2] combined the

artificial neural network (ANN) and the genetic algorithm (GA) to analyze the behavior of the blank in two-point incremental forming process. The results show that the developed approach is a useful tool for prediction of the forming force in different directions. The prediction of forming force leads to better estimation of allowable thinning ratio and prevention of the blank failure.

Meier et al. [3] studied the fabrication of a part with two movable forming tool. The two-point incremental forming process was carried out by controlling the movement of the tool by a robot arm. Jeswiet et al. [4] studied the variation of forming force in SPIF and TPIF process. Their goal was comparison of required force in single point and two-point incremental forming processes. Fiorentino [5] proposed a sheet rupture criteria according to the variation of force in incremental forming. This criteria predicts the magnitude of stress exerted on the sample and ultimate strength of the material in incremental forming. Eftekhari and Fazli [6] proposed a new method for improving the thickness distribution in incremental sheet metal forming process. In the proposed method, a pre-form is added to the steps of incremental forming and the thickness at the bottom of workpiece is reduced, consequently, the minimum thickness at the wall of workpiece is increased and the thickness distribution improved.

Nikdooz et al. [7] studied the formability of truncated pyramid from aluminum alloy in one stage and two stage of incremental forming process. The results show that the minimum thickness increased in two stage forming in comparison by the one stage forming. Jackson and Allwood [8] studied the deformation mechanics of copper sheets fabricated by SPIF and TPIF. They concluded that the deformation mechanism in both SPIF and TPIF processes were stretching and shear in the plane perpendicular to the tool direction. Göttmann et al. [9] investigated laser assisted SPIF and TPIF processes. They used laser beams on the same side as the forming speed and concluded that the formability was improved in forming of TiAl6V4 in both SPIF and TPIF. In the incremental forming, thickness reduction is a very important criterion for judging the success of a workpiece forming. Some papers have been focused on thickness distribution of fabricated specimen by incremental forming.

Duflou et al. [10] proposed multi-pass toolpaths for controlling the thickness of deformed specimen by incremental forming. Azaouzi and Lebaal [11] developed a method for obtaining a homogenous thickness distribution in a deformed specimen by incremental forming using response surface method (RSM). Duflou et al. [12-13] found that in the incremental forming of pyramidal parts, the thickness distribution is increased on the planar face along the tool moving direction until the location of semi-vertical ribs.

Malhotra et al. [14] employed a double sided incremental forming technique in order to uniformly distribute the thickness of a specimen fabricated by SPIF.

According to the literature review, it can be concluded that new challenges can be defined in production of complicated shapes by SPIF and TPIF and the process capability can be extended by the researchers. The literature survey in the two-point incremental forming process shows that the researchers mostly investigated the fabrication of single cavity workpieces by the incremental forming process. In this article, two-point incremental forming of a complicated workpiece with two cavities (external and internal cavities) will be investigated experimentally. The main novelty of the work is the concurrent existence of external and internal cavities in the workpiece. In this way, the die set is designed and manufactured and the effect of forming parameters including forming increment, rotational speed of tool and the forming sequence pattern on the thickness distribution and the thinning percent of manufactured parts will be discussed. The current work introduces new process parameters (forming sequence) which is important in forming two-cavity shapes.

2 MATERIALS AND METHODS

Figure 1 shows the drawing of workpiece which will be produced in this study. “Table 1” shows the dimensions of the workpiece. The workpiece is a conical part with 70° external and internal slope angle (θ_o and θ_i). Two internal and external cavities exist in the workpiece and the complicated shape will be manufactured by the two-point incremental forming process.

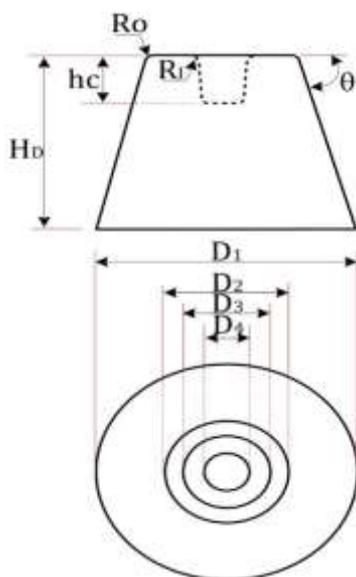


Fig. 1 The drawing of the investigation workpiece.

Table 1 Dimensions of the workpiece in mm

Parameter	Symbol	Magnitude
Outer diameter of the external cavity	D_1	144.50
Internal diameter of the external cavity	D_2	75.40
Outer diameter of the internal cavity	D_3	48.80
Internal diameter of the internal cavity	D_4	19.69
Total height of the external drawing	H_D	95
Height of the internal cavity	h_c	40
Outer fillet radius	R_o	5
Internal fillet radius	R_i	5
Slope angle of the external cavity	θ_o	70°
Slope angle of the internal cavity	θ_i	70°

Figure 2 shows the die and fixture used for the two-point incremental forming process. In addition, a formed workpiece manufactured by TPIF is shown in “Fig. 3”. Complicated workpiece is produced successfully. No tearing or cracks were observed in the manufactured workpiece.



Fig. 2 The die and fixture used in this research drawing.



Fig. 3 The manufactured specimen with two-point incremental forming.

The material of the initial blank was AA3105 aluminum alloy. The initial blank was a 200mm square sheet with 2mm thickness. The designed and fabricated die set has appropriate rigidity to prevent unwanted deflection and increase the quality of final manufactured part. The die set includes the die, guide, ISMF tool, die clamp and fixtures are manufactured from MO40 (1.7225) steel. The initial blank is clamped by M8 steel screws. The two-point incremental forming process leads to the thinning of the blank. The thickness distribution is important. In this way, the workpiece is cut by WireEDM machine and the thickness is measured in different locations. Figure 4 shows the cut workpiece. The measurement path starts from outside edge and 20 points are selected for thickness measurement. Thinning percent is defined as “Eq. (1)”:

$$\text{Thinning Percent} = \frac{t_0 - t_{\min}}{t_0} \times 100 \quad (1)$$

t_0 is the initial thickness (2mm) and t_{\min} is the minimum thickness measured along the measurement path which was shown in “Fig. 4”. It should be noted that a criterion is used to judge the success of the fabrication of the desired specimen in this paper with TPIF process. Production of the specimens with a thinning percent less than 25% means a successful production of the desired specimens with TPIF. The effect of process parameters will be studied in this research. In this way, the selected parameters are forming increment (0.2, 0.4 and 0.6mm), the rotational speed of tool (200, 400, 800 rpm) and the forming sequence. The forming sequence is selected as Internal/External (First, the internal cavity and then the external cavity are formed) or External/Internal (First, the external cavity and then the internal cavity are formed). The workpiece has an external and an internal cavity. The External/Internal sequence consists of forming the 95mm height external cavity at first and then the 40mm height internal cavity will be formed. In the Internal/External sequence, the internal cavity will be formed firstly.

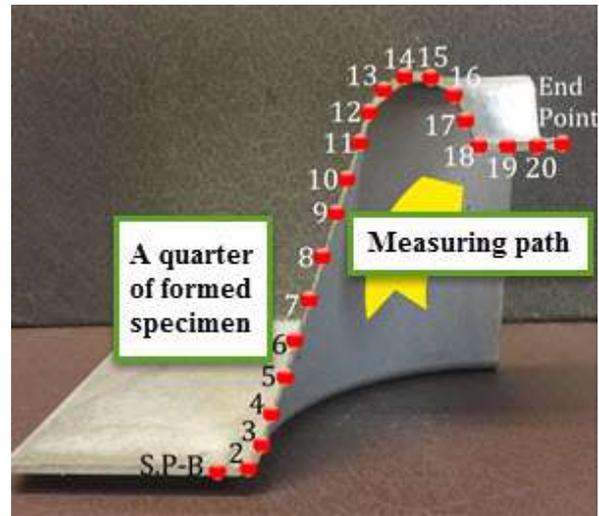


Fig. 4 A quarter of formed specimen with thickness distribution measuring path.

3 RESULTS AND DISCUSSION

3.1. The Effect of Forming Increment

Three different forming increments (0.2, 0.4 and 0.6mm) are selected for investigation. Figure 5 shows the thickness distribution along the defined path in “Fig. 4” for different forming increments.

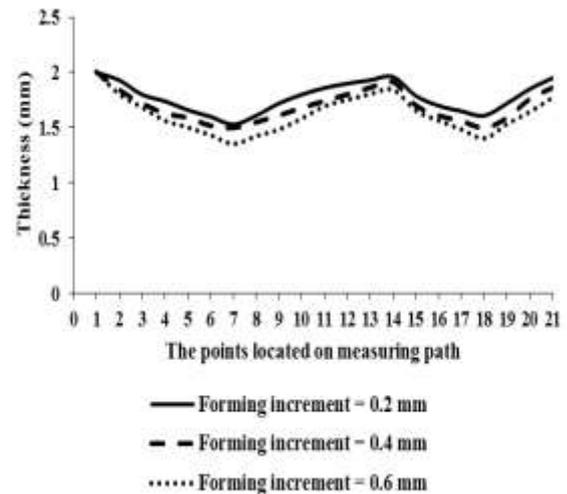


Fig. 5 Thickness distribution of manufactured specimens for various forming increments.

The rotational speed was 400 rpm and the forming pattern was Internal/External sequence. As can be seen in “Fig. 5”, the thickness of the workpiece will be decreased in different zones of forming by increasing the forming increment. The minimum thickness for the increments is measured and the thinning percent is calculated as 23.5, 25 and 32.5% for 0.2, 0.4 and 0.6 mm increment respectively. According to the failure

criterion defined previously, the fabrication of the desired specimen by 0.6mm increment is not successful. In addition, it was observed that the formability of the blank will be decreased in TPIF process by increasing the forming increment due to creation of higher tensile stresses in the process.

3.2. The Effect of Tool Rotational Speed

To study the effect of tool rotational speed on thickness distribution, three different speeds (200, 400 and 800 rpm) are selected. The forming increment was 0.2mm and the forming pattern was Internal/External sequence. Figure 6 shows the thickness distribution along the defined path. By increasing the tool rotational speed, the thickness at different zones of the workpiece will be increased. This is because of the generated heat in the forming process. By increasing the rotational speed, the temperature of the sheet surface will be increased, consequently little softening will be happened and the sheet forms more easily. So, the thickness reduction will be decreased. According to the minimum thickness and “Eq. (1)”, the thinning percent is calculated as 26, 23.5 and 17.5 % for 200, 400 and 800 rpm tool rotational speed respectively. According to the failure criterion defined previously, the fabrication of the desired specimen by 200 rpm rotational speed is not successful.

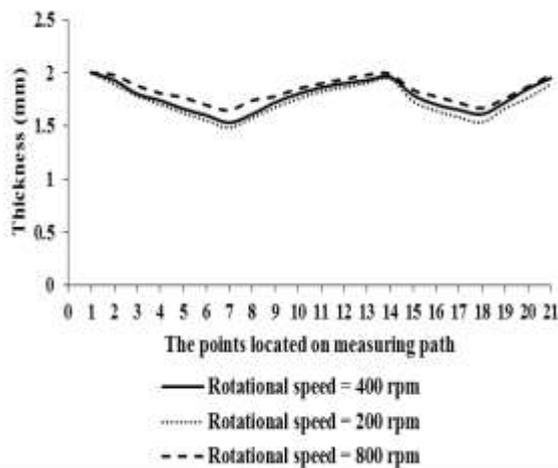


Fig. 6 Thickness distribution of manufactured specimens for various rotational speeds.

3.3. The Effect of Forming Sequence

The Internal/External and External/Internal forming sequence is selected for examination. The forming increment and the rotational speed are selected as 0.2mm and 400rpm respectively. Figure 7 shows the thickness distribution along the defined path in “Fig. 4” for different forming sequence. The thickness distribution shows that using the External/Internal forming sequence leads to more decrease in the thickness comparatively. Consistent with the measured thickness and “Eq. (1)”, the thinning percent can be calculated as 17.5 and 22.5 % for Internal/External and External/Internal forming sequence respectively. The thickness distribution shows

that the External/Internal forming sequence causes more thinning at constant forming increment and tool rotational speed. This is due to the strain hardening happened when deformation of external cavity. When the external cavity forms, the plastic work applied at the sheet causes strain hardening, later, when the internal cavity starts to form, the material can not be drawn into the internal cavity zone.

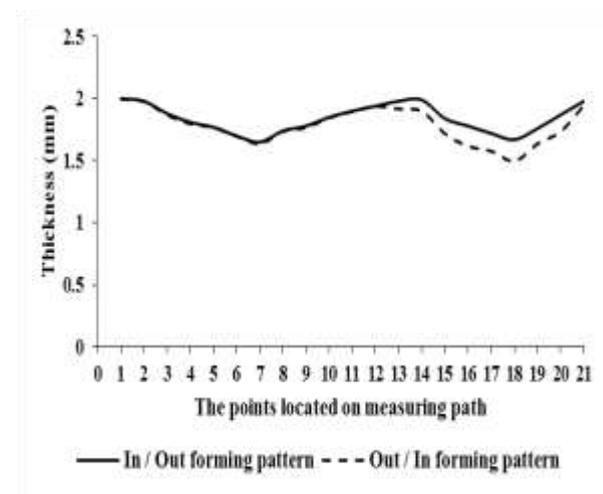


Fig. 7 Thickness distribution of manufactured specimens for various forming patterns.

As can be seen in “Fig. 7”, the thickness distribution is similar in 11 points which are at the external cavity zone. So, the Internal/External forming sequence is a better sequence for TPIF of the selected workpiece.

4 CONCLUSION

In this article, manufacturing of a complicated workpiece was investigated experimentally by the two-point incremental forming (TPIF) process. The part consists of two positive and negative cavities with 90 and 40 mm height of external and internal cavities respectively. The workpiece is manufactured successfully and the effect of process parameters (forming increment, tool rotational speed and forming sequence) are investigated. The results show that the thickness will be reduced by increasing the forming increment, decreasing the rotational speed and selecting the External/Internal forming sequence. So, for more proper part production it is suggested that finer increments higher rotational speed and forming from internal to external are used by the producer. The thinning percent are measured as 23.5, 25 and 32.5% for 0.2, 0.4 and 0.6mm forming increment respectively, the thinning percent is calculated as 23.5, 25 and 32.5% for 0.2, 0.4 and 0.6 mm increment respectively and the thinning percent is calculated as 17.5 and 22.5% for

Internal/External and External/Internal forming sequence. The thickness reduction will be decreased by increasing the tool rotational speed. The best TPIF process parameters for manufacturing the selected workpiece of study are 0.2 mm forming increment, 800rpm tool rotational speed and Internal/External forming sequence (thinning percent 17.5%).

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