Feasibility study of single point incremental forming of aircraft canopy for polycarbonate sheet

Abozar Barimani-Varandi[1*], Mohammad Kazemi Nasrabadi[2], Bahram Abedi Ravan[3]

[1] Faculty of Mechanical Engineering, K. N. Toosi University of Technology
[2] Faculty of Aerospace Engineering, Shahid Sattari University of Aeronautical Engineering
[3] Faculty of Basic Sciences, Shahid Sattari University of Aeronautical Engineering

ABSTRACT

The canopy as a clear cockpit protector is one of the strategic polymer parts in aviation industry. Conventional forming processes aren't cost-effective for individual production of transparent polymer canopies due to high energy consumption and high costs of machinery, equipment, and tools. In this paper, rapid prototyping of geometry similar to integral canopies is investigated using incremental forming process of transparent polycarbonate sheets on a laboratory scale. Polycarbonate sheets with suitable mechanical, thermal, chemical, and optical properties are used in manufacturing of the latest integral canopies. In single point incremental forming experiments, effect of tool rotational velocity on apparent transparency and effect of toolpath strategy on geometric accuracy were investigated. Three toolpath strategies including raster, spiral from outside, and spiral from inside were applied. Post-forming heating at about 55˚C for 30 min resulted in a 50% reduction in spring back by releasing process-induced residual stresses. The use of a non-rotating tool as well as a mechanical-chemical surface polishing improved the final finishing and transparency of samples. Additionally, the amount of deviation for the raster strategy in both depth and radial directions was less than 1 mm, which was within the allowable range of process window of single point incremental forming.

KEYWORDS

Rapid prototyping, aircraft canopy, SPIF, polycarbonate sheet, toolpath strategy.

* Corresponding Author: Email: barimani.abozar@email.kntu.ac.ir

1. Introduction

The canopy is one of the strategic polymer parts in aviation industry used in various aircrafts as a transparent enclosure of the cockpit. The kind of the canopy is a main measure to compare the advanced level of the fighters. Integral canopies as the newest technology used in fourth-generation fighters e.g. *F*-16 and *F*-22 are developed via an integrated injection moulding of the polycarbonate by the USA army [1-3].

Polycarbonate sheets with fantastic properties improved the challenges of increased temperatures and collisions with birds for velocities below Mach 2.5 [1]. It is noteworthy that conventional methods are not cost-effective in the small-batch production of polymer products [4, 5]. Incremental forming process patented in 1967 by Leszak Edward [6] in which, a hemispherical tool through a predefined toolpath formed the final geometry with the induced local plastic deformations.

For incremental forming processes, high flexibility in fabricating complex geometries, short time to fabricate the final product due to no need to design and make special tools, use of simple equipment, and high economic efficiency in mass production have been reported. In the present study, the single point incremental forming (SPIF) of geometry similar to the aircraft canopy was investigated with polycarbonate sheets to assess the feasibility of the rapid prototyping of integral canopies. To this end, the effect of toolpath strategy and tool rotational velocity on geometric accuracy and apparent transparency were studied, respectively. Besides, the post-forming heating was utilized to solve the spring back problem.

2. Methodology

In all experiments, Lexan American polycarbonate commercial sheets [7] with a thickness of 2.25 mm were used to perform the SPIF experiments. The sheets dimensions were 170 mm ×170 mm with nylon covers on both sides of the sheets which relatively protected the formed surface from process-induced scratches.

A dedicated fixture mounted on a CNC milling machine equipped with a Siemens 802 controller was used to perform all the SPIF experiments as shown in Figure 1. The constant input parameters according to the Table 1 were extracted based on the literature review on polymer sheets [8, 9]. Condaform 3442 E was used as a lubricant during the forming process. The side window geometry of a training aircraft was used with a surface scale of 1:7 due to the SPIF practical limitations. The scaled model surfaced in a cavity form is similar to a fourth-generation integral canopy used in the fourth-generation fighters.

Figure 1. Performing the SPIF process on a CNC milling machine.

Table 1. Constant input parameters

Tool dia.	Feed rate	Rotational velocity	Tool step
10 mm	2000 mm/min	1000 rpm	0.25 m

Three toolpath strategies involving raster (Rst.), spiral from outside (S_{out}), and spiral from inside (S_{in}) were applied to evaluate the geometric accuracy. After forming, a new proposed mechanical-chemical surface polishing was utilized to enhance the apparent transparency. In addition, heating at about 55 °C for 30 min was applied subsequent to the forming to release the residual stresses.

Mahr MarSurf PS 10 was used to measure the roughness average (Ra). The clarity of the orthogonal lines through the samples was inspected with the naked eye to evaluate the transparency of the samples [10]. The amount of geometric deviation of a critical curve passing through the deepest points of the product model on the inner surface of the samples was compared to the corresponding curve in the 3D model for the three applied toolpath strategies. The torsion of the flat surface of the formed products taken out of the fixture was a criterion to measure the spring back. In which, the height of the two vertices of corresponding diameters on the same side was compared.

3. Results and Discussion

3.1 Effect of rotational velocity

Roughness average was compared with and without the rotating tool to investigate the influence of rotational velocity of the tool. Increased friction by tool rotation may lead to material sticking, distortion, and local oxidation. As presented in Figure 2, the surface roughness increased by 62% compared with using the rotating tool, with a small effect of strategy type on the final finishing.

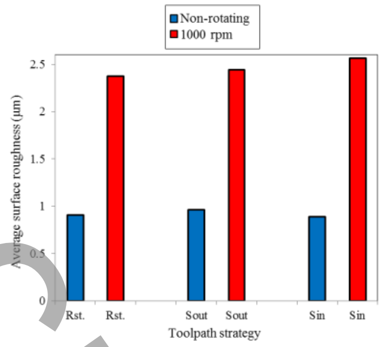
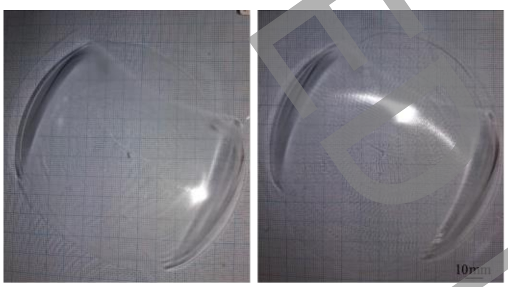


Figure 2. Average surface roughness for various strategies

Furthermore, as shown in Figure 3, orthogonal lines were much clearer through the samples formed with a non-rotating tool. Higher generated friction at the rotational velocity of 1000 rpm significantly affected the final finishing as well as the apparent transparency. Besides, the proposed mechanical-chemical polishing method subsequent to the SPIF experiments could highly improve the surface quality.



(a) (b)

Figure 3. Comparison of the transparency of the sample formed with the raster strategy: (a) without rotating tool and (b) rotational velocity 1000 rpm

3.2 Effect of toolpath strategy

The variations for the critical curve belonged to the samples formed in various strategies are plotted in Fig. 4. For the critical curves in S_{out} and S_{in} strategies, the radial material flow led to a large deviation with the accumulation of the material in the central part of the sample and side corners, respectively. However, the swept material flow from one side to the other side in Rst. strategy did not cause vortex flow either accumulation of the material. Accordingly, the occurred deviation was below 1 mm in both deep and radial directions for the raster strategy. For this strategy, the tolerance ±1 mm is within the allowable range of the SPIF process window as reported [11, 12].

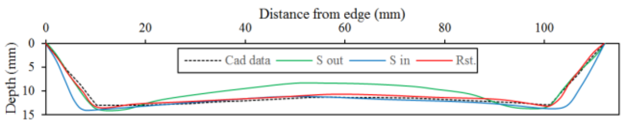


Figure 4. Comparison of the effect of toolpath strategy on geometric accuracy for the critical curve

3.3 Effect of post-forming heating

It is generally necessary to find a solution to defeat the spring back problem, particularly for the polymer sheets. The small amount of elastic modulus relative to the metals, low yield stress, small sheet thickness, and large induced strains causes to increase in the spring back severity for polymer sheets. To this aim, samples formed by raster strategy with a non-rotating tool were heated subsequent to the SPIF for 30 min at about 55 ˚C to release the residual stresses. The results are depicted in Figure 5.

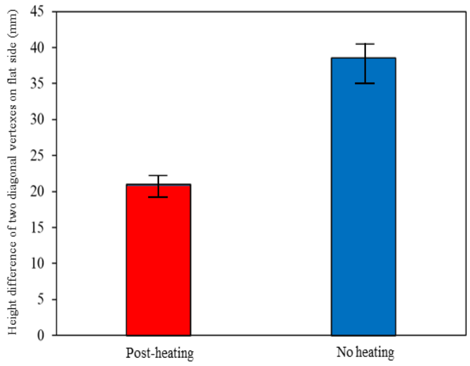


Figure 5. Comparison of the spring back for the formed samples with raster strategy without rotating tool

As shown in Figure 5, post-heating treatment reduced the spring back by almost 50%. Note that optimizing the amount of temperature and holding time for post-heating treatment will result in a much more reduction in spring back.

4. Conclusions

The results showed that the non-rotating tool led to a 62% improvement in surface quality compared with the rotating tool. Besides, employment of the proposed mechanical-chemical surface polishing dramatically improved the apparent transparency. However, for the raster strategy, the less geometric deviation was created for the critical curve in both depth and radial directions below 1 mm, which was within the allowable range of the SPIF process window. In addition, releasing the process-induced residual stresses by applying the post-forming heating for 30 min at 55 ˚C reduced the amount of the spring back by approximately 50%.

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