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ORIGINAL ARTICLE

Torsion analysis of the anisotropic behavior of FDM technology

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Abstract

Several reports have studied the mechanical properties of the material extrusion additive manufacturing process, specifically referred to as fusion deposition modeling (FDM) developed by Stratasys. As the applications for 3D printed parts continue to grow in diversity (e.g., gears, propellers, and bearings), the loading conditions applied to printed parts have become more complex, and the need for thorough characterization is now paramount for increased adoption of 3D printing. To broaden the understanding of torsional properties, this study focused on the shear strength of specimens to observe the impact from additive manufacturing. A full factorial (4^2) design of experiments was used, considering the *orientation* and the *raster angle* as factors. XYZ, YXZ, ZXY, and XZY levels were considered for the orientation parameter, as well as 0°, 45°, 90°, and 45°/45° for the raster angle parameter. Ultimate shear strength, 0.2% yield strength, shear modulus, and fracture strain were used as response variables to identify the most optimal build parameters. Additionally, stress-strain diagrams are presented to contrast elastic and plastic regions with traditional injection molding. Results demonstrated an interaction of factors in all mechanical measured variables whenever an orientation and a raster angle were applied. Compared to injection molding, FDM specimens were similar for all measured torsion variables except for the fracture strain; this led to the conclusion that the FDM process can fabricate components with similar elastic properties but with less ductility than injection molding. The orientation in YXZ with the raster angle at 0^0 resulted in the most suitable combination identified in the response optimization analysis.

Keywords Torsion test · Additive manufacturing · Anisotropy · Fused deposition modeling · Stress strain · ABS

1 Introduction

Additive manufacturing (AM) has been gaining ground in the last decade through the introduction of new platforms for the fabrication of prototypes and, more recently, of functional components for specialized industries including the biomedical and aerospace ones. Due to the reduced cost of thermoplastic materials (particularly when compared to metals or photocurable resins) and to the introduction of affordable desktop printers, thermoplastic material extrusion printing is being used in many factories, schools and even homes. For example, worldwide sales estimates for 2016 were of 455,772 units, more than twice the 219,168 units shipped in 2015 [1]. Of the seven process categories developed by the ASTM F2792-12a [2], material extrusion AM has been forecasted to lead market sales through 2020 [1].

Despite the fact that FDM has a lot of applications, standardization for the mechanical properties of printed parts is difficult to establish. Even the same object can have different mechanical behavior when printed in different orientations. Thus, determining printer parameters according to the target functionality is required to ensure the correct operation of the objects and endure the external and internal mechanical forces. One of the forces involved in many practical applications, and little explored for 3D printed thermoplastics, is torsion [3]. Many products involving rotation require specifications for torque to design components according to the

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