Effect of 3D-printing parameters on the tensile strength of acrylonitrile butadiene styrene (ABS) polymer

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Abstract. In this research, the tensile strength behaviour of 3D-printed ABS polymer was studied. In particular, the following printing parameters were investigated i.e. angle orientation of 0°, 30° and 45°, layer thickness of 0.2 mm, 0.3 mm and 0.4 mm, and printing speeds of 60 mm/s, 40 mm/s and 20 mm/s. The samples were subjected to tensile loading in order to determine the stress-strain curve, UTS and the elastic modulus. The results indicated that the speed has no major impact on the strength of the 3D-printed samples. On the other hand, the 0.4 mm layer thickness gave the highest stiffness, whereas the angle orientation of 45° gave the highest tensile strength. However, the combination of 3D parameters that resulted in the overall best results was determined as 0.4 mm layer thickness with an angle orientation of 30°.

Keywords: tensile test, ABS polymer, 3D printing

1. Introduction

Over the years, the manufacturing industries have revolutionised their process capabilities to be more efficient and cost-effective including the use of IoT and 3D-printing [1-3]. In particular, 3D-printing which is also known as additive manufacturing, is a rapid-prototyping technique used to produce geometrical shape items by simply depositing thin layers of materials over and over again until the intended geometry is formed. This near-net shaping process which is widely used to produce any polymer product including very thin sections, requires data obtained from computer aided design (CAD) based 3D model or a computed tomography scanner [4, 5].

The main advantages of 3D-printing technologies are that it can produce complex shaped product precisely, and within shorter span of time if compared to the traditional manufacturing processes which requires considerable amount of time and effort to produce a good and decent quality product [6]. Another advantage of 3D printed product is that it produces less waste material, so they will cause less harm to the environment and the ecology [7].

A variety of different materials have been used for 3D-printing including that of ceramics, gypsum, metals and concrete, however the most recommended materials are polymers such as polyamide, acrylonitrile butadiene styrene (ABS), polylactic acid (PLA) and polyvinyl alcohol (PVA) [3, 8]. Among these materials, PLA and ABS have been widely used for 3D-printing to produce various products because of their excellent thermal, mechanical and biodegradable properties [9, 10]. However,
it has been reported that the printing parameters can have an influence on the properties of the printed polymers [11]. In this study, the effect of selected 3D printing parameters on the tensile strength behaviour of ABS have been studied.

2. Methods and Materials
In this work, the design of the sample was done using the Autodesk Inventor Professional 2016 CAD software. The initial dimensions selected for the sample were based on previous work [12] and to suit the 3D printing machine model ‘UP Plus 2’. The final dimension of the dog bone shape ABS sample used in this study is as shown in Figure 1.

![Figure 1. Schematic diagram of the sample used in the present work. All dimensions shown are in mm.](image)

In a typical sample preparation procedure, the sample was sketched using a CAD software and subsequently exported as a stereolithography file (stl) into the available 3D printer software. The filament used to print the sample was a commercial acrylonitrile butadiene styrene (ABS) polymer. Samples were prepared by varying the printing parameters i.e. speed (20 mm/s, 40 mm/s and 60 mm/s), layer thickness (0.2, 0.3 and 0.4 mm) and angles of printing or the raster orientation (0°, 45° and 90°). A typical 3D printed ABS sample is as shown in Figure 2. A total of 54 samples were manufactured and the final dimensions of the printed samples were measured prior to tensile test.

The tensile test was conducted at room temperature based on ASTM D695 using a universal testing machine model Instron 5565. The strain of the samples was measured from a gauge length of 33 mm using an extensometer. The sample was loaded at a rate of 0.5 mm/min. and data were collected continuously by the system software to calculate the ultimate tensile strength, percentage elongation and modulus of elasticity.

![Figure 2. A typical 3D printed ABS tensile test sample used in the present work.](image)
3. Results and discussion
The stress-strain diagrams for the samples fabricated with different thickness as a function of raster orientation and printing speed are as shown in Figures 3, 4 and 5.

![Stress-strain curves for samples thickness of 0.2 mm as a function of raster orientation and printing speed.](image)

**Figure 3.** Stress-strain curves for samples thickness of 0.2 mm as a function of raster orientation and printing speed.

Figure 3 shows that for sample of thickness 0.2 mm, the strain of the sample reduced with the angle of orientation regardless of printing speed. It was also found that the UTS of the sample with orientation of 0° was not affected at printing speed of 60 mm/s and 40 mm/s (i.e. the value remained at about 18 MPa) but decreased to about 10 MPa when the printing speed reduced to 20 mm/s. Similarly, the stiffness of this sample also decreased as evident from the slope of the linear section of the curve. In contrast, the UTS of the samples having orientation of 30° and 45° remained almost unchanged at above 18 MPa regardless of printing speed. The results also showed that sample printed with a raster orientation of 30° exhibited the lowest strain value.
Figure 4. Stress-strain curves for samples thickness of 0.3 mm as a function of raster orientation and printing speed.

Comparison of the stress-strain graphs shown in Figure 4 for samples having 0.3 mm thickness indicated that regardless of the printing orientation and printing speed, the UTS did not change very much (18 – 19 MPa) between the samples. On the other hand, sample having orientation of 30° exhibited the lowest strain before fracture for all printing speed as observed for the 0.2 mm thickness samples. It was also revealed that the sample printed at an orientation of 45° exhibited the highest strain value for speeds of 60 mm/s and 40 mm/s, while sample of orientation 0° had the highest value when printed at 20 mm/s.
Figure 5. Stress-strain curves for samples thickness of 0.4 mm as a function of raster orientation and printing speed.

For 0.4 mm layer thickness, the stress-strain graphs shown in Figure 5, exhibited a wider range of UTS data for different speeds and orientation angles. A different behaviour could be seen in these graphs if compared to that observed for the lower thickness samples shown in Figures 3 and 4. Nevertheless, the 30° printing orientation samples exhibited the highest UTS (above 20 MPa) when compared to the lower thickness samples. For different printing speeds, there were minor differences that could be observed in Figure 4. Therefore, it is assumed that the speed of printing does not have any effect on the strength of the samples. As mentioned in the previous section, speed consumes the most time to complete printing of one specimen.

Typical view of the fracture morphology of the samples as shown in Figure 6 indicated that a brittle type fracture was inevitable for all samples regardless of sample thickness, printing orientation and speed.
Figure 6. Typical brittle fracture of the 3D printed samples of thickness 0.4 mm and printing speed of 60 mm/s. (a) 0° orientation, (b) 30° orientation and (c) 45° orientation.

4. Conclusions
In the present work, the effects of 3D printing parameters on the tensile behaviour of ABS were investigated. The results showed that the UTS of the printed ABS was affected by the layer thickness and the printing or raster orientation. Within the boundary set for this study, the findings indicated that the layer thickness of 0.4 mm and at a raster orientation of 30° resulted in the overall best tensile properties. It was also found that the speed of printing did not have a major influence on the tensile behaviour of the ABS polymer.

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