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# Strength and porosity of additively manufactured PLA using a low cost 3D printing

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**ABSTRACT** – Nowadays, with rapid advancement in 3D printing, a relatively low cost 3D for polymer based printers using an open-source self-replicating prototype has increasingly been used in many applications. The printer variants can fabricate any complex parts. In this study, the tensile strength and porosity of PLA and its utilization in 3D printing for standard usage of low cost 3D printers using open-source has been investigated. It was found that, the parts printed from a low cost 3D printer produce relatively acceptable tensile strength and porosity as those from mid-range commercial manufacturer.

## 1. INTRODUCTION

Three dimension (3D) printing or also can referred as additive manufacturing (AM) process is the method of creating three-dimension rigid item from a digital data. This process of making of product is accomplished by layering down layer by layer of material until the complete product is created. The working principle of the 3D printer starts by creating the object desired to be printed with Computer Aided Design (CAD) for a new object or 3D scanner to make digital copy of an existing 3D object [1]. The materials being utilized for 3D printing possess long history of usage since the early decades of technological revolution [2]. There are many different types of materials that can be used in 3D printing. One of commonly used materials is polylactic acid (PLA) due to its competitive price and more environmental friendly. With the rapid development of low cost 3D printer, it is necessary to study the mechanical properties of these printer. The mechanical properties of 3D printed product is very much influenced by the porosity and mechanical structure during layer formation [3]. This study concentrates on strength and porosity of a low cost 3D printed material by using PLA material. In this study, the relationship between layer height, porosity and tensile strength are studied and presented.

## 2. METHODOLOGY

In order to determine the mechanical properties of 3D printed materials at different setting, the parameter

during the 3D printing and slicing are varied. In this study, samples with the layer height from 0.1mm to 0.4mm was produced and their tensile strength and porosity are determined. Table 1 shows the printing parameters being utilized in this investigation. Tensile test specimen (as shown in Fig. 1) which is based on the ASTM: D638 [4] were produced. During fabrication, CAD data was prepared in which later Slic3r and Cura software were used for slicing the STL files and converting it to machine readable G-code respectively. All specimens were printed solid with a setting of 100% infill; the actual positive or negative air gaps vary among printers due to printer differences. This affects the part as air gap has been shown to be an important contributing factor to tensile strength [5]. Testing was performed on Instron machine. The machine was controlled by the Bluehill Software. Stress, strain, and modulus calculations were performed. Moreover, the porosity of PLA at different layer height was determined using Archimedes principles and observed using optical microscope (Zeiss Axiovert 200 Matt).

Table 1 RepRap 3-D printer slicing variables.

Pattern orientation (°)	90
Layer height (mm)	0.1, 0.2, 0.3, 0.4
Infill (%)	100
Printer type	Kossel RepRap

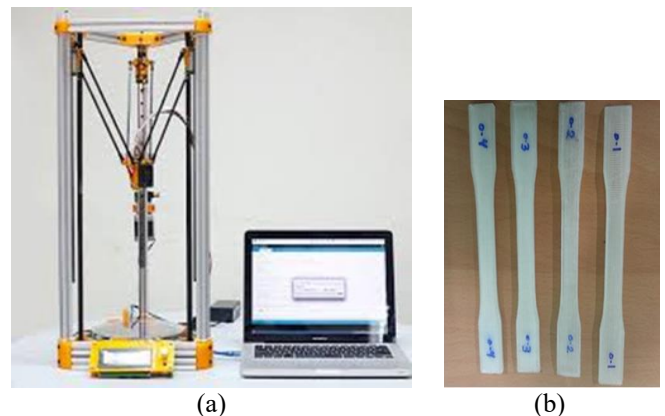


Figure 1 (a) Kossel mini printer and (b) printed PLA specimen according to ASTM: D638.

### 3. RESULTS AND DISCUSSION

The average values of tensile strength were obtained at different values of layer height. Based on the tabulated results in Table 2 and Figure 2, it is shown that, the greatest tensile strength of PLA is 45.56 MPa were recorded at 0.2mm layer height, while the lowest tensile strength is 32.01 MPa at 0.4 mm layer height. The results indicate that a low cost 3D printer has a comparable tensile strength to mid-range commercial 3D printer which is at 46.77 MPa based on the manufacturer data [6].

Table 2 Average tensile strength and average elastic modulus at 90 ° orientation.

Layer height (mm)	Average tensile strength (MPa)	Average elastic modulus (MPa)
0.1	35.90	1005
0.2	45.56	1125
0.3	45.04	1090
0.4	32.01	725

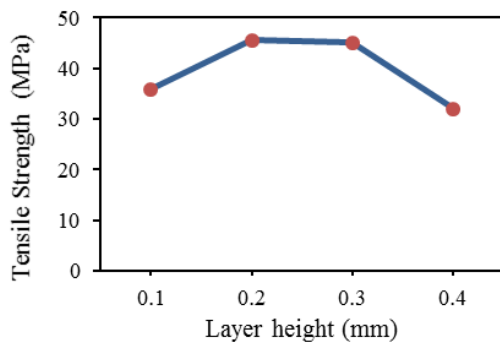


Figure 2 Effect of layer height on the tensile strength of PLA.

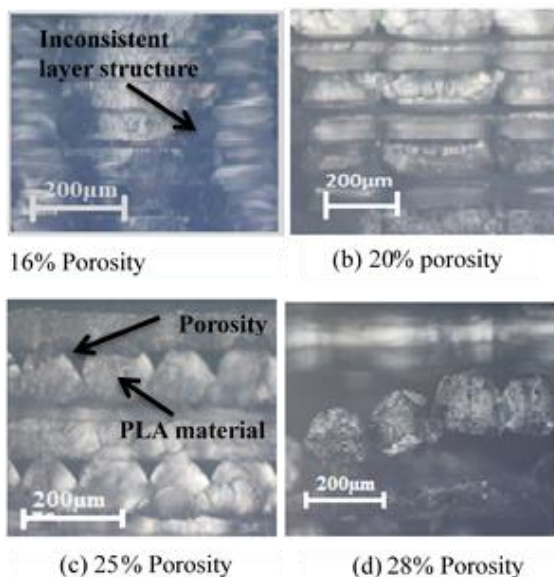


Figure 3 Layer structure and porosity at various layer height, (a) 0.1mm layer height, (b) 0.2 mm layer height, (c) 0.3 mm layer height, (d) 0.4 mm layer height.

The obtained results of porosity testing are shown in Figure 3. The results show the porosity percent increases as the layer height increases. The porosity was

the highest percent at 28% when the layer height was set at 0.4 mm. This explain why the tensile was the lowest at 32.01 MPa. The lowest porosity percentage was found at 16% when it is at 0.1 mm height layer. Whereas, the percentage of porosity at 0.2 and 0.3 mm layer height are 20% and 25% respectively. The porosity of PLA is the lowest at 0.1 mm layer height but the tensile strength was a bit lower compared to when the layer height was 0.2 mm. This is because of the disorganized and inconsistent layer structure formed at a very low layer height. During layer formation and nozzle movement, the material deposited on the top layer may cause damage to the previous layer due to very small clearance between the layers. Furthermore, material that is extruded through the nozzle is not consistent at low layer height. As a result, inconsistent layer structure as shown in Figure 3 (a) was produced.

### 4. SUMMARY

The study shows relationship between the strength and porosity of PLA material in 3D printing through standard tensile tests. The results show that the highest average tensile strength of the printed parts is 45.56 MPa at 0.2 mm height layer for PLA. Porosity of PLA increases with the increase of layer height. Lowest percent of 16% at 0.1 mm layer height and highest percent porosity of 28% at 0.4 mm layer height. The study also demonstrated, at the setting parameter that was used in the study, only a slight drop in the value of tensile strength between the 3D printers. Hence, a relatively comparable strength to mid-range commercial printer can be obtained by a low cost 3D printer using an open source system.

### ACKNOWLEDGEMENT

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