Effect of some process parameters on geometric errors in two point incremental forming for Al-Cu-Mg Aluminum Alloy

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Abstract. Two point incremental forming receives widespread study with its advantages of economy and flexibility in small batch products, such as aircraft parts. Aircraft parts, however, are rigorous in their shape errors. In this paper, one real airplane part is selected and formed with different process parameters to investigate the shape error level of part. Comparing the geometric errors caused by different process parameters, such as tool diameter, step size, feed rate and tool path, it is found that the geometric errors reduce as tool diameter increases. Meanwhile, the effect of step size is not linear. Influence law of feed rate is various with different other parameters. The bidirectional tool path, having opposite processing direction at adjacent layer, reduces the errors.

1. Introduction

Incremental sheet forming (ISF) has the advantage of flexible processing, short lead time and low costs for small-batch production. In ISF, the forming tool imposes a localized deformation on sheet and the desired part is formed by the accumulation of these localized deformations [1]. Aircraft parts, which generally are small-pitch and various, are very suitable for technical characteristics of ISF. In the meantime, aircraft part is a place where all things are accurate. For this reason, it's significance to investigate applications of this forming process in the aviation industry.

A type of ISF is called Single point incremental forming (SPIF) in which the sheet deforms under the action of forming tool without constraint of die as shown in Fig.1a. But the geometrical accuracy of the parts, manufactured by this process, is generally poor while aircraft parts are rigorous in their shape errors. Two point incremental forming (TPIF) is a particular type of ISF in which the sheet deforms under the action of forming tool with constraint of die placed under the sheet showed in Fig.1b [2].
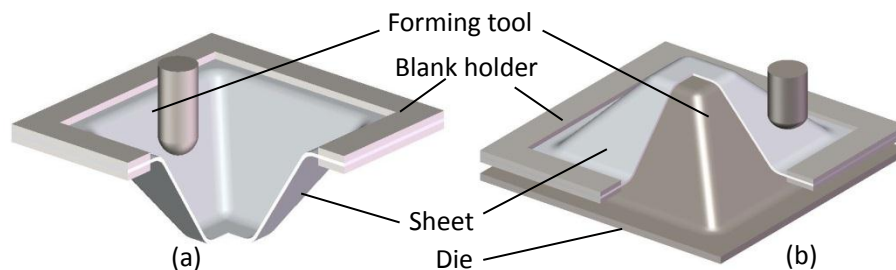

Fig.1-SPIF and TPIF (a) SPIF and (b) TPIF [1]

In previous study, it's observed that process parameters have significant impact on geometric errors [3, 4]. The objective of current study is to investigate the effect of the major process parameters, namely tool diameter, step size, feed rate and tool path, on geometric error [5, 6], with realization of a real airplane part made of Al-Cu-Mg aluminum alloy with different process parameters of positive TPIF at room temperature.

By coordinate measuring machine (CMM), 3D models of the forming part are obtained. Then, the values of geometric errors of the parts are calculated by comparing the forming shape with the desired shape. Finally, the effect of process parameters can be obtained and analyzed by comparing the values of geometric errors.

2. Experimental tests

To realize a real airplane part which 3D model is reported in Fig.2a, the part is further designed to accord with the process of ISF for its special shape as shown in Fig.2b. The part is manufactured on an incremental forming machine (Fig.3). To reduce the geometric errors of parts, TPIF function of this machine is used in

present study. As shown in Fig.4, the sheet is clamped on the machine and deformed by the pressure applied from tool and positive die. To obtain the better geometric accuracy, the sheet is pre-bent with dead-weight of gripper mechanism, making sheet abut against the die.

Sheet is made of Al-Cu-Mg aluminum alloy, with 1.00 mm thickness and 600mm×400mm dimensions. The chemical composition of the material is listed in Table 1. The material of the die is wood. During the forming process, the lubricant is smeared on the surface of the part.

Fig.2-3D model (a) 3D model part of an airplane part and (b) the part designed
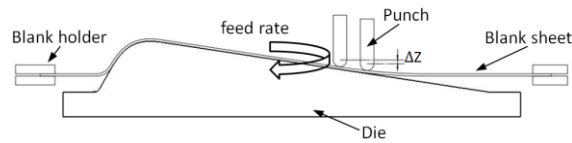

Fig.3-Incremental forming machine   Fig.4- Positive TPIF

Table 1 chemical composition of Al-Cu-Mg aluminum alloy

Element	Cu	Mg	Mn	Fe	Si	Ti	Al
wt.%	3.8~4.9	1.2~1.8	0.3~0.9	0.3	0.2	0.1	Bal.

To study the effect of TPIF process parameters on geometric errors, the major process parameters are selected, which are tool diameter, step size, feed rate and tool path. According to the principle of a single parameter, the design of experiments is carried out and showed in Table 2. The two different tool paths are called unidirectional and bidirectional tool path showed in Fig.6a and b respectively [6]. In unidirectional tool path, the processing direction of each layer keeps same showed in Fig.6a. On the comparison, the processing direction of adjacent layer has opposite processing direction in bidirectional tool path showed in Fig.6b. All of experiments are conducted with the same thickness, dimensions and lubricant.

Table 2 Design of experiments

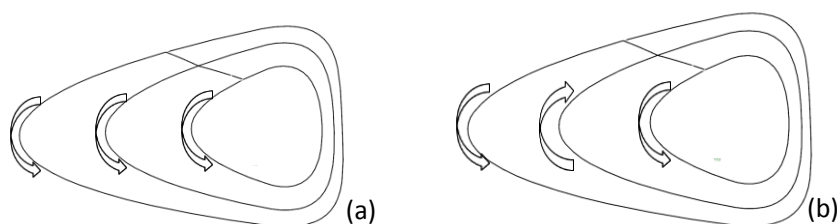| Exp.#	Tool diameter [mm]	Step size [mm]	Feed rate [mm/min]	Tool path
1	12 mm	0.25 mm	5000 mm/min	Unidirectional
2	12 mm	0.25 mm	8000 mm/min	Unidirectional
3	12 mm	0.25 mm	12000 mm/min	Unidirectional
4	12 mm	0.50 mm	5000 mm/min	Unidirectional
5	12 mm	1.00 mm	5000 mm/min	Unidirectional
6	10 mm	0.25 mm	5000 mm/min	Unidirectional
7	25.4 mm	0.25 mm	5000 mm/min	Unidirectional
8	12 mm	0.25 mm	5000 mm/min	Bidirectional
9	25.4 mm	0.50 mm	12000 mm/min	Unidirectional
10	25.4 mm	0.50 mm	12000 mm/min	Bidirectional

Fig.6- Tool path (a) unidirectional tool path and (b) bidirectional tool path in which arrow represents the direction of the tool path

3. Result and discussion

To evaluation of the geometric error, the point clouds of the outer surfaces are obtained by CMM, and the 3D models are generated by these clouds of points via software. In order to get discrepancies between the desired and experimental geometry, these 3D models are intercepted in three location at x=0mm, x=50mm and x=100mm respectively. As shown in Fig.7, these sections of each model are compared with the desired corresponding sections in the same location for observing shape defects of obtained shape. Then, a quantitative analysis of the obtained results, namely the value of geometric error, is carried out on the basis of the mean root square error between actual and desired profiles.
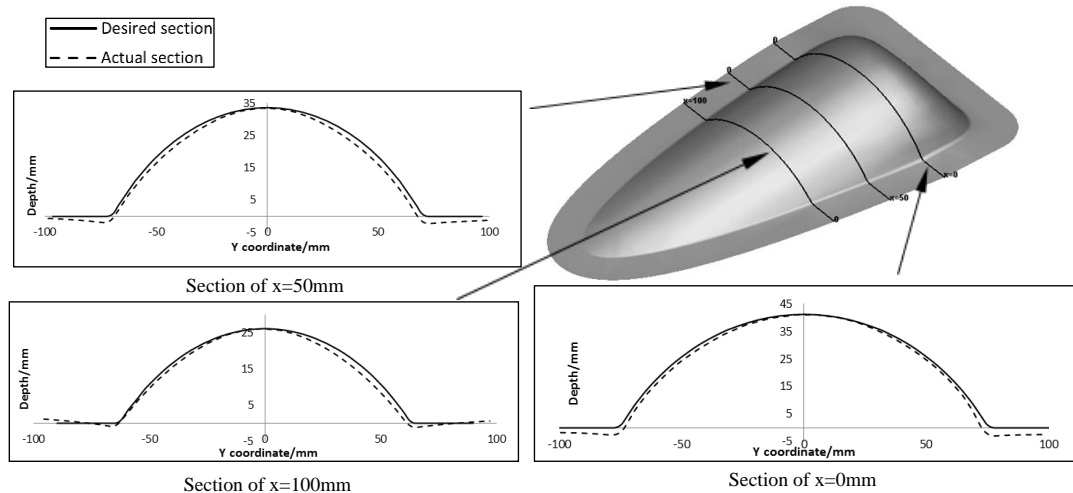

Fig.7-Sections of 3D model

3.1 Effect of tool diameter

Comparing geometric errors of various tool diameters with constant step size and feed rate of 0.25mm and 5000mm/min as shown in Fig.8, it is observed that the increment of tool diameter leads to decrease of geometric error. This phenomenon is due to the increment of tool diameter leads to increment of forming force, as a result of that the geometric error decreases as the forming force increasing [1, 2].

3.2 Effect of step size

The parts are formed at constant tool diameter and feed rate of 12mm and 5000mm/min. As shown in Fig.9, geometric errors decreases at first then increases as the step size increasing. The increment of step size leads to increment of forming force, as a result of decrease of the geometric error [2]. However, as the increment of step size, local strain rate increases, leading to the incremental yield stress. The increment of yield stress makes sheet harder to realize desired shape. Due to this reason, the geometric error decreases from 0.25mm to 0.50mm but increases from 0.5mm to 1.00mm.
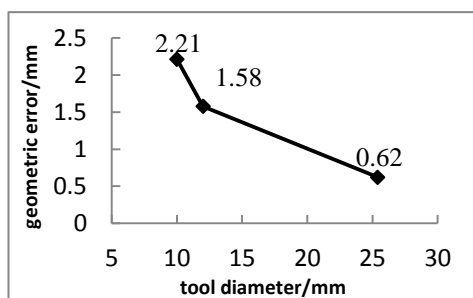

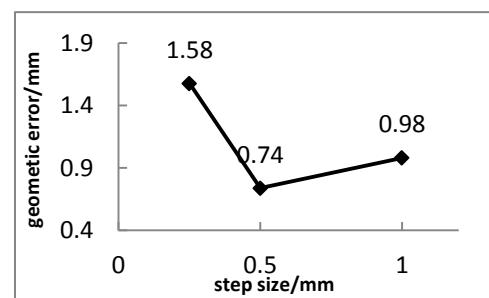Fig.8-comparison of various values of tool diameter with step size 0.25mm, feed rate 5000mm/min, unidirectional

Fig.9-Comparison of various values of step size with tool diameter 12mm, feed rate 5000mm/min, unidirectional

3.3 Effect of feed rate

As showed in Fig.10, it is found that the influence law of feedrate on geometric error is various with different other parameters. When the part is formed at tool diameter and feed rate of 12mm and 5000mm/min by unidirectional tool path, the geometric error increases as feedrate increases. However, the increment of feedrate leads to the decrease of the geometric error of the part, which is formed at tool diameter and feed rate of 25.4mm and 12000mm/min by bidirectional tool path. It is confirmed that the effect of feedrate on geometric error is difference with various other process parameters
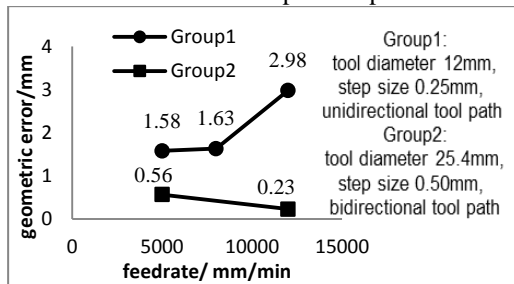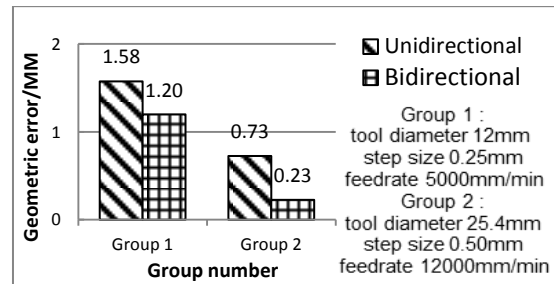

Fig.10-Comparison of various values of feed rate

Fig.11-Comparison of geometric errors of different tool path

3.4 Effect of tool path

With different tool path and other same parameters, the parts are compared in Fig.11. It is obvious that the bidirectional tool path shows better geometric accuracy compared to unidirectional tool path. It is due to tool path of same processing direction of each layer shows worse twist, as a result of worse geometric accuracy [6]. Decreasing geometric errors effectively, bidirectional tool path can be used to improve geometric accuracy.

4. conclusion

As a preliminary study, with realization of airplane part made of Al-Cu-Mg aluminum alloy, the effect of process parameters on geometric error is obtained and analyzed. The primary conclusions are summarized as following:

1. As discussed above, it is obtained that the increment of tool diameter leads to the reduction of geometric errors.

2. The influence law of step size is not linear. Therefore, it is meaningful to study the suitable step size under the premise of insuring geometric accuracy to realize the improvement of TPIF production efficiency.

3. Influence law of geometric error affected by feed rate is various with different other parameters.

4. In this paper, bidirectional tool path has been shown to reduce the geometric errors.

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