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A novel approach to improve mechanical properties of parts fabricated by fused deposition modeling

Jianlei Wang [a,c], Hongmei Xie [a], Zixiang Weng [a,c], T. Senthil [a], Lixin Wu [a,b,*]

[a] Key Laboratory of design and assembly of functional nanostructures, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou 350002, China
[b] Fujian Provincial Key Laboratory of Nanomaterials, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou 350002, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

The mechanical properties of fabricated parts by fused deposition modeling (FDM) are impaired by significant voids between deposition lines. In this study, a novel approach that adding thermally expandable microspheres into matrix and combining FDM process with thermal treatment was proposed to tackle the problem. The influences of microsphere content, heating temperature and heating time were investigated. The results show that appropriate conditions of thermal treatment exert a positive influence on mechanical properties. With the addition of 2 wt.% microspheres, tensile and compressive strength of samples heated at 140 °C for 120 s increase 25.4% and 52.2%, compared to untreated samples, respectively. A new process is developed to prepare foam materials based on FDM, which will have the potential applications in shoes industry.

1. Introduction

Additive manufacturing (AM) has captured the world's horizon since Charles Hull firstly invented the new manufacturing technique called stereo lithography (SLA) in 1984. As the computer processing technologies make breakthroughs, AM is developing at an amazing pace in the speed and accuracy of printing, the type and property of material and manufacturing cost [1]. Fused deposition modeling (FDM) invented and developed by Stratasys Inc. in the early 1990s is the most widely used technique among all AM technologies, showing high potentials for fabricating plastic parts with the capacity to compete with conventional processing techniques [2,3]. The range of applications of FDM is extensive, ranging from medical treatment [4,5], mould design [6] to automotive [7] and aeronautics [8].

In the FDM process, the thermoplastic filament as feedstock is fed into heating chamber by a stepping motor and extruded through the nozzle in a prescribed manner upon its melting temperature, then solidified and deposited on the platform on a layer by layer basis [9,10]. Although the deposition lines can be integrated into adjacent deposition lines a bit by its own gravity and the force of stepping motor, there exist significant voids between deposition lines, which impairs the mechanical properties of fabricated parts to a great degree. Also the extruded material cools quickly from melting temperature to chamber temperature, resulting in development of inner stresses responsible for weak bond between two deposition lines, which leads to inter- and intra-layer deformation in the form of cracking, delamination or even part fabrication failure [11].

In recent years, researchers mainly worked towards two directions and tried to improve the mechanical properties of fabricated parts. Some researchers investigated the nature of FDM and the effects of process parameters and algorithm. Sun. et al. [12] experimentally demonstrated that bond quality between adjacent filaments depended on envelope temperature and variations in the convective conditions within the building part. Qiu and Langrana [13] studied the toolpath effects in FDM and proposed an algorithm to match the toolpath with the extrusion speed to eliminate voids and to correct overfill and underfill defects. Zhang and Chou [14] conducted a parametric study of part distortions in FDM using 3D FEA. The simulation results showed that the scan speed was the most significant factor to part distortions followed by the layer thickness. Furthermore, they reported that residual stresses increased with layer thickness and deposition line's width to a less extent. Antreas Kantaros and Dimitris Karalekas [15] investigated the effects of layer thickness and deposition orientation on the residual strains at the end of the fabrication process recorded by an optical sensor with a short fiber Bragg grating (FBG) embedded at the midplane of FDM built samples.

Meanwhile, other researchers studied the problem from the aspect of materials, adding fibers or particles into thermoplastic matrix to improve mechanical strength and modulus. Gray IV et al. [16] added

* Corresponding author at: Key Laboratory of design and assembly of functional nanostructures, Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou 350002, China.
E-mail address: lxwu@fjirsm.ac.cn (L. Wu).

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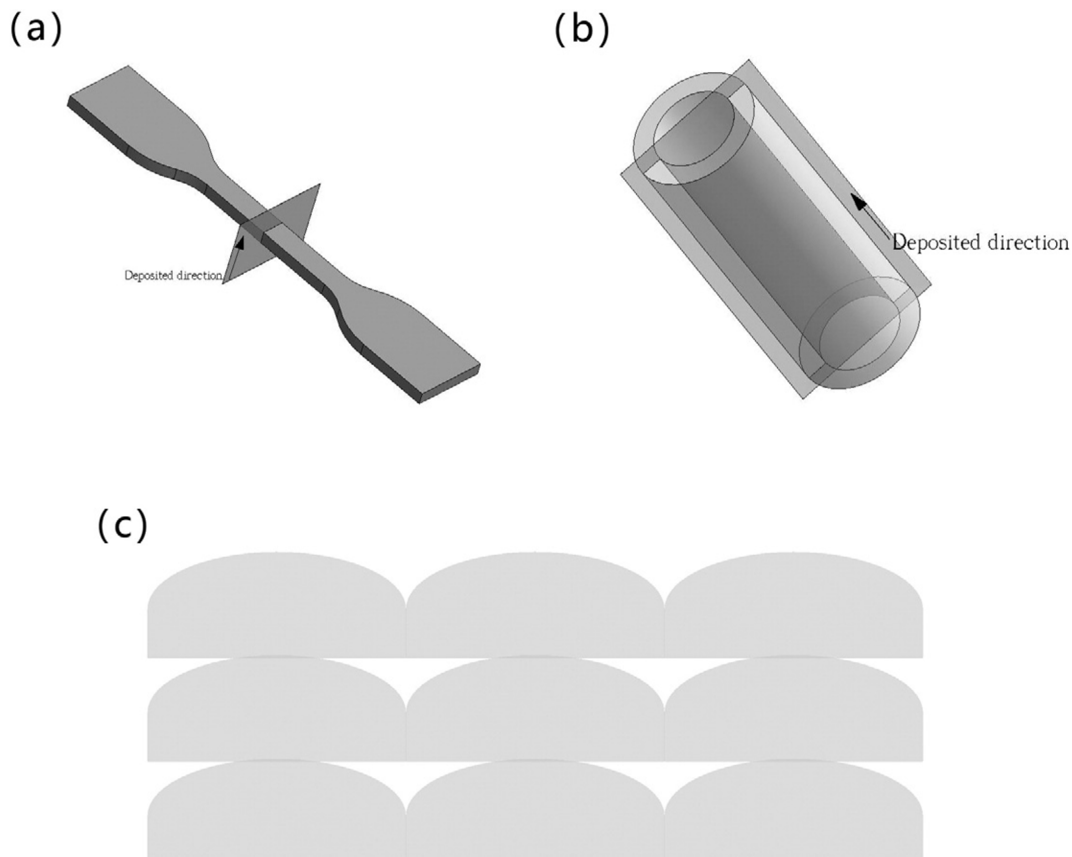

Fig. 1. Types of specimens printed by FDM: (a) tensile; (b) compressive; (c) section topography of black rectangle plane in (a) and (b).

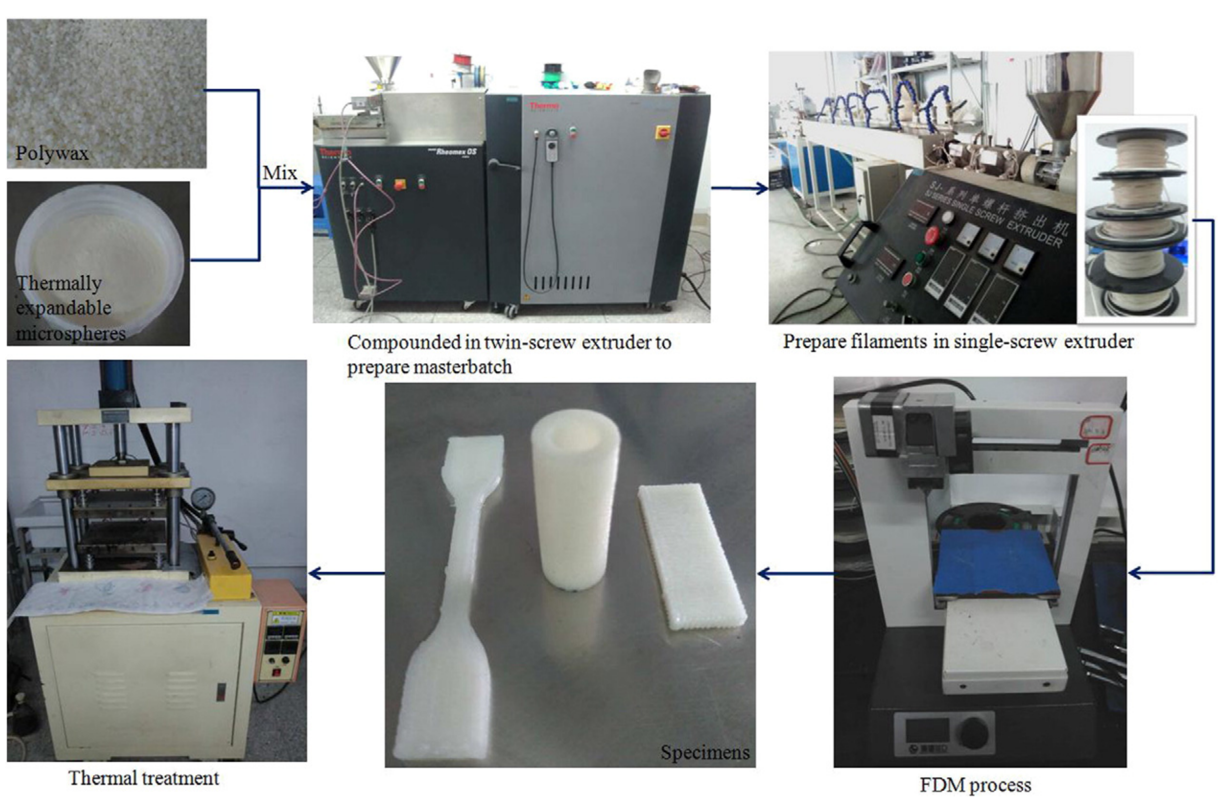

Fig. 2. The process flow chart of fabrication of specimens.