Mechanical Properties of 3D Printed PLA Specimens with Various Infill Shapes and Volumes

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ABSTRACT

Traditional manufacturing methods contain removing excess materials by trimming, cutting and sanding to get the projected shapes; however, additive manufacturing contain direct manufacturing of the objects utilizing computer assisted design model by adding a layer of material at a time. During the design of 3D printed functional objects, most important issue is to provide strength and durability of the final products. Main focus of 3D printing process includes materials selection, overall design (size, complexity, pore volume and shape), and printing orientation. Slicing software can be used to arrange patterns within a desired solid percentage for the printing process. Designed pattern and percent rate are two main factors for infill specimens which affect the material usage, print time, strength, weight, as well as decorative properties. Polylactic acid (PLA) is a biodegradable and bioactive thermoplastic that is obtained from renewable resources, such as cassava roots, corn starch, sugarcane, and so on. The present study reports different infill shapes of PLA specimens with various volume contents to analyze the effects of the infill shapes and volume on the tensile and compression properties of the biodegradable materials. Based on the mechanical test results, infill shapes and volume percentages significantly changed the mechanical properties of the 3D printed parts. This study also highlights that material properties can be increased using the different infill shapes and volume percentages in 3D printing process for different industrial applications.

Keywords: Infill Structures, 3D Printing, PLA Specimen, Mechanical Properties.

1. INTRODUCTION

The correlated problems during design of a component involves selection of a material, specifications and the manufacturing process. If the selection of materials and processes are accurate, the design has enormous benefits for the final products, such as lower cost, reduction in production time and service life of the product increases. 3D printing (also known as additive manufacturing or rapid prototyping) have been developed to maximize profit towards large scale manufacturing for inexpensive plastic products [2]. 3D printers are feasible and used currently to print complicated shapes with structural integrity and less usage of materials and energies. The main research objective is to understand the fused deposition modeling of 3D printing technique, various infill shapes and volumes and testing them according to the standards. The tensile and compression test results are used to calculate material properties such as modulus of elasticity, yield strength, ultimate strength, elongation and strain energy for the samples to verify accuracy. Selection of materials is extremely important in any design project. Metals, resins, nylon, metals, ceramics, paper and biomaterials can be used in 3D printing applications, among which the most common materials used are polymers [2].

3D printing shows that thermoplastics can be utilized as they become soft when heated instead of thermosets [3]. In the fused filament fabrication (FFF) 3D printing technique, thermoplastic in filament forms is fed through the heated extruder nozzle to make the part soft and pliable. After heat is removed, the material is hardened into final desired shapes [3].

Polylactic acid (PLA) and acrylonitrile-butadiene-styrene (ABS) are the most commonly used polymeric materials in 3D printing techniques because of their higher strength and lower emission and availability in the market. Some of the common sources to get PLA are cornstarch, tapioca root and sugarcane [4]. Temperatures are very important in 3D printing; the melting point of PLA is between 50-60 °C. When it is left to break down, it reverts to lactic acid. It is widely accepted as the greenest material with various colors for 3D printing. Figure 1 shows the schematic overview of the fused FFF process used in many industrial applications [5,6].

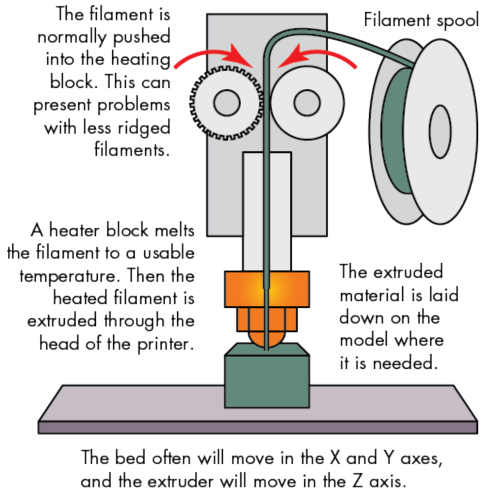

Figure 1: Schematic overview of the fused filament fabrication (FFF) process [5,6].

The 3D printing parameters are divided into 3 categories; those associated with filament, printer, and the print itself. The selection for printing equipment and material availability, filament setting and print settings are determined based on the requirements and needs. The main focus is to print setting category as it contains all 3D printed model parameters. Layer height and speed of the nozzle are also the major parameters in layer-by-layer printing process [1-5]. Figure 2 shows the schematic view of the deposition step of the 3D fused FFF process [5,6].

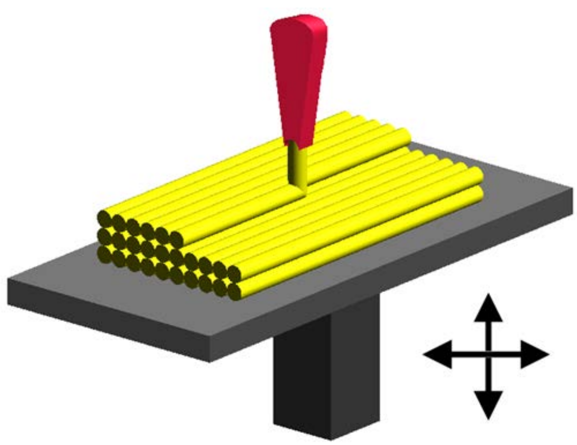

Figure 2: Schematic view of the deposition step of the 3D fused FFF process [5].

In the printing process, perimeters and infills are two main parts. The boundary or shell of the part is defined by perimeter as it serves the purpose of holding the parts together and can be thick or thin depending on the user. Infill is added to interior of the part inside of the perimeters, as it gives more structural resilience to the parts. While selecting infill several considerations are taken into account, such as strength, time and material, infill represents usually in percentages. Geometry and percentage are the main options in selecting an infill. The orientation of infill pattern with respect to each layers differs geometrically to give parts more isotropic structures [5-8].

2 MECHANICAL PROPERTIES OF 3D PRINTS

The first step in experimental is to design the part/specimen in CAD program. Slicing program is used to split into desired number of layers for the 3D part. The program helps the user specify the layers height, print speed, extrusion width and various infill parameters. In order to control extruder nozzle temperature, printer interface program is selected, which communicates well with the code to printer and provides monitoring data. Design of the specimen also depends on thickness and dimensions to be used.

Filament feeding is the actual printing process. Feeding the filament by heating the extruder/hot end, filament is extruded. Geometrical shapes were printed for testing multiple parts that can be arranged on the same bed using 3D printing software, so manufacturing time is reduced. In the printing process, ambient room temperature and filament quality are usually limited.

A visual inspection is done on each specimen for filament delimitation issues or any other flaws in the structure. 'Layer Shift' is the defect in many shapes of the printed samples, so is discarded in 3D printing process. To measure the dimensions digital calipers were used and the results are quantified. Deviation values and average values are noted as per each measurement per infill configuration is calculated.

Series of calculations were performed to compare the geometrical configurations of infills. Excel is used based on load tension data obtained by the TestWorks Software. The behavior of material is predicted and the properties of deformation of the specimen can be noted. In terms of the individual filament 50% of the internal fibers are oriented in the direction of the axis of the applied load. Consistent perimeter width was used for rectangular infill and the performance of the internal shape (infill) of each sample can be accurately isolated. For the result comparison, tensile properties of various infill shapes are compared. As is seen in Figure 3, average tensile strength of hexagon and rectangular specimens are higher than solid and diamond shapes.

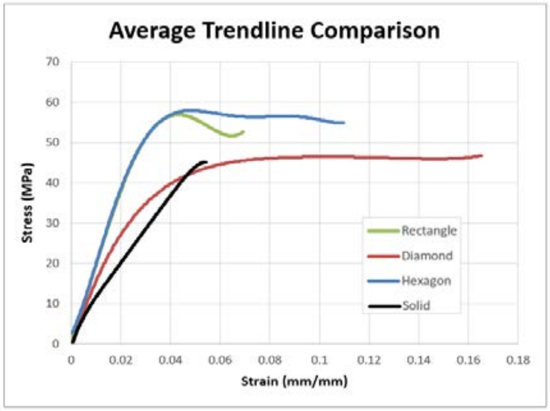

Figure 3. Stress vs. strain diagram exhibiting average tensile trendline for each infill configuration.

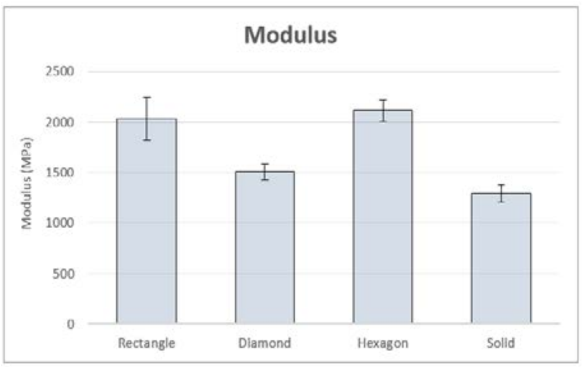

Figure 4. Calculated tensile modulus values for four different infill shapes.

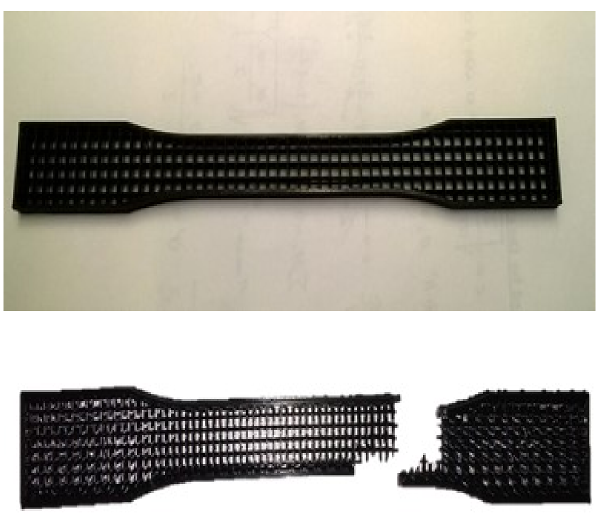

Figure 5: Images shoeing the 3D printed parts a) before and b) after tensile testing.

Considering the modulus of elasticity, the hexagon and rectangular infilled specimen provide the higher mechanical strength values. Figure 4 shows the calculated modulus values for four different infill shapes. Especially, the hexagon infill shape showed the highest value which is about 64% greater than that of the solid specimen. Figure 5 also shows the images of the 3D printed parts before and after tensile testing.

Compression tests were also conducted on the 3D printed specimens of different shapes (e.g., diamond, triangle, hexagonal and square) with 20, 40, 60 and 80% infill rates [7]. The test studies indicated that the yield strengths of the samples were changed significantly depending on the volume of shapes and amount of the infills. The 100% infill rates (solid samples) revealed the highest compression yield strength (59.78MPa), whereas the 80% infill shapes provide the next highest yield strength. The yield strength values of the 3D specimens were similar for 60 and 40% infill rates. However, the 3D printed parts with the 20% infill rate delivered the lowest mechanical properties. The primary reasons of the low yield strength may be attributed to the lack of supporting materials, internal and external cracks, defects and voids in the structure [7].

A number of tests were also conducted on the same 3D printed parts to determine the elastic modulus of the 3D printed specimens for triangle, diamond, hexagonal and square with 20, 40. 60 and 80% infill rates. The test results for the elastic modulus among the infill rates confirms almost the same patterns with the compression yield strengths. The only difference is that there is drastic reductions started from 100% through 80, 60, 40 and 20% infill ratios, correspondingly. Even though the elastic modulus distribution on different shapes (e.g., diamond, hexagonal, square and triangle) are quite negligible, triangle shape with the 80% infill rate provides the highest (˜1516 MPa) value [7].

3D printing processes have been gaining much attention in the world due to their abilities, handlabilities and ease of operation for various complex geometries and industrial applications. The 3D printed parts can be used in several industries, such as energy, automotive, space, aircraft, defense, electronics, construction, medical food, and pharmaceutical. Infill shapes and volume contents are important points of considerations for the mechanical properties of 3D printed parts in different applications.

4. CONCLUSIONS

The tensile and compression studies conducted on the 3D printed specimens showed that the major factors affecting the mechanical properties of the specimens were the shapes of infills (e.g., diamond, triangle, hexagonal and square) and volume ratios (20 to 100%). The tensile and compression test results showed that the high infill shapes provide better mechanical properties compared to the other options. The present studies may open up new opportunities for various industrial applications of 3D printed infill shapes.

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