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MECHANICAL PROPERTIES ASSESSMENT OF 3D PRINTED SPECIMEN AT DIFFERENT STRUCTURE ORIENTATION

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ABSTRACT

Acrylonitrile Butadiene Styrene (ABS) is the most generally utilized thermoplastics as a part of 3D printing for making models, prototype, instruments and end-utilize parts. In any case, there is an absence of precise comprehension of the mechanical properties of 3D printed ABS parts, including structure introduction subordinate rigidity. These mechanical properties are fundamentally required for plan and utilization of 3D printed segments. The primary goal of this research is to observe a 3D printed component of different structure and determine the mechanical properties. It focuses on two main phases of the investigation of the effects of build parameters on the tensile failure of 3D printed parts. The first stage concentrated on delivering 3D printed part at a different angle and structure. The second stage consists of tests studying the effects of varying orientation and structure orientation on printed parts. The tensile test experiments that at honeycomb infill design structure had the most elevated elasticity values, 30.56 MPa and Young Modulus 2.02 GPa took after by the rectilinear and afterward the line infill pattern. The line design at a different orientation, 45° had the highest tensile test values, 31.40 MPa and Young's Modulus 2.02 GPa. It was trailed by 90° and after that 180°. In any case, the 90° orientation had higher values than the 180° orientation because of the resistance of the covering to the force that was parallel to the layer orientation.

1. Introduction

Additive manufacturing (AM), originally known as Rapid Prototyping or 3D printing, is becoming increasingly popular, with applications ranging from industry through design and architecture to medicine. The technology is now used to produce not only models and prototypes but also finished and semi-finished products. The present state of knowledge and future potential of additive manufacturing have been discussed, for instance. Campbell (2012) has reported on the advancement of additive manufacturing materials, analyzes design possibilities and overviews industrial applications [1]. Among the different factors affecting the mechanical properties of fabricated parts, the build orientation is often one of the most influential factors and one of the few factors prevalent in almost all AM processes [2].

The build orientation impacts the accuracy, build time, cost, surface roughness and much more, and its optimization is a fundamental problem in additive manufacturing which has been tackled by many researchers [3], also from the theoretical side [4]. In many aspects, the effect on the mechanical properties is the most important factor as it determines the functionality and not just the visual aspects of a part [5], yet no commercially available software allows for positioning parts on the print table according to the load introduction and direction. One possible reason is that most processes and their effects still aren't fully understood. In order to get a better understanding, empirical data need to be collected through experiments, which can then be used in models. Extensive research has been undertaken in the area [5], but most of it focused on either orientations along the main axes of the coordinate system, or on continuous orientations within only one plane instead of considering the full three-dimensional space. While in some processes, such as in Fused Deposition Modeling (FDM), the effect of the orientation is relatively small because of indistinct layers 6) in other processes such as in inkjet 3D printing, the effect cannot be neglected [5].

AM or 3D printing is defined as a layer based manufacturing process [4]. This statement generally holds true, but, due to a large number of different printing processes, sometimes the layers are not very distinct. For example, in Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM), the material is cured voxel by voxel, and not line by line or layer by layer. Hence, the bonding strength between two layers is identical to the bonding between two printed lines within a layer, with only a difference in time. A crucial feature of the FDM process is its potential to fabricate parts with locally controlled properties like mechanical properties, density, and porosity [7].

It is even becoming possible to manufacture functional parts in addition to prototypes. In order to fully evolve the FDM into a manufacturing tool, a number of improvements are essential [8]. The functional parts require the process improvements for greater dimensional control and better tolerances, improvements in surface finish, the variety of polymers available for use should increase and the mechanical properties of the prototyped parts should be enhanced to maintain their integrity during working [9].

To improve this promising technology, recent years have seen a substantial amount of research in the area of FDM manufacturing process planning. Research work has included the consideration of processing parameters and their optimization [3] and mechanical properties

2. Methodology

Figure 1 shows a flow chart of the methodology of the research

A. Design Specimen

Specimen preparation is following the American Society for Testing and Materials (ASTM D638) standard. The specimens were modeled using Solid Work software and converted to STL (stereolithography) format. STL format was imported to Fused Deposition Modeling FDM software. Fig 2 shows the specimen geometry.

The material used for this research is ABS filament. Two influencing factors were considered in the experiments which are sample structure and angle of the nozzle.

B. Printing 3D Printed Specimen

3D printer machine used for these experiments was the model Vagler V-821. The printer software version was Sapphire Vagler International (Beta) software.

Three different sample structures were produced which are honeycomb, line and rectilinear pattern structure at angle 90°. In addition, three different angles (45°, 90° and 180°) are used to fabricate the line specimen. Figure 3 shows the research pattern, structure, and orientation for printing the specimens.

C. Infill Pattern and Infill Percentage (Density)

There are several considerations when choosing an infill pattern: object strength, time and material, and personal preferences. It can be inferred that a more complex pattern will require more moves, and hence take more time and material. The infill pattern that been used in these research are honeycomb, line and rectilinear which illustrated in Fig 4 (a) –(c) respectively

D. Tensile Testing

The tensile test is one of the most important mechanical property evaluation tests. The tensile test was conducted using a Universal Tensile Testing Machine (Zwick) shown in Fig. 5 and the test Expert Zwick data acquisition software.

Six samples of each structure were tested and the data were collected. The data were observed including the elastic modulus, yield strength, ultimate tensile strength. Each specimen was measured with the calipers to determine the thickness of the cross-section.

The Zwick load frame, shown in Fig. 6 was preloaded using the scroll wheel to ensure that the specimen was properly loaded in the frame. The test was started, and the specimen was loaded. The test continued until fracture, where the software stopped the moving crosshead and finished gathering data. The specimen was removed, and the crosshead was reset to the initial position to start another tensile test. The testing procedure was repeated for the rest of the specimens.

3. Results and discussions

E. 3D Printed Specimen

Three different sample structures were produced which are honeycomb, line and rectilinear pattern structure at angle 90° and three different angles which are 45°, 90° and 180° are used to fabricate the line specimen. Fig 7 shows the infill pattern at 90°while Fig. 8 shows a line pattern at a different angle.

F. Tensile Properties

Mechanical properties for materials are essential to be tested in order to ensure the items that to be delivered have a great quality which relies on upon the material utilized. The properties are referring to the ability of the material to get past any stress or defection which can influence the items physically [10].

Figure 9(a) shows the tensile specimen of the 3D printer component after the testing. Figure 9(a) shows the failure occurs in the middle area of the specimen. Fig. 9(b) shows a crack pattern on the test specimen. From Fig. 9, it can be seen that ABS is a brittle material, it is relatively little plastic deformation

G. Tensile Properties of Line Pattern at Different Angle

Typical stress-strain curve for 3D printed specimens are illustrated in Fig. 10. The curve includes regions of elastic and plastic deformation, accompanied by necking deformation. The stress-strain behavior under tensile stress was initially nonlinear [11]. It shows a ductile material characteristic, which 45° printing orientation has higher ultimate stress and yielding stress compare 90° and 180° printing orientation [12].

The tensile properties of a line pattern at a different angle are given in Table 1. The highest tensile stress of line pattern was at angle 45° which is 31.40 MPa, followed by angle at 90°, 30 MPa and the lowest tensile stress of line pattern is at angle 180° which is 28.92 MPa. This shows that when angle orientation is increasing, the ultimate tensile stress is decreased. This is because the 3D printed specimen was built layers by layer, which suggests its laminate weaknesses between the layers [13].

Modulus elasticity is also known as Young's Modulus. It shows the slope of the engineering stress-strain curve in the elastic region. As shown in Table 1 the highest Young's modulus for the line pattern is at angle 45°which is 2.02 GPa and the lowest value at angle 90° orientations are 1.95 GPa respectively. The higher Young's modulus, the higher the strength of the material. The modulus elasticity is important in order to indicate the estimation of deformation of an element when the load is applied. Table 1 shows the tensile testing result of the 3D printed specimen at line structure.

As the tensile stress increases, the failure will start at the weakest raster and next weakest raster will break, in sequence, until aggregate failure of the example. At the point when the stress reaches a certain constant value, a long propagation process occurs in the neck [14]. The craze is the main plastic deformation mechanism of ABS, with a great number of crazes appearing perpendicular to the direction of the tensile loading. Crazes initiate, widen, and then suffer a breakdown of the raster as tension increases. If crazes extend to both ends of the sample, the sample fails with insignificant necking deformation, because molecular chains initially in an un-oriented state transform to a more highly oriented state of necking. The transformation process causes strain hardening and ensures the uniform expansion of crazes extending to both ends, which is similar to metal deformation hardening caused by uniform deformation [4].

Although ABS individual raster had melted together, we can still distinguish every raster in the images, and the fracture of ABS was mainly caused by damage to the raster pulling and rupturing. As the load force increased, the force per unit area would reach the filaments tensile limit. In the printed samples the fracture would begin approximately at the weakest filament, and the fracture would propagate until the samples failed. The result is that the stress continues to increase and the next weakest raster will fail. At the same time, the 3D printed example was conjointly designed with lower weights that turn out the region with high porosity, consequently bringing down the mechanical properties [15].

Figure 11 shows a bar chart of UTS value and Modulus Elasticity line pattern structure at different angle. These results can be explained by looking at the tensile forces that would be exerted on each layer. In the 45° layers, every layer will be carrying the same load [16]. However, in the layers with alternating 0° and 90° angles, the layers with the 90° raster angles will be carrying the vast majority of the load [16]. Because of the gaps between the infill roads, the layers with 0° angles will only be carrying load through the shells [16]. This means that only about half of the layers in the part are carrying the majority of the load. Thus, the 0° or 90° parts fail before the 45° parts. These results are consistent with those found by other researcher [16, 17].

4. Tensile Properties on infill pattern at 90°

The stress-strain curves of tensile bars in different infill pattern at 90°are plotted in Fig. 12. The highest ultimate tensile stress is specimen was built in a honeycomb pattern which is 30.56 MPa while the lowest ultimate tensile stress was line pattern which is 30 MPa. This is because the process of 3D printer is layer by layer process which means there are gaps between layers. Thus, because of the porosity, the propagation process is easy to occur on the structure of materials and at the same time, the cracks occur easily. The stress intensity factor, K is a convenient way of describing the stress distribution around a flaw [18]. The pattern at the highest modulus elasticity is rectilinear, 2.95 MPa and the pattern that have the lowest modulus elasticity is line pattern, 1.95 MPa. In polymers, the tensile modulus and compressive modulus can be close or may vary widely.

This variation may be 50% or more, depending on resin type, reinforcing agents, and processing methods. The combination of high ultimate tensile strength and high elongation leads to materials of high toughness. Table 2 described the result of the tensile test that has been carried out for the ABS 3D printed specimen 90° orientation at different infill pattern. It shows rectilinear have the highest value compare to the line and honeycomb pattern. The higher Young's modulus, the higher the strength of that material. For the ultimate tensile stress, the difference was insignificant. However, it was influenced by several factors which are a region in the material which doesn't seem to be absolutely dense have a lower mass/volume quantitative relation resulting in lower absolute strength and stiffness values [19].

Besides that, the fabrication process technique also influenced by the high differences of UTS [20]. Line, rectilinear and hexagonal are all fairly comparable in terms of strength. The plastic filaments also touch but there are (nearly) no more air voids in the material. Therefore the plastic deformation is not localized anymore and the whole specimen behaves as a single plastic filament would [21].

Figure 13 shows a comparison UTS value and modulus elasticity at angle 90° with different infill pattern. For rectilinear infill pattern, the filaments touch and form a continuous 3D material, but it is porous because there are lots of small air voids in [21]. In this case, the stress concentrates around the voids so the strain is localized around the void areas. The voids behave like faults that expand to eventually join and break, but leads to a lower elongation at break [21].For line infill pattern, the extruded ABS filaments constituting each layer do not touch each other along the specimen axis: there are clear gaps in the mesh [21].

The mechanical properties show that ABS is an isomeric mixture of two materials: Styrene-acrylonitrile (SAN) a hard, transparent and brittle thermoplastic and cross-linked Poly-butadiene which is soft elastomeric phase [23]. These materials are prepared by polymerizing styrene in acrylonitrile onto poly-butadiene in a poly-butadiene latex, the resultant material poly-butadiene phase i.e. the rubbery phase is then compounded with the SAN which is plastics phase. The plastic phase is 70 percent of the mixture. Generally speaking, when the content of SAN increases the strength and rigidity of ABS increases. But when the content of the rubber phase is increased, strength, hardness and heat resistance of ABS increases [23].

The mechanical properties of ABS can be divided into low strain behavior and high strain behavior or impact conditions. In low strain behavior, a tensile test of ABS was done in which load-displacement curve shows semi-elastic region up to 2.2-7.8% strain which is followed by yielding at 30.00 MPa – 30.56 MPa. In the end, strain-softening place in which load remains constant until ultimate stress is attained [22]. The fracture toughness is due to rubber content in ABS. Higher rubber portion leads to more toughness up to the point when a decrease in modulus counteracts the elongation to break. The main reason for adding rubber in SAN is to improve toughness when impacted at high strain rate. Around 20% of rubber content present by volume, ensures otherwise brittle matrix to yield under plastic deformation using different energy mechanism. The presence of the rubber phase increases the magnitude of impact resistance or toughness of material by one and two. Due to this, a large damage region was created in a volume which is very large as compared to adjacent crack surface and a large increase in energy dissipated before crack can move through [22].

5. Conclusion

Testing the mechanical execution of 3D printed ABS relying upon infill example and edge of introduction. While the concentration of the review was on mechanical execution, we made a point to incorporate quality, cost and speed as key necessities on top of quality for 3D printer users.

Purely on mechanical performance, 3D Matter also found interesting results, such as the fact that elongation at break is that Line, Rectilinear and Hexagonal patterns show equivalent performance. Honeycomb infill pattern tends to be stronger than rectilinear and line infill pattern.

The infill design, honeycomb had the highest tensile strength took after by the rectilinear and afterward the line infill design. This because of the long continuous layers parallel to the length of the specimen for the honeycomb, making the covering harder to break.

The line design at various introduction, 45° had the highest UTS three-point tensile test values. It was trailed by 90°and after that 180°. Once more, 45° was most elevated because of the long persistent layers parallel to the length of the sample. In any case, the 90° orientation had higher qualities than the 180°orientation because of the resistance of the covering to the constraint that was parallel to the layer introduction.

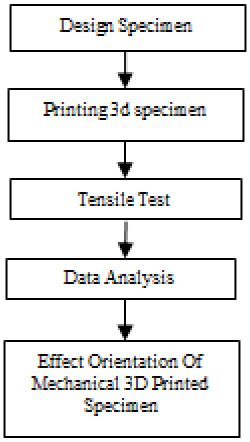


Fig 1: *Flow Chart of research work*

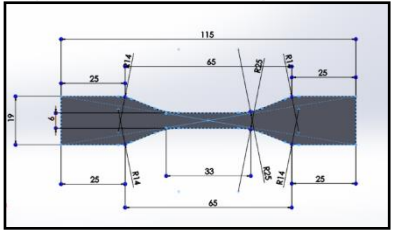
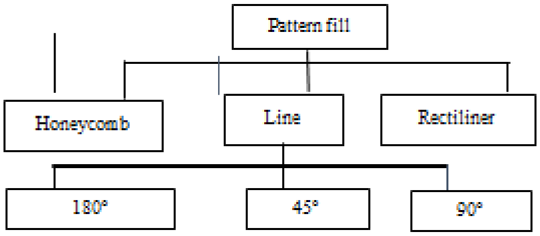
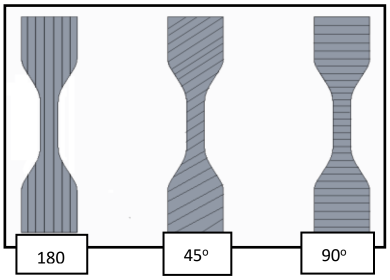


Fig 2: *Dog Bone shape specimen (mm)*

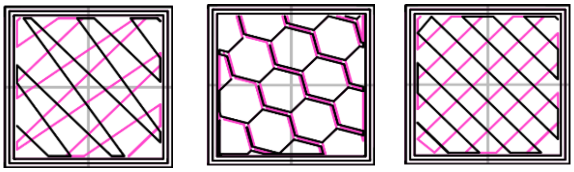


(a)



(b)

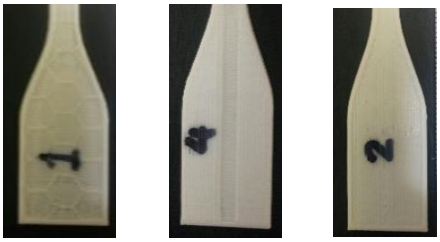
Fig 3*: Specimens design; (a) research pattern and (b) line structure at a different angle*



(a) (b) (c)

Fig 4: *Infill pattern; (a) Honeycomb, (b) Line and (c) Rectilinear*

Fig. 5: *Universal Tensile Testing Machine*

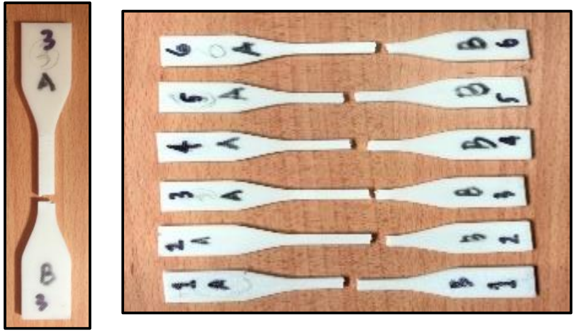


(a) ***(b)*** ***(c)***

Fig. 7: *Infill pattern at 90°: (a) Honeycomb (b) Line (c) Rectilinear*

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

Fig. 8: *Line pattern at different angle: (a) 45 (b) 90 and (c) 180°*



(a) (b)

Fig. 9: *(a) Test Specimen Failure and (b) Crack pattern on test Specimen Failure.*

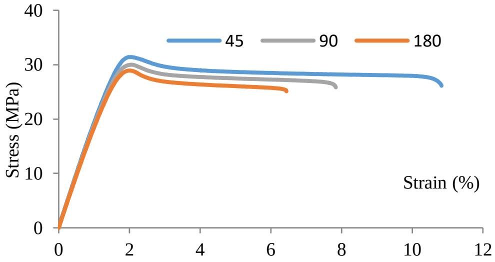


Fig. 10: *Graph stress vs strain for ABS 3D printed line specimen at a different angle*

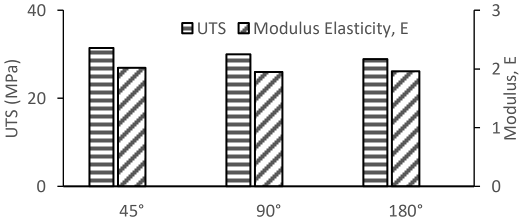


Fig. 11 *A comparison UTS value and Modulus Elasticity at line pattern structure at a different angle*

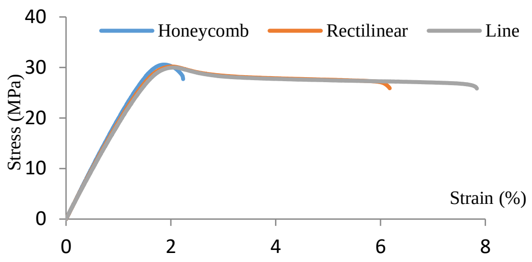


Fig. 12: *Graph stress vs. strain for ABS 3D printed honeycomb, line and rectilinear specimen at 90o*

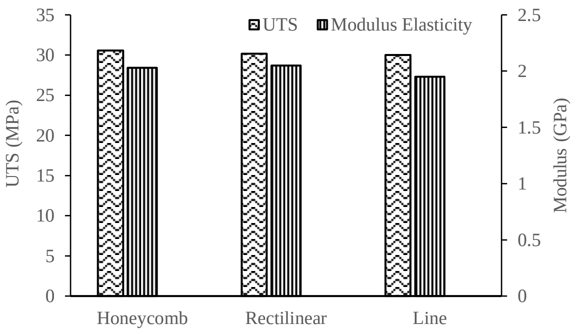
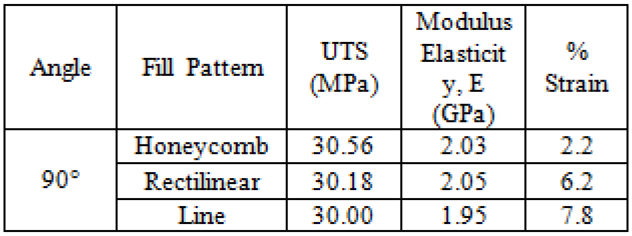


Fig. 13: *A comparison UTS value and Modulus Elasticity at angle 90°*

Table 1: *Tensile testing result of a 3D printed specimen at line structure*

Fill Pattern	Angle	UTS (MPa)	Modulus Elasticity, E(GPa)	% Strain
Line	45°	31.4	2.02	10.8
	90°	30	1.95	7.8
	180°	28.92	1.96	6.4

Table 2: Tensile testing result of the 3D printed specimen at 90°



Angle	Fill Pattern	UTS (MPa)	Modulus Elasticity, E (GPa)	% Strain
90°	Honeycomb	30.56	2.03	2.2
	Rectilinear	30.18	2.05	6.2
	Line	30.00	1.95	7.8

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