# Experimental and FEA Studies of ABS Parts Produced by FDM Process

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**Abstract:** ***Fused deposition modelling (FDM) process is the most use additive manufacturing (AM) technique that produces parts using different materials. Enhance the quality of product with minimum resource utilization is an important issue in the manufacturing of complex geometries. The aim of this study to minimise the material uses without compromising the strength of the object and keep the object weight as light as possible. The tensile behaviour of ABS components with varying parameters (infill density and filling pattern) have been studied. The virtual modelling and testing of ABS components performed using SolidWorks and ANSYS software packages. In addition, to validate the results of finite element analysis (FEA), the experiments were conducted based on the design of experiment methodology. The 3D printer according to the ASTM D638 standard fabricated the "Dog Bone" test specimens with a triangular, tri-hexagon pattern having 20%, 50%, and 80% infill density. Then the effect of printing pattern and infill density on Ultimate tensile strength (UTS)-weight ratio were evaluated. The results show that the combination of tri-hexagon pattern with 20% infill density had the highest UTS/weight ratio compare to the other specimens also compared with the FEA results to ensure that how much difference occurred into the stress concentration.***

**Keywords:** FDM, Additive manufacturing, tensile strength, modelling and FEA Simulation**.**

## 1. Introduction

Additive manufacturing (AM) is one of the most versatile and fast growing technology to create three-dimensional objects with a complex design having better material properties [1]. Previously various technologies such as fused deposition modelling (FDM), Stereolithographic apparatus (SLA), Selective laser sintering (SLS) and Selective laser melting (SLM) has been developing to fabricate complex geometry. 3D printing is define under the ASTM F42 Technical Committee [2]. Some other title is used for the AM technology is an additive fabrication, rapid prototyping layer manufacturing and solid fabrication [3]. This provides benefits in minimize material wastes as well as it's cost and manufacturing time.

A number of stages are required in additive manufacturing technology during the conversion of virtual CAD representation into the physical fabrication of the object. In most of the AM system the stages involve in between virtual CAD model to the physical fabrication of the object are common but the generation of each slice of the object is different for the different AM system. The fabrication of the specimen by additive manufacturing technology is start with creating the CAD (Computer Aided Design) model using CAD software. In the next stage, a standard interface is required to transmit various geometric information from professional CAD software to the additive manufacturing system. Thus, the CAD model is to be converted into STL (Stereo Lithography) file, which converts the CAD model into triangular mesh formats. Further STL file is transferred to the AM system where machine parameters (orientation, infill line direction, slice height, infill density, infill pattern and materials) set accurately before the fabrication process starts. In the next stage the physical object is fabricated according to the virtual CAD geometry, now in the next step fabricated physical object is removed from the build chamber and perform some post-processing operation before the actual use of the product. In the final stage, the product now ready to be used.

### 1.1 Fused Deposition Modelling (FDM)

FDM is easily available and most widely used AM technique for different useful applications. In 1990s Stratasys Inc was developed FDM process, FDM is the layer manufacturing technology [3]. In this technology filament type of material are used, which is extruded from the heated nozzle in the semi-molten form on the built surface. The deposited material cools solidify and make bonds with a previously deposited layer. When all layer is deposited then build surface move downward and start with the next layer deposition process and this process is continued until the completion of the object as shown in figure 1. Properties of the object depend on the setting of different parameter fixed at the time of the fabrication. Usually thermoplastic like ABS, PLA and nylon are used for FDM 3D printer [4] in this sturdy ABS material is used for the testing, it is easy to use and resistance to high temperature.

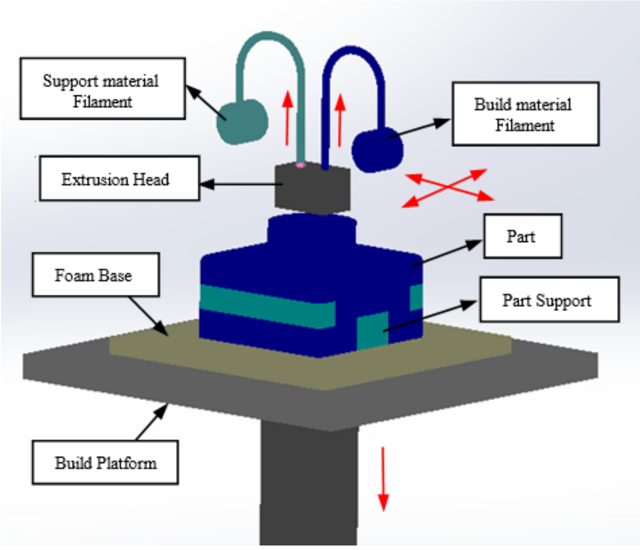



**Figure 1**: Fused deposition modeling (FDM)

ABS can be used to make lightweight, moulded and solid product such as piping, musical instrument, automobile body parts, wheel cover, aircraft component, electronic digital assemblies and biomimetic robotic application.

Biomimetic application has found to be more prominent for this study as the effect of printing pattern and infill density on the strength of the material is found to be more, while deigning the parts for such applications. Biomimetic is the study of the biological system of nature with the extraction of design, in term of structure and functions, for engineering application of materials and machines in modern technology [5]. Therefore, if we use the ABS material for a biomimetic application then it is important to ensure what is the mechanical properties of the material and which material is the best suited for that type of the robot for making the weight of robot as light as possible without compromising the strength of material.

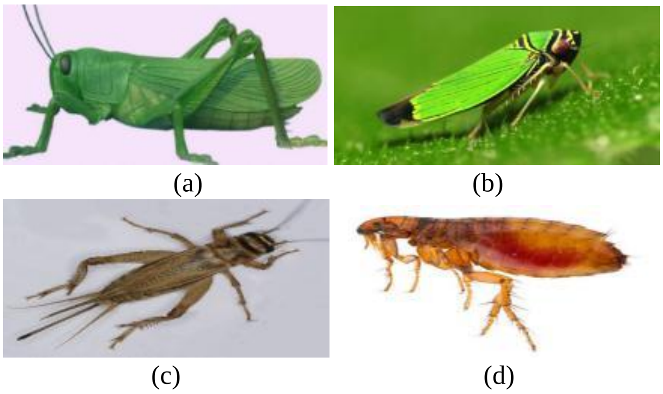



**Figure 2**: Jumping animals (a) grasshopper, (b) leafhopper, (c) cricket, (d) flea [Modified from Fei Li et al [6]. [7]]

Many animals and insects move through jumping like grasshopper, frog, kangaroo and the harpegnathos saltator ant (insects) [6], [8]. For jumping robots, the weight of the robot is one of the factors affecting the height and distance at the time of jumping. Therefore, it is important to ensure the robot weight as light as possible. To achieve the better tensile strength, tensile test is perform on changing parameters of specimen. In this study printing pattern and infill density use as a parameter for tensile test.

Earlier some author conduct the tensile test on ABS material for biomimetic robotic applications [7] they test the ABS material specimen on a different orientation. Another early work conducted; in which author uses layer thickness with 0.2mm and 0.4mm, perform the tensile test on the specimen produce by FDM process, and found that 0.2mm layer thickness give the better strength compared to other material [9]. One author change the build orientation, raster angle, contour width, raster width, and raster-to-raster air gap to get the desire output [10]. Therefore according to our need parameter can be adjust and investigate the different effect parameters on the strength of the material. Therefore the objective of this paper is to estimate the tensile strength of the ABS material using virtual and experimentally. First experimental study performs then validates the FEA simulation results with experimental data.

## 2. Methodology

The aim of this study is to investigate the better strength with changing the parameters like printing pattern and infill density. Thus to achieve this ABS material specimen is fabricated with the different combination of filling pattern and infill density according to the design of experiment as shown in table 1. Then specimen was tested experimentally, further, the experimental result compare with FEA simulation results. The methodology of this study shown in figure 3.

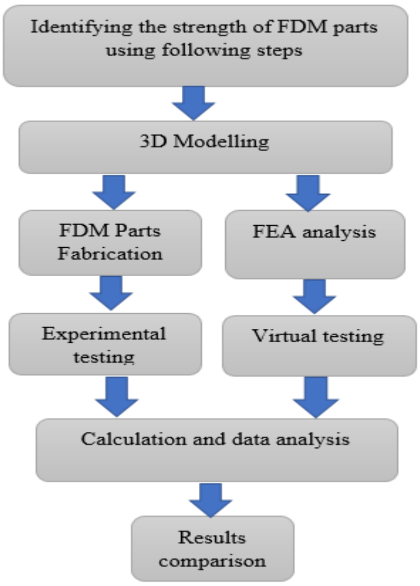



**Figure 3:** Flow chart of the methodology

Taguchi design of experiment method is adopted to reduce the experiment count [11]. It identifies all possible combinations and reduces the no of the experiments. During the manufacturing process, 0° orientation is adopted and the layer thickness set to 0.15mm.

**Table 1:** Design of experiment

| No | Infill density (%) | Printing pattern |
|---|---|---|
| 1 | 20 | Triangular (T) |
| 2 | 20 | Tri-hexagon (TH) |
| 3 | 50 | Triangular (T) |
| 4 | 50 | Tri- hexagon (TH) |
| 5 | 80 | Triangular (T) |
| 6 | 80 | Tri-hexagon (TH) |

### 2.1 Sample preparation

Geometry was set according to ASTM D638 TYPE I specimen geometry is shown in figure 4. Then CAD model of test specimen are created in SolidWorks as shown in figure 5.

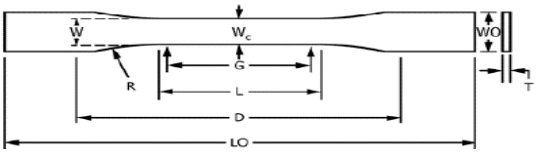



**Figure 4:** Geometry of the test specimen

**Table 2:** specimen dimensions accounting to ASTM D638

| Specimen type | Dimensions |
|---|---|
| W- width of narrow sections | 13 mm |
| L- the length of narrow section | 57 mm |
| Wo- width overall | 19 mm |
| G- gage length | 50 mm |
| D- the distance between grips | 115 mm |
| R- radius of the fillet | 76 mm |
| Lo- length overall | 165 mm |

In the specimen design, infill density is defined how much material is used in the specimen, and two types of infill pattern are used first is triangular and second is tri-hexagon (combination of triangular and hexagon pattern). Infill pattern plays a very important role in the strength of the object and makes it light in weight. Different type of pattern used by the researchers like rectangular circular triangular, hexagon and tri-hexagon etc. [12]. In this study, the infill patterns are triangular (T) and tri-hexagon (TH) with 20%, 50% and 80% infill density that are represented in figure 6. Infill density only created in gage area (50×19×4). Only infill pattern and infill density are used in the specimen design to reduce the difficulty in fabrication.

### 2.2 Tensile Test Procedures

To calculate the strength of the specimen was tested on Universal Tensile Machine (UTM) having the maximum test load 25kN. The 3D printed specimen was gripped into the UTM and load was applied gradually.

The displacement, $\Delta L$, and force, F, was generated during the experimental process and recorded into the system and the stress $\sigma$ and strain $\varepsilon$ value can be calculated using the equations (1).

$$\sigma = F/A \quad \varepsilon = \Delta L/L \qquad (1)$$

Where A denotes cross-section area, L is length, and $\sigma$ and F have the unit of Pa and N, respectively.

**Figure 5:** SolidWorks design of specimen

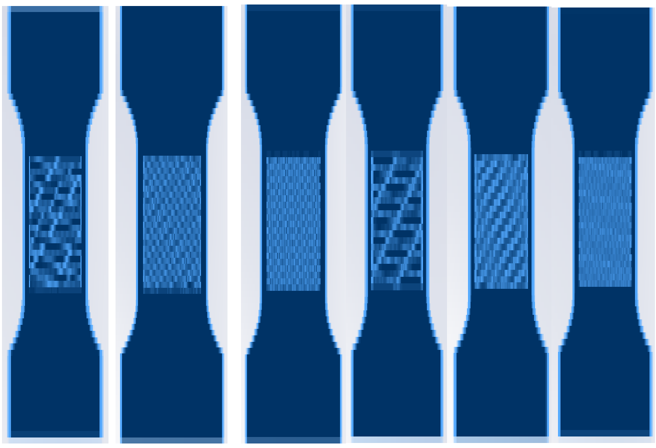


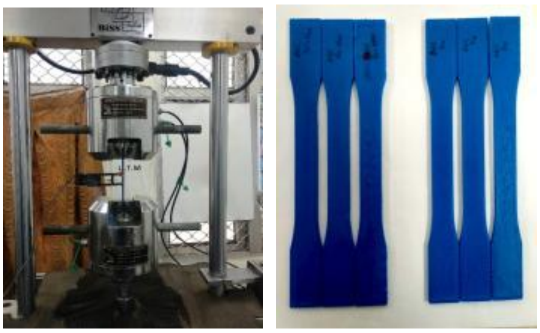
**Figure 6:** SolidWork geometry of triangular pattern and tri-hexagon pattern with 20%, 50% and 80% infill density

### 2.3 Experimental setup and results

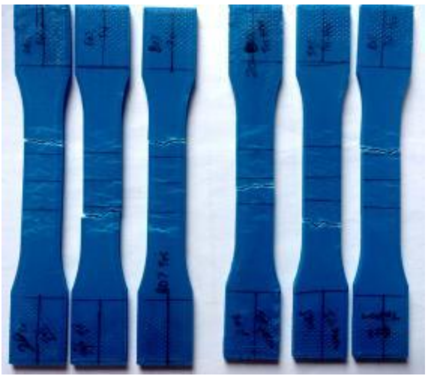
The UTS is used for the tensile test, model Bi-05-172, serial 10-08-150-172-04 with a capacity of 25KN and dog bone 3D printed specimen are shown in figure 8. The test specimen was gripped into the gripper and upper grip was travelled at 2.5 mm/min. each specimen goes under the tensile testing process and recorded the stress-strain curve and force-displacement curve ware plotted in figure 9 and 10.

(a) (b)

**Figure 7:** (a) Specimen fabrication using FDM Process (b) Infill density and pattern can easily visible when the light is applying opposite to the specimen.



(a) (b)



(c)

**Figure 8:** (a) UTS use for tensile test, (b) specimen use for tensile test fabricated by FDM, (c) Specimrn after the test.

For each sample, the behaviour of stress vs strain curve shows the nature of ABS- first linear elastic deformation appears, and then it follows the neck formation. The ultimate tensile strength is defined as the peak point of stress vs strain curve. The ultimate tensile strength, modulus of elasticity, deformation, and UTS to weight ratio value are shown in table 3.

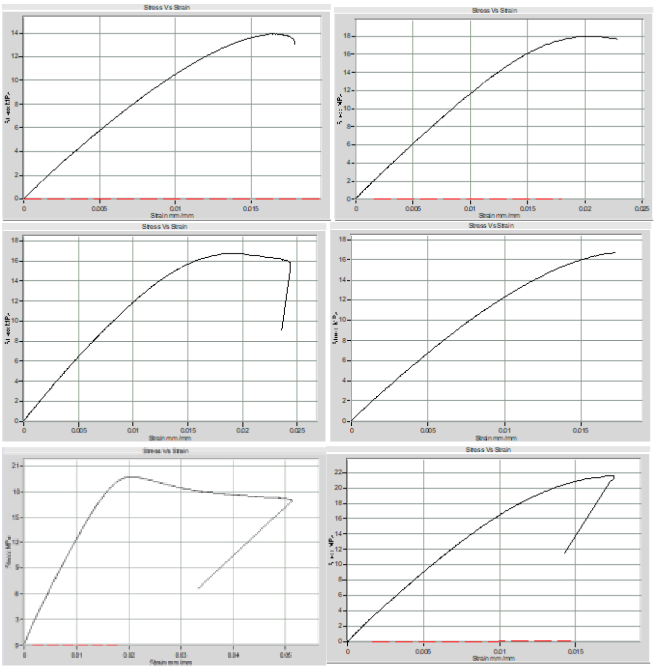


**Figure 9**: Stress-strain curve for specimen under tensile testing.

As demonstrated in table 3, the stress-strain curve and young modulus E, shows a major difference, according to the infill density and pattern. While comparing the different infill pattern with infill density shows that UTS/ weight ratio varies with different combination, previous research [13] shows that 20% infill density with a triangular pattern having the highest value of UTS to weight ratio. In this study, tri-hexagon infill pattern especially 20% infill density possessed the highest strength to weight ratio its means part is low in weight and having good resistance. The 20% infill density having a cost-effective option using less material and gives good strength compared to the triangular pattern. This type of combination of process parameter gives better strength and make object weight lighter.

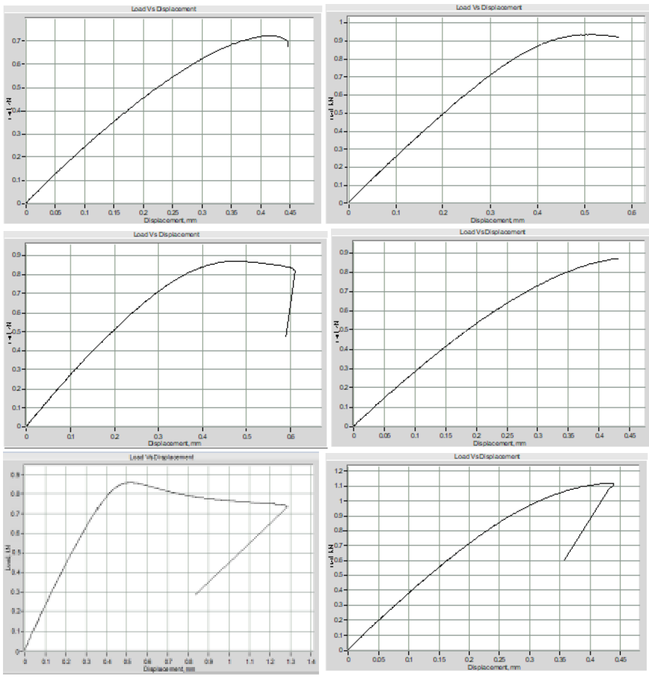


**Figure 10:** load-displacement cure for specimen under tensile testing.

## 3. FEA simulation methodology and results

Experimental result was most effective but fabrication and experiment are costly and time taking, so finite element analysis is the alternative for modelling and simulation for the tensile strength of the real object. In this study, finite element models was created on design software SolidWorks, SolidWorks file was converted into IGS file format and then import into the ANSYS workbench, then static structure analysis was performed.

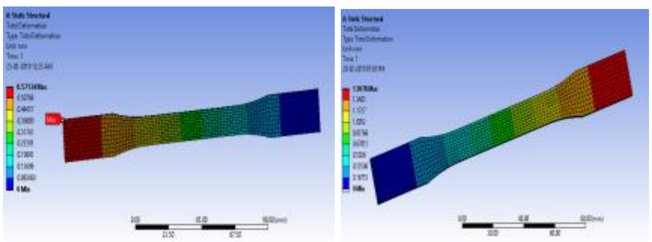
The simulation starts with some basic setup like adding material properties, meshing and loading conditions. Which is used for all tensile specimen. The stress distribution was investigated using ANSYS workbench. Maximum stress develops in the edge of the specimen and in the region of gage length of the specimen; it is due to sudden change into the cross section near to gage length and sharp corners.

### 3.1. Total deformation (Triangular pattern)

Total deformation calculates from the square root of the summation of the square of all the deformations in X, Y and Z- direction that is shown in equation (2).

$$\text{Total displacement} = \sqrt{X^2+Y^2+Z^2} \qquad (2)$$

Total deformation of the Triangular pattern and Tri-hexagon pattern are shown in the figure, 11 and 12, which was calculated from the ANSYS 18.2 software package.



**(a)** **(b)**

**Table 3**. Results of experiment data of Tensile strength, modulus of elasticity and displacement of all sample tested

| No. | Printing pattern | UTS (MPa) | Modulus of elasticity (MPa) | Displacement (mm) | Weight (g) | UTS/weight (MPa) |
|---|---|---|---|---|---|---|
| 1 | 20% Triangular | 14 | 510 | 0.409 | 6.828 | 2.050 |
| 2 | 20% Tri-Hexagon | 18 | 1095 | 0.515 | 7.128 | 2.456 |
| 3 | 50% Triangular | 17 | 1074 | 0.475 | 8.564 | 2.108 |
| 4 | 50% Tri-Hexagon | 17 | 1177 | 0.431 | 8.015 | 1.985 |
| 5 | 80% Triangular | 19 | 1208 | 0.516 | 8.584 | 2.213 |
| 6 | 80% Tri-Hexagon | 22 | 1645 | 0.421 | 9.568 | 2.299 |

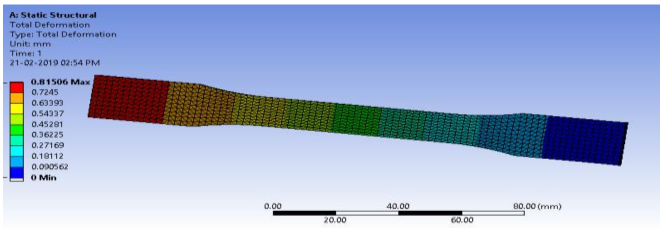



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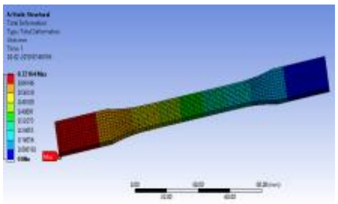
**Figure 11:** Figure (a), (b) and (c) shows the total deformation of triangular pattern with 20%, 50% and 80% respectively

### 3.2. Total deformation (Tri-hexagon pattern)



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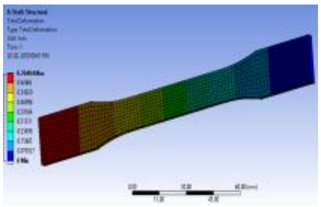

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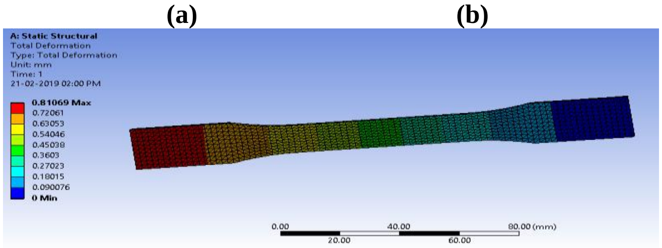


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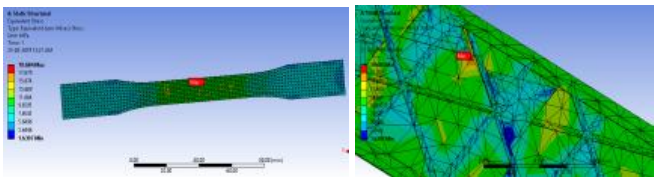
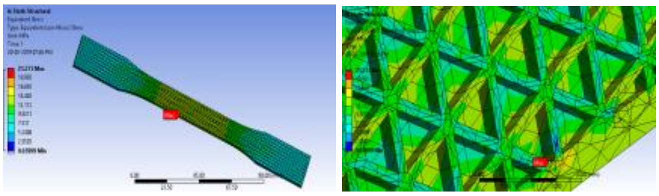
**Figure 12:** Figure (a), (b) and (c) shows the total deformation of tri-hexagon pattern with 20%, 50% and 80% respectively

### 3.3. Equivalent Stress (Triangular pattern)

Equivalent stress is also called von Mises stress; it is mainly used for ductile materials, according to the von Mises stress theory when material under tensile loading condition is equal or greater than yield limit under simple tension then material start yielding. Equivalent stress results shown in figure 13 and 14, which were calculated from ANSYS workbench.



(a)



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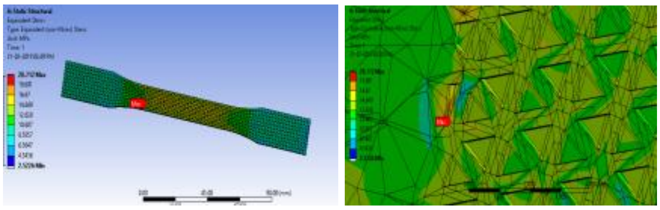

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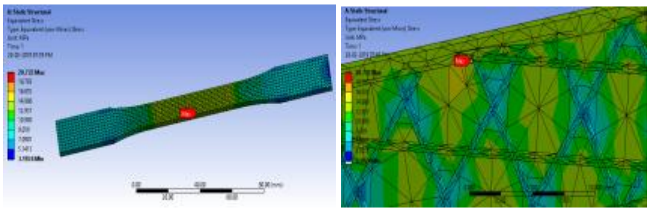
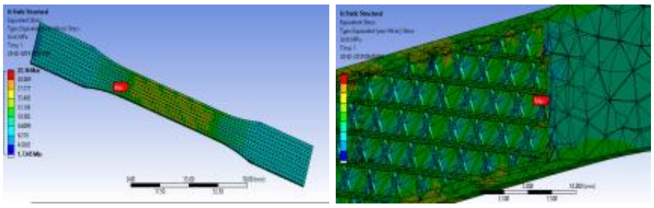
**Figure 13:** Figure (a), (b) and (c) shows the Equivalent Stress of triangular pattern with 20%, 50% and 80% respectively

### 3.4. Equivalent Stress (Tri-hexagon pattern)



**(a)**



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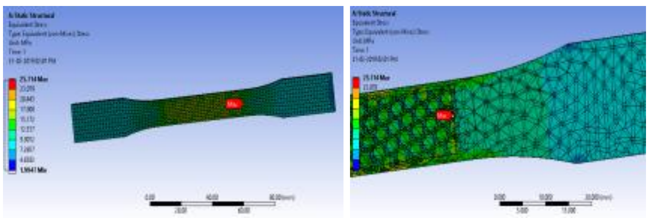

**(c)**

**Figure 14:** Figure (a), (b) and (c) shows the Equivalent Stress of tri-hexagon pattern with 20%, 50% and 80% respectively

### 3.5. Results

The value of total deformation and equivalent stress from the FEA analysis shown in table 3 and 4.

**Table 3.** Results of Triangular pattern

| Infill Density | | Total Deformation (mm) | Equivalent Stress (MPa) |
|---|---|---|---|
| 20% | Min | 0 | 1.6397 |
| | Max | 0.5713 | 19.684 |
| 50% | Min | 0 | 0.6599 |
| | Max | 1.5078 | 21.273 |
| 80% | Min | 0 | 2.5226 |
| | Max | 0.8151 | 20.712 |

**Table 4.** Results of Tri-hexagon pattern

| Infill Density | | Total Deformation (mm) | Equivalent Stress (MPa) |
|---|---|---|---|
| 20% | Min | 0 | 3.1924 |
| | Max | 0.7216 | 20.732 |
| 50% | Min | 0 | 1.7345 |
| | Max | 0.7049 | 22.360 |
| 80% | Min | 0 | 1.9947 |
| | Max | 0.8106 | 25.714 |

## 4. Conclusion

In this paper, mechanical behaviour of ABS material fabricated by fused deposition modelling (FDM) process has been studied. The experimental studies where carried out to study the effect of UTS/ weight ratio on infill pattern and infill density. The stress-strain curve is optained during experimentation of work piece for tensile testing. The results show that tri-hexagon would be beneficial for UTS to weight ratio. Tri-hexagon is the combination of triangular and hexagon pattern, which give better results, compare to triangular infill pattern, the 20% tri-hexagon pattern had the highest UTS to weight ratio. The data from the tensile test is compared with the FEA results. The FEA results show some differences in stress value for the specimen and found 20% to 50% error in simulation stress values compares to experimental stress value. The reason could be the material properties, which was used in FEA simulation process. Therefore Finite element analysis is beneficial for visualization of stress concentration areas where the fracture occurred. So that the decision can be made to modify the design for better functionality. The futher studies can be carried out for the investigation of compression behavior, buckling behavior and bend test of polymer specimen with help of experiment or FEA.

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