Influence of layer thickness and 3D printing direction on tensile properties of ABS material

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Abstract. The 3D printing process is a kind of additive manufacturing, that the basic principle of this process is adding material layer by layer to form a product. The purpose of this research was to study tensile properties of 3D printing ABS (Acrylonitrile Butadiene Styrene) material with axial and lateral direction. The specimen was printed according to ASTM D 632-02 by layer thickness variation around 0.1 mm, 0.2 mm and 0.3 mm. Moreover, three specimens were made for each printing axial and lateral direction. Tensile test was performed using Zwick Roell Series Z.021 machine. Then, the fracture surface was studied by SEM testing used ZEOL JSM-6510LA. Based on the research from 6 variation layer of 3D printing, the optimal result was found on the axial direction of 0.3 mm thickness layer with tensile strength 30.60 MPa and able to receive maximum load 551.13 N. The lateral direction of 0.3 mm thickness layer has tensile strength 19.42 MPa and able to receive maximum load 349.12 N. The voids were seen at the fracture surface of specimen.

1. Introduction

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The formation of a 3D printed object is achieved using additive processes. In an additive process an object is formed by laying down successive layers of material until the entire object is produced. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object [1].

Figure 1. The printer parts (Source: Up Box Printer).
Rapid prototyping process begins by creating a 3D design using CAD software. The design file is converted into a file that can be read by 3D Printer software such as the STL file. The printer will read the design of the STL file and do the slicing layers. Layer by layer material formed and joined together automatically to make a product.

In the printing process, the nozzle will move in the direction of the X axis and Y axis. The platform will move in the direction of the Z axis layer by layer according to the product design data in the STL file. The printer parts are shown in figure 1.

There are many references that review about 3D printing. The research regarding to enhancement of the mechanical properties for FDM processes by adjusting the printing orientation or material composition. Heechang et al. [2] observe the possibility for improving the mechanical properties of FDM-printed products with multiple materials were conducted based on the orientation and infill rate. Letcher et al. [3] showed that the mechanical properties such as the ultimate tensile strength can be advanced by altering the raster orientations in PLA on an entry-level 3D printer. Kyle et al.[4] define the effect of specimen mesostructured on the monotonic tensile behaviour of ABS parts manufactured by FDM. The experiment for plastics is designed around two key criteria, orientation of the pieces, and infill part during the printing process. Divyaethej et al.[5] analysis of mechanical properties of 3D printed ABS Material by varying layer thickness. Linlin et al. [6] study the effect of printing orientation on the tensile strength of 3D printed specimens. The results showed that the 0-degree orientation as it was defined has the highest mechanical properties, as shown with largest Young’s modulus and ultimate strength. This study is limited to one-layer thickness.

In this research studied the influence of tensile strength ABS material 3D printing process to the direction of printing axial and lateral. The thickness layer is varied at 0.1 mm, 0.2 mm and 0.3 mm. Then in the tensile test fracture surface microstructure was observed by SEM to determine the shape of the surface layer fracture.

2. Materials and methods
In this study, specimens were made with ABS materials. ABS are ideal materials for 3D printing, based on their relatively low melting temperatures and low thermal conductivity [7]. It consists of 15% -35% acrylonitrile, 5% -30% butadiene and 40% -60% styrene [8]. The shape and size of the specimen refers to standard ASTM D 638-02 type 4 [5,9,10], as shown in Figure 2.

![Figure 2. Standard of ASTM D638-02 type 4.](image)

| No. | Specimen | Printing direction | Layer thickness (mm) |
|-----|----------|-------------------|---------------------|
| 1.  | M1 0.1   | Axial             | 0.1                 |
| 2.  | M1 0.2   | Axial             | 0.2                 |
| 3.  | M1 0.3   | Axial             | 0.3                 |
| 4.  | M2 0.1   | Lateral           | 0.1                 |
| 5.  | M2 0.2   | Lateral           | 0.2                 |
| 6.  | M2 0.3   | Lateral           | 0.3                 |

Table 1. Printing variations.
The direction of printing and thickness layer the specimens varied. Any variations made three test specimens. Variations in the process of making specimens can be seen in Table 1.

Specimen design used CAD Software in the form of 3D design files. Then the files are converted into STL files so they can be read and used in the "UP Box 3D Printer" application. The printer will print specimens one by one according to the variable printing direction and layer thickness. The direction of the axial and lateral layers can be seen in Figure 3. So, in this study used 6 specimens as in Figure 4.

2.1. Tensile testing

Tensile testing is used to determine the tensile strength, strain and modulus of elasticity material by pulling the specimen until it breaks. Tensile testing is carried out with the Zwick Roell Series Z 020 tensile testing machine. Each variation of tensile tests carried out three times and average the data retrieved.

2.2. SEM testing

SEM testing was carried out on the fracture surface of the tensile test. SEM testing used ZEOL JSM-6510LA. Tests are selected on specimens that have the greatest tensile test values, in axial and lateral directions.
3. Results and discussion
The tensile test results for average data the six specimens are shown in Figures 5 and 6. In Figure 5 it can be seen that the maximum force in the three specimens with axial direction is greater than the lateral direction. Specimen M1 0.3 printing in axial direction which has the ability to receive maximum force of 551.13 N. Whereas the lateral direction which has the ability to receive maximum force is the M2 0.3 specimen, which is 349.12 N.

![Figure 5. Maximum force in the tensile test.](image)

![Figure 6. Tensile strength of specimens.](image)

Figure 6 shows the value diagram of the tensile strength of 3D printing results. This diagram shows same tendency that the three axial direction specimens have a higher tensile strength compared to the lateral direction. M1 0.3 specimens have the greatest tensile strength, which is 30.60 MPa in axial direction and M2 0.3 specimens have tensile strength the largest in the lateral direction is 19.42 MPa.
The tensile test results show that the tensile strength of polymer molecules in one layer is greater than the tensile strength inter layers. This is because in one layer, the polymer molecules have the same conditions of heating and cooling so that between the polymer molecules secondary and tertiary bonds form a stronger structure. The thicker the layer makes the stronger the bond, it occurs because more polymer chains are involved in forming bonds. This looks on the axial and lateral 3D printing results of specimens with a thickness of 0.3 mm having the greatest force and the greatest tensile strength. The thickness of the 0.1 layer for axial direction shows higher force values and tensile strengths compared to layer thickness 0.2. These results indicate similarities with Divyathej's [5] that layer thickness affects the tensile strength. The printing orientation affects the tensile test results [6]. In the axial direction shows a higher tensile strength value when compared with the lateral direction. The axial direction there is a greater tensile strength between polymer molecules in one layer compared to the tensile strength between layers.

In Figure 7 the morphology of SEM image of specimen M1 0.3 with 75x magnification show a non-dense layer arrangement and there are many voids.

![Figure 7. Result of SEM M1 0.3.](image)

In figure 8 SEM image of specimen M2 0.3 with 75x magnification shows a dense layer arrangement. From the SEM image can be seen that the difference in the two 3D printing results, where in Figure 5 there is a part that still clearly shows the shape of the layer but many voids occur. In contrast to Figure 6, the layer does not look void, it due to the layer-by-layer coating and hardening, so that laterally the 3D printing layer is denser than axial 3D printing. 3D printing layer layers are laterally more numerous than axial 3D printing, so that it is caused lateral 3D printing results have more dense layer and fewer voids [2].

![Figure 8. Result of SEM M1 0.3.](image)
4. Conclusions
The results of this research can be concluded that the maximum force and tensile strength of the axial direction of 3D printing specimens are higher than the lateral direction. The thicker layer tends to have greater maximum force and tensile strength. Among the six specimens, specimen M1 0.3 has maximum force and the largest tensile strength. The SEM images were observed that the stacking of the axial direction was less dense and many voids compared with the lateral direction layer. The more layers will form a tight structure but the strength inter layers is lower than the strength between polymer molecules in one layer.

Acknowledgment
Thank you to Engineering Faculty which has provided an opportunity to complete this research through Penelitian Unggulan scheme, as well as to Universitas Negeri Jakarta who has provided this research grant.

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