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Feasibility of manufacturing low aspect ratio parts of PLA by ultrasonic moulding technology

U. Heredia[a], E. Vázquez[a], I. Ferrer[b], Ciro A. Rodríguez[a], J. Ciurana[b]

[a] *Tecnológico de Monterrey, Av. Eugenio Garza Sada #2501 Sur, Monterrey, N.L. 64849, México.*
[b] *Department of Mechanical Engineering and Industrial Construction. University of Girona. C/Maria Aurèlia Campany,61,Girona 17071, Spain.*

Abstract

Ultrasonic moulding is a promising technology capable of producing complex mini and micro components highly demanded both electronical and medical sectors. This research work presents a preliminary study to evaluate the feasibility of producing low aspect ratio parts of polylactide acid (PLA) by ultrasonic moulding process. Additionally, mould design considerations are presented to increase literature regarding USM tooling. Finally, some moulding trials were performed to demonstrate the process feasibility to obtain parts fulfilling dimensional requirements.

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Keywords: Ultrasonic moulding process, mould design, mould simulation, low aspect ratio, micro parts

1. Introduction

Ultrasonic moulding process (USM) is a novel technology created to produce micro components with weights lighter than one gram. USM process can be used to mold complex 3D micro parts with a wide variety of polymeric materials. Here the ultrasonic vibration energy is applied by a sonotrodo to heat and plasticized the polymeric material, different to the conventional injection process, where frictional and thermal energy is applied to heat the material by means of a reciprocated screw.

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: ines.iferrer@udg.edu

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According Grabalosa et al.[1] the process can be divided in four phases: feeding, vibration initiation, filling and packing and cooling phase. First, in feeding stage, the thermoplastic material is introduced in pellets form inside of a plasticization chamber which is formed by the two halves of the mould used in the process. Then, in vibration initiation stage, the sonotrode moves down until the tip reaches the pellets and starts to vibrate at a specified frequency producing ultrasonic waves that heat the material and starting to melt it. The sonotrode remains vibrating at the top of the plasticization chamber while the plunger located at the bottom of the chamber is used to inject the melted material through the runners until the cavity mould. Finally, a packing and cooling phase is required giving the final properties and dimensions of the moulded part. At the end, the sonotrode returns to its initial position and the mould is opened to extract the moulded part. In this step the plunger helps to demould the part. Unlike the process description introduced in [1-3], the only difference with the above explanation is that in the sonotrode pushes the melted material while the plunger remains in a particular position in the bottom plate during the injection phase.

There are in the literature several studies related to this technology. Michaeli et al. [4] developed a platform to prove the micro injection capabilities of USM. Effects of process parameters also was studied on polypropylene (PP), polyoxymethylene (POM), and polypropylene using blue and yellow master batches. Planellas et al. [5] found out that ultrasonic energy mixes in a homogenous way a dispersion nanoclays in a polylactide (PLA) and polybutylene succinate (PBS) matrices. High orientation of clay nanosheets was found in the direction of polymer flow too. In other words, the ultrasonic moulding brings out the possibility to prepare nanocomposites materials based in polymer matrices. Sacristán et al. [6] studied the effects of ultrasonic moulding on the chemical and mechanical properties of PLA specimens founding a degree of material degradation due to the amount of applied ultrasonic energy, making evident the importance of process parameters. Grabalosa et al [1] researched about design considerations of a stepped sonotrode. They developed a sonotrode operating frequencies map with the aim to increase sonotrode life cycle. Recently Negre et al. [3] studied the ultrasonic moulding process parameters for manufacturing polypropylene parts.

As an emerging technology, there is a limited literature regarding the design and fabrication of tooling and how the filling behaviour is influenced by part geometry. In this last issue several simulations about the heat generation mechanisms performed in the USM process have been developed [7]-[8]. However filling behaviour simulations haven't been studied yet. In [9] a commercial injection moulding simulation software (Autodesk® Moldflow®) was used to improve part quality and process parameters optimization of a PLA micro-stitch used in medical applications. Furthermore, Estrada et al.[10] presented a micro moulding case study of a locking ligation system , where they incorporated preliminary simulations of this Autodesk® Moldflow® to develop a methodology to design and manufacturing micro-cavities for micro moulded parts.

Therefore, the aim of this research work is to provide a preliminary study to evaluate the feasibility of producing low aspect ratio PLA plates by ultrasonic moulding process. Additionally, mould design considerations are presented to increase literature regarding USM tooling. Finally, some moulding trials were performed to validate mould functionality with a quality and dimensional approach.

2. Research method

The target geometry is a rectangular part of 20x25 mm and a thickness of 400 µm, therefore having a low aspect ratio part of 0.0125. The raw material used for the experiments is Ingeo™ Biopolymer 3251D (PLA) from NatureWorks. Considering this target geometry, the methodology is broken down into four steps (see Fig.1).

2.1. Moldflow simulation.

Autodesk® Moldflow® Adviser student version was used to simulate the filling process and to compare it with experimental trails. The part filling, air tramps location and the frozen layer fraction were analyzed. Ingeo Biopolymer 3251D (Commercial name) was chosen as the processing material. This simulation was performed considering the next assumptions: i) the polymer is injected at 190°C and it is completely melted while the mould temperature was setup to 45°C, ii) the injection moulding machine can reach up to 180 MPa of injection pressure, and iii) dual domain mesh type resulting: 4716 CAD triangles and 2360 CAD nodes generated.