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Temperature influence on Single Point Incremental Forming of PVC parts

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Abstract

Incremental sheet forming techniques, such as Single Point Incremental Forming (SPIF), have an appealing potential in rapid prototyping and processing low volume plastic sheet products. Fitting a conventional CNC milling machine to accomplish SPIF is easy and cheap: just design and assembly a rigid frame and manufacture a semi-spherical end punch. Nevertheless, polymeric SPIF parts have a lack of dimensional accuracy and surface quality because of springback and friction effects. This experimental work shows the influence of temperature and force on final dimension and surface finishing of PVC SPIF specimens. In order to produce a temperature and force variation, the following parameters are modified: punch material, spindle rotational speed and sense.

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1. Introduction

The need of cheaper and flexible tools to obtain sheet products fosters the development of Incremental Sheet Forming (ISF) methods [1]. These techniques allow to deform a clamped sheet along a tool-path, which can be

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controlled by a conventional CNC. ISF provides prototypes and low volume functional products for aeronautic and automotive industry, as well as biomedical prostheses and implants.

Single Point Incremental Forming (SPIF) is a simple ISF method that requires a minimum set-up and produces sheet products without expensive tools and dies. Nevertheless, it is observed that SPIF produces parts with high dimensional inaccuracies [2].

Taking into account the recent interest in single point incremental forming of polymers [3, 4], several scholars conduct experimental studies regarding to the process performance. Bagudanch et al. [5] prove that spindle speed and forming depth influence the temperature of the sheet during the forming process, which has significant effect on formability and roughness of Polyvinyl chloride (PVC) sheets obtained via SPIF processes. Davarpanah et al. [6] show how high incremental depths increase formability in polymer SPIF, but depending on part shape and tool rotational speed, high forming depths can produce sheet wrinkling.

Further experimental studies, based on, testing similar and/or different parameters, can contribute to improve our knowledge of polymer SPIF processes. We propose a study to analyze the relationship of several SPIF parameters (spindle's speed, rotational direction, and punch material) to process temperature, dimensional accuracy and surface quality of PVC SPIF parts. Additionally, we evaluate forming forces.

This paper has five sections. Section 2 describes the experimental set-up and the measurement systems. We define the experimental procedure in Section 3, while Section 4 portrays the experimental results. Main conclusions are drawn in Section 5.

2. Materials and experimental set-up

2.1. Specimen material and geometry

In the experimental test, we process 205x205 mm PVC sheets with a thickness of 3 mm. Good formability, low springback (comparing to other polymers) and low cost [4] make PVC a good choice for SPIF. The maximum size of the sheet is a little bigger than the working space of the CNC machine (in our case is 200x200 mm), in order to properly fix the sheet to the milling machine.

Fig. 1 portrays the specimen shape and its theoretical dimensions. We chose a cone's opening angle of 60° in order to not exceed the maximum angle of deformation for this type of material, which avoids material cracks during the forming process [7].

2.2. Experimental set-up

We use two different tools, one made of aluminum and one of steel, to determine the influence of the punch material on the forming process.

Both tools have the same dimensions and a semi-spherical tip of 10 mm in diameter. The aluminum punch has a roughness average (*Ra*) of 0.918 μm and the steel punch 1.005 μm.

The SPIF process is performed using a conventional milling machine model ALECOP-ODISEA. We developed an in-house fixing system (Fig. 2.a) to accomplish SPIF in the milling machine. The sheet fixing system is placed on the machining bed, and it consists of a frame made of four aluminum profiles, a die with a hole of 140 mm diameter and an upper die. Several screws join the two dies to provide the necessary fasten during the deformation process of the sheet.

A KISTLER model 9257BA dynamometer table (Fig. 2.b) is used to measure the value of the force in each of the Cartesian axes. The dynamometer table is placed between the milling table and the in-house fixing system.

A Flir T335 thermal imaging camera, with a 320 x 240 pixel resolution, provides the temperature measurements (Fig. 3.a). On the other hand, a probe joined to the aforementioned milling machine is used to determinate the depth of several points of the formed surfaces (Fig. 3.b). The roughness is measured using a MITUYOTO portable roughness meter model SJ-210.