# ANALYSIS ON STRESS-STRAIN PERFORMANCE OF ABS/PLA MATERIAL USED IN GEOSPATIAL SOLUTION

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**ABSTRACT:** This paper presents tensile testing measurement on two type FDM filament material which are ABS and PLA. Tensile testing was conducted according to ASTM D638 by using Universal testing Machine for testing both material under tensile loading in order to determine the material properties. Based on the result, both of the material behavior shows the material break of fail after yield occur. The PLA material has higher value of tensile strength, yield strength and modulus of elasticity compare to ABS Material. The performance show by PLA material is greater than ABS material because the tendency of PLA material to exert amount of force before failure is higher, the ability to resist plastic deformation is higher due to high yield strength and has high stiffness due to high value of modulus elasticity.

**KEYWORDS**: *Tensile Testing; FDM; 3D printing; ABS; PLA*

## 1.0 INTRODUCTION

Tensile test is the measurement of strain and stress of material due to tensile loading. It is also known as tension test and can be considered as the most basic type of mechanical test on material. Tensile test are simple, relatively inexpensive and fully standardize. The concept of this testing is by pulling the testing material in order to determine the reaction behaviour of the material when the forces are being applied. When the material is being pulled, it reveals the strength and elongation properties.

Commonly, FDM 3D printing uses two types of material, namely Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA), which are available in filament form. It involves the extruding method to produce 3D printing part according to the STL files that contain 3D part data. In this experiment, the investigation of stress-strain performance of FDM material is based on the theory of material tensile properties.

The objective of this study is to investigate the mechanical effect on preliminary 3D printed geospatial product of FDM material. It focuses on tensile test by using Universal Testing Machine in compliance to ASTM D638 standards

## 2.0 RESEARCH METHODOLOGY

### 2.1 Samples Preparation

The samples for tensile test were fabricated by using two types of 3D printer, which are printer 1 and printer 2. Printer 1 fabricated samples by using ABS material and printer 2 fabricated samples using PLA material. The printers had similar parameter set up as for printing geospatial product. Table 1 shows the printing parameters to print testing specimens, which are similar as printing geospatial product by using ABS and PLA materials. The parameters to print geospatial product were estimated to be the maximum specifications for both 3D printers.

Table 1: Printing Parameters

| Parameter \ Printer | Printer 1 | Printer 2 |
|---|---|---|
| Material | ABS | PLA |
| Nozzle diameter | 0.2mm | 0.2mm |
| Nozzle temperature | 260-270 | 200 |
| Temperature of Bed | 50 degree celcius | 70 degree celcius |
| Infill | Solid-100% | Solid-100% |
| Infill type(Print Orientation) | Rectilinear | Rectilinear |
| Print speed | 40-60 mm/s(normal) | 80mm/s |
| Layer thickness | 0.2mm | 0.2mm |
| Build Orientation | Horizontal | Horizontal |

The specimen size for the testing was called "dumbell" and prepared according to the ASTM D638 standard for both materials. In previous studies, type IV specimen was used to study the tensile properties of FDM extruding material by considering the non-rigid plastic properties [1]. It is stated in ASTM standard as shown in Figure 1 and the dimension is shown in Table 2.

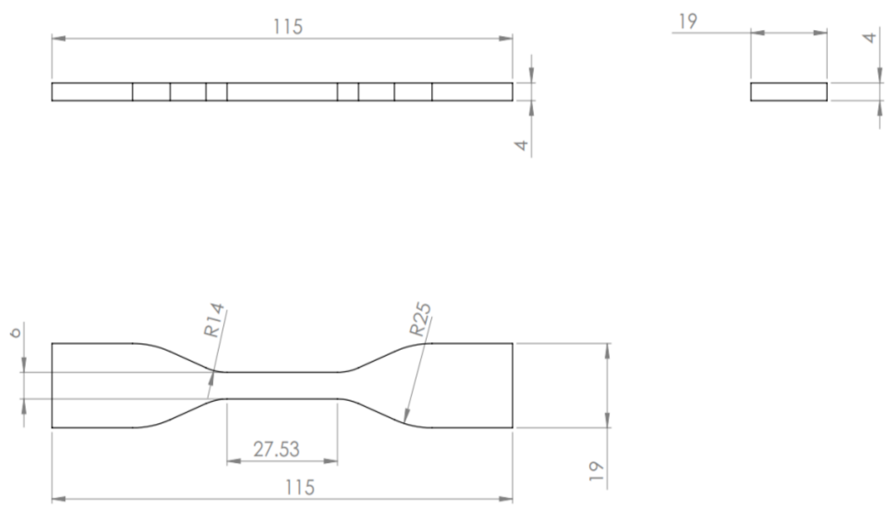


Figure 1: Specimen for Tensile Test ASTM D638 (Type IV)

Table 2: ASTM D638 type IV dimension for tensile test

| Dimension (mm) | | | |
|---|---|---|---|
| Length | Width | Thickness | Gauge length |
| 115 | 19 | 4 | 25 |

**2.2 Tensile Test**

Tensile test is the measurement of material strain and stress due to tensile loading. From the recorded data, the material properties can be determined. This test was conducted according to ASTM D638 [2] standard as a guideline. The concept of this testing is by pulling the testing material in order to determine the material behavior when the forces were applied.

For the purpose of this study, fifteen samples of each material were tested. The average and standard deviation values were used for analysis. For this study, Universal Testing Machine was used to test the tensile properties of the material. The testing speed of 5mm/min was used as according to ASTM D638 standard. The specimen was clamped at jaw as shown in Figure 2 and the test was run until the specimen broke or fractured.

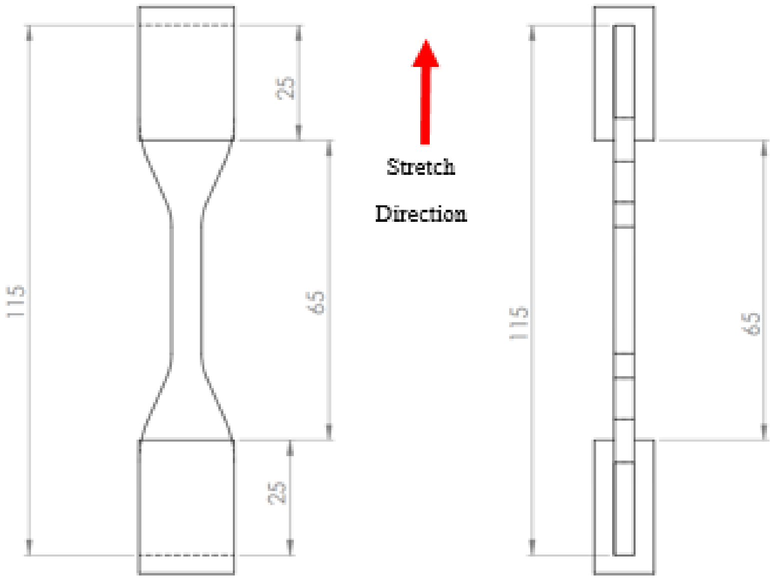


Figure 2: Schematic of the Tensile Test

## 3.0 RESULTS AND DISCUSSION

**3.1 Tensile Test Results**

The universal testing machine was used to test the material under tensile loading. Table 3 shows the values of material properties under tensile loading.

Table 3: Specimens Material Properties

| Material | No. Specimen | Max. Force (N) | Max. Stress (MPA) | Max. Strain (mm/ mm) | Modulus Elasticity (MPa) | Yield stress (MPA) | Stress failure (MPa) |
|---|---|---|---|---|---|---|---|
| ABS | 1 | 868.67 | 36.19 | 0.08 | 782.37 | 30.28 | 35.49 |
| | 2 | 820.52 | 34.19 | 0.08 | 738.37 | 30.00 | 31.92 |
| | 3 | 870.34 | 36.26 | 0.09 | 816.56 | 31.00 | 34.03 |
| | 4 | 856.91 | 35.70 | 0.08 | 737.29 | 33.5 | 33.11 |
| | 5 | 831.11 | 34.63 | 0.07 | 802.99 | 31.02 | 33.13 |
| | 6 | 847.98 | 35.33 | 0.08 | 785.6 | 30.76 | 33.23 |
| | 7 | 848.77 | 35.37 | 0.07 | 720.7 | 34.24 | 33.32 |
| | 8 | 848.77 | 35.37 | 0.07 | 720.7 | 33.6 | 33.32 |
| | 9 | 815.42 | 33.98 | 0.07 | 758.9 | 31.87 | 32.21 |
| | 10 | 857.79 | 35.74 | 0.08 | 808.85 | 32.00 | 34.01 |
| | 11 | 817.97 | 34.08 | 0.08 | 770.68 | 31.24 | 32.09 |
| | 12 | 806.79 | 33.62 | 0.07 | 777.0 | 31.50 | 31.14 |
| | 13 | 804.83 | 33.53 | 0.07 | 712.39 | 31.32 | 31.61 |
| | 14 | 825.82 | 34.41 | 0.08 | 766.48 | 32.17 | 30.94 |
| | 15 | 817.19 | 34.05 | 0.07 | 790.85 | 31.02 | 33.06 |
| | Average | 835.93 | 34.83 | 0.08 | 765.98 | 31.70 | 32.84 |
| | Std. Dev | 22.24 | 0.93 | 0.006 | 33.58 | 1.23 | 1.21 |
| PLA | 1 | 922.22 | 38.43 | 0.07 | 862.88 | 35.00 | 36.79 |
| | 2 | 904.57 | 37.69 | 0.08 | 869.60 | 33.00 | 35.91 |
| | 3 | 858.77 | 35.78 | 0.08 | 841.61 | 32.47 | 35.08 |
| | 4 | 902.7 | 37.61 | 0.07 | 881.68 | 34.13 | 37.19 |
| | 5 | 905.06 | 37.71 | 0.08 | 866.7 | 34.12 | 36.46 |
| | 6 | 876.03 | 36.50 | 0.07 | 880.96 | 33.00 | 35.39 |
| | 7 | 873.77 | 36.41 | 0.07 | 877.8 | 32.88 | 35.09 |
| | 8 | 914.77 | 38.12 | 0.09 | 868.2 | 34.00 | 37.11 |
| | 9 | 896.03 | 37.33 | 0.08 | 709.24 | 32.51 | 35.59 |
| | 10 | 853.87 | 35.58 | 0.07 | 804.75 | 33.17 | 35.15 |
| | 11 | 876.81 | 36.53 | 0.07 | 825.27 | 33.61 | 35.10 |
| | 12 | 880.64 | 36.69 | 0.09 | 869.81 | 33.1 | 34.67 |
| | 13 | 937.42 | 39.06 | 0.08 | 898.23 | 35.96 | 37.97 |
| | 14 | 939.58 | 39.15 | 0.08 | 899.9 | 35.12 | 37.07 |
| | 15 | 939.58 | 39.15 | 0.08 | 899.9 | 35.12 | 37.07 |
| | Average | 898.79 | 37.45 | 0.08 | 857.10 | 33.81 | 36.11 |
| | Std. Dev | 28.41 | 1.18 | 0.007 | 48.83 | 1.08 | 1.04 |

The stress-strain diagrams consist of stress-strain curve for fifteen specimens of ABS and PLA material are shown in Figure 3 and 4, respectively. Graphs for both materials show the same behavior or pattern. At the proportional limit of the strain stress curve, it shows the sigmoidal strain curve graph pattern. Then, the tensile stress begins to fall at certain elongation ratio and rises again until it reaches the fracture or failure [3]. Next, the stress of the material is increasing to yield at a single position, which then produces necking due to non-uniform distribution of strain along the gage length. At the neck position, the material requires greater stress to stretch and it propagates outward from the initial yield location. At the end of neck location, material is stretched to a strain position and the stress rises until it fails.

The average tensile strength and maximum strain for ABS material are 34.83MPa and 0.08 mm/mm, respectively. For modulus elasticity or Young's modulus, the average value for ABS material is 7765.98MPa and the average stress at material fracture is 32.84MPa. The stress-strain curve for ABS material is shown in Figure 3. The average tensile strength and maximum strain for PLA material are 37.45 MPa and 0.08mm/mm, repectively. For modulus elasticity or Young's modulus, the average value for PLA material is 857.10MPa and the material fails at average stress of 36.11MPa. The stress-strain curve for ABS material is shown in Figure 4.

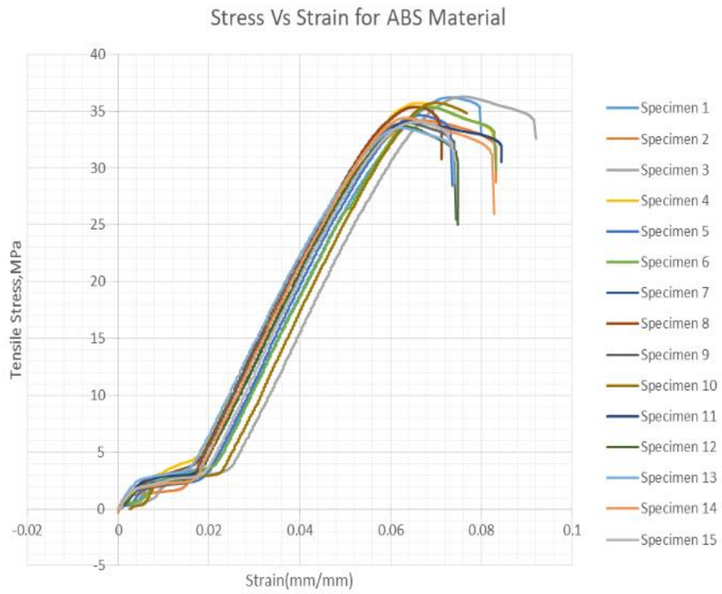


Figure 3: Tensile Stress versus Strain for Fifteen Specimens of ABS Material

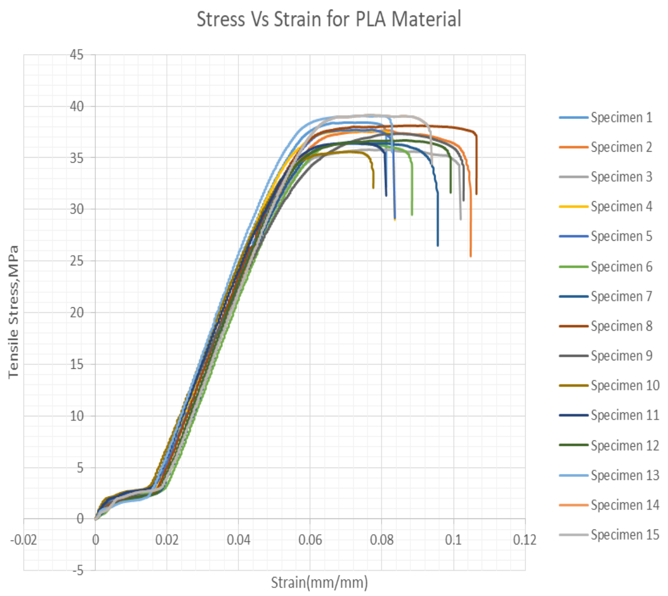


Figure 4: Tensile Stress versus Strain for Fifteen Specimens of PLA Material

### 3.2 Material Properties Comparison of ABS and PLA

By making comparison between the ABS and PLA tensile test results, properties correlation and relationship between these materials can be summarized. According to Figure 5, the average yield strength of PLA material is higher than ABS material yield strength with 33.81MPa and 31.02MPa respectively. The difference of percentage between PLA and ABS materials is 8.25%. It indicates that PLA material requires higher stress as compared to ABS material to achieve plastic deformation.

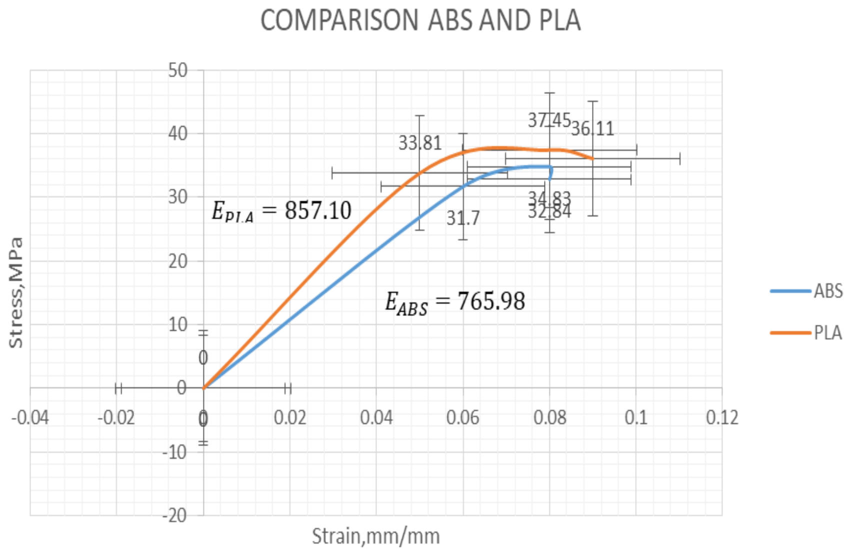


Figure 5: Comparison of Tensile Stress between ABS and PLA Material

In addition, the average tensile strength of PLA material is also higher than ABS material with 37.45MPa and 34.83MPa, respectively. The difference between average tensile strength of PLA material and ABS material is 7%. This means that the PLA material ability to sustain load without undue deformation or failure is higher than ABS material. For fracture strength, the result shows that PLA material has higher fracture strength than ABS material with 36.11MPa and 32.84MPa respectively. The fracture strength difference between PLA and ABS materials is 9.05%. The material fracture stress at necking strain of PLA material is also higher than ABS material.

For modulus elasticity or Young's modulus, the average modulus elasticity of ABS and PLA material is 857.10 MPa and 765.98 MPa respectively. By referring to Figure 5, the modulus of elasticity of PLA material is higher than ABS material by 13.45%. It can be illustrated by the steeper slope of curve in elastic deformation region of PLA as compared to ABS material. It also proves that PLA material resistance to elastic deformation under load is higher than ABS material. The modulus elasticity or Young's modulus relates to the stiffness of material. It is because, modulus of elasticity is directly proportional to the material stiffness. In this test, the results show that the stiffness of PLA material is greater than ABS material due to higher modulus of elasticity.

## 4.0 CONCLUSION

This study determined the material properties under tensile loading by conducting tensile test on the FDM 3D printing material. The Universal Testing Machine was used for the test and material properties such as tensile strength, yield strength, fracture stress and modulus elasticity were determined.

From the obtained results, performance of PLA material is greater than ABS material. PLA material showed better performance to withstand plastic deformation because it requires higher stress to pass through yield point for the transition from elastic to plastic deformation. This PLA material ability to sustain load without undue deformation or failure was also higher as compared to ABS material by 7%. It also possessed greater stiffness by examining the material modulus of elasticity and higher fracture stress. It can be concluded that, PLA material offers better material properties for geospatial model or product by having higher tensile strength, yield strength, modulus elasticity and fracture stress to withstand mechanical effect of tensile loading.

**REFERENCES**

[1] Burk, S., & Driscoll. (1998). The Basics of Testing Plastics: Mechanical Properties, Flame Exposure, and General Guidelines. West Conshohocken.

[2] ASTM D638-14, Standard Test Method for Tensile Properties of Plastics, ASTM International, West Conshohocken, PA, 2014, www.astm.org

[3] Roylance, D. (2001). Stress-Strain Curves. Massachusetts Institute of Technology Cambridge, Department of Materials Science and Engineering, Cambridge MA.