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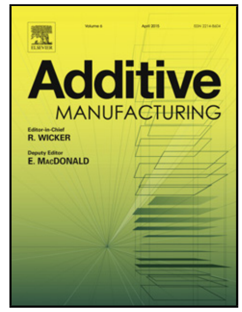

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Authors: Marcin P. Serdeczny, Raphaël Comminal, David B. Pedersen, Jon Spangenberg

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Experimental validation of a numerical model for the strand shape in material extrusion additive manufacturing

Marcin P. Serdeczny, Raphaël Comminal, David B. Pedersen, Jon Spangenberg

Department of Mechanical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

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Abstract

We investigate experimentally and numerically the influence of the processing conditions on the cross-section of a strand printed by material extrusion additive manufacturing. The parts manufactured by this method generally suffer from a poor surface finish and a low dimensional accuracy, coming from the lack of control over the shape of the printed strands. Using optical microscopy, we have measured the cross-sections of the extruded strands, for different layer heights and printing speeds. Depending on the processing conditions, the cross-section of the strand can vary from being almost circular to an elongated rectangular shape with rounded edges. For the first time, we have compared the measurements of strands' cross-sections to the numerical results of a three-dimensional computational fluid dynamics model of the deposition flow. The proposed numerical model shows good agreement with the experimental results and is able to capture the changes of the strand morphology observed for the different processing conditions.

Keywords: Material extrusion additive manufacturing; Fused filament fabrication; Strand cross-section; Numerical simulations; Experimental validation.

1. Introduction

In material extrusion Additive Manufacturing (AM), also known as fused filament fabrication or fused deposition modeling, a semi-liquid material is extruded through a nozzle and selectively deposited in the form of a strand, to create the layers of a sliced three-dimensional object. The parts manufactured by material extrusion AM used to be primarily employed for prototyping and rapid tooling; however, their areas of application as finished components have broadened every year as the process more frequently meet the stringent requirements to deliver end-use products [1, 2]. The most common material extrusion AM machines use thermoplastics, where the feedstock is a solid filament fed into a liquefier that melts the material before the extrusion [3]. The extruded strands bond to the previously deposited material by the mean of a temperature-driven diffusion process [4].

The material extrusion AM process is often more economical than other AM techniques [3] and easier to use as the popular build materials are non-toxic [5]. AM technologies are especially attractive in applications with low volumes of production and complex geometries, e.g. unmanned aerial vehicles [6]. However, the components produced by material extrusion AM have anisotropic mechanical properties that are affected by the build orientation of the part [7] and the tool path calculated by the slicing software. The mechanical properties of the components can be improved by using a feedstock material reinforced with fibers and metallic/ceramics particles [8, 9, 10]. Another inherent feature of the layered-based manufacturing methods is that the finished parts have rough surfaces, which are more difficult to post-process in the case of thermoplastics than for metals [3]. Therefore, the processing conditions must be well controlled for an optimal rendering of the surfaces [11, 12, 13].

The fabrication time and the manufacturing resolution depend on the size and the shape of the extruded strands, which relate themselves to the processing conditions. The strand shape was idealized with mathematical expressions in [11, 14] in order to predict the dimensional accuracy and the surface roughness of the parts. The cross-section of the strand is also an important parameter for the bonding strength between the layers, as it determines the width of the bonding area [4, 15, 16]. Moreover, the