Effects of Infill Pattern on the Tensile Properties of 3D Printed Dog-Bone Coupon Specimens

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Abstract— Fused deposition modeling (FDM) is an additive manufacturing (AM) process in which meltable materials are fed into a print core, then melted and extruded on a printing plate. The infill pattern via AM has, no doubt, an impact on the mechanical properties of printed specimens, but the studies on this topic are limited. This study was aimed to examine the effects of infill patterns on the tensile properties of 3D printed dog-bone coupon specimens made using a desktop FDM 3D printer. Tensile specimens were designed using AutoCAD and SketchUp and made using an Ultimaker 3D printer. Five infill patterns set to 'lines' with different line direction angles (namely 0°, 30°, 45°, 60°, and 90°) and one infill pattern set to 'grid' were employed to print the specimens using polylactic acid (PLA) filament. In addition, one 'line' pattern from the above five was selected to make a group of specimens using wood-based PLA filament as the control. Tensile tests were conducted to measure the ultimate tensile strength (UTS) and modulus of elasticity (MOE) of the printed specimens. It was found that tensile properties increased with an increase in the line direction angle, with the maximum UTS and MOE appearing in the line pattern with a 90° infill line direction. It was also discovered that the wood-based PLA filament had a UTS of 11.66 MPa and an MOE of 330 MPa, which were 25.8% and 25.2% lower than those made of pure PLA filament using the 90-degree lines pattern.

Keywords—3D printing, infill pattern, polylactic acid (PLA), wood-based PLA, ultimate tensile strength, modulus of elasticity.

I. INTRODUCTION

Traditional subtractive manufacturing (SM) has been used for thousands of years; however, this method has its own limitations in terms of making complicated objects and its large consumption of good quality materials. As a complement to the entire manufacturing process, additive manufacturing (AM), which is commonly known as three-dimensional (3D) printing, was first commercially introduced in 1984 by Charles Hull [1]. Contrary to traditional SM that cuts away materials, AM makes products by adding materials layer by layer [2]. Fused deposition modeling (FDM) is one of the commonly used AM processes in which meltable materials are fed into a print core, that melts and extrudes onto a printing plate [3].

Desktop FDM 3D printers typically use acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) thermoplastic filaments [4]. Li et al. [5] pointed out that the properties of fabricated FDM parts could be controlled by changing deposition density and orientations. Meanwhile, Samykano et al. [6] attempted to study the influence of layer height, raster angle, and infill density on printed specimens using ABS material by also indicating that 0.5mm layer thickness, 55° raster angle, and 80% infill percentage gave the maximum mechanical properties. Masood et al. [7] found that the tensile strength of FDM printed polycarbonate (PC) specimens was 70% to 75% among those that were moulded and extruded, and also discovered that the FDM printing process had an influence on tensile properties. Similarly, Lanzotti et al. [8] pointed out that layer thickness, infill rate, printing orientations, and infill patterns could change the tensile properties. This technical note was aimed to examine how infill pattern and infill direction impact the tensile properties of dog-bone coupon specimens printed using PLA and woodfill PLA.

II. MATERIALS AND METHODS

Dog-bone coupon specimens were printed using an Ultimaker S5 desktop 3D printer with 2.85mm diameter PLA filament (Manufacturer: Ultimaker) and wood-based PLA filament (Manufacturer: Formfura), which were directly purchased from the market.

The geometric shape and dimensions of the 3D printed dog-bone coupon specimens were adopted according to ISO 527-2-2012 "Determination of tensile properties Part 2: Test conditions for molding and extrusion plastics" [9], Fig.1.

Fig.1. Shape and dimensions of a specimen

Firstly, the specimen was designed using AutoCAD [10], Version Q.104.0.0. Then, a stereolithography (STL) file was generated using SketchUp Pro [11], Version 20.0.373. Finally, slicing work was done using the software Cura, Version 4.4.0, provided by Ultimaker [12]. The specimens were extruded by a 0.4-mm-diameter AA printing core at a printing speed of 60 mm/s and a height layer of 0.2-mm, producing a wall thickness of 0.8mm and an infill density of 50%. Six (6) groups of specimens, composed of two (2) infill patterns and five (5) infill line directions, were used to print the specimens using PLA, including a grid set at a 0° line, and lines set at 0°, 30°, 45°, 60°, and 90°. As a control group, the wood-filled PLA specimens was printed following the lines pattern set at an infill line direction of 90°. Thus, seven (7) groups of specimens were made and each group had 10 specimens, producing a total of 70 specimens.

Each specimen was weighed prior to testing and the thickness and width of each specimen were measured at the centre using a caliper. A mechanical testing machine (Model: Instron 3367) was employed to conduct the tensile tests. The specimen was mounted between two grips, meanwhile an Instron's 25-mm strain gauge (CAT. No. 2630-032) was mounted on the middle part of the specimen, Fig. 2. The loading speed used was 5 mm/min, while the elapsed time, crosshead movement, strain, and load were logged at a rate of 4 Hz.

Fig.2 Tensile test setup

III. RESULTS AND DISCUSSION

The mean UTS and MOE of each group are provided in Fig.3 and Fig.4. The group of line pattern set at 90° had the highest average UTS (41.38 MPa) and MOE (1310 MPa), at about 60% and 25% higher than those of the group of line pattern set at 0°, respectively. The group made of wood-based PLA with the line pattern of 90° had the lowest average UTS (11.66 MPa) and MOE (330 MPa), around 25% as large as those printed using PLA following the same infill pattern. Overall, the tensile properties of the specimens printed using the line pattern increased with increasing line direction from 0° to 90°. Meanwhile, an MOE exception was apparent for the group of line pattern with a line direction set at 0°, however the reason was not clear and requires further investigation. The group printed using the grid pattern of a 0° line direction had similar average UTS and MOE to the printed group of line pattern set at a 45° line direction.

Fig.3 Average UTS value of each group

Fig.4 Average MOE value of each group

IV. CONCLUDING REMARKS

Overall, the infill pattern (i.e. line and grid) had a strong impact on the tensile properties. The highest MOE and UTS appeared in the specimens printed with the line pattern set at a line direction of 90°. Within the same line pattern, MOE and UTS increased with an increase in the line direction angle. The specimens made of wood-based PLA filament exhibited the lowest MOE and UTS among the groups tested, suggesting a need to improve wood-based PLA filaments.

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