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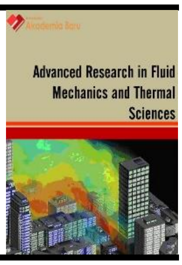

Effect of Acetone Vapor on Mechanical Properties of Fused Deposition Modeling Printed Part

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ABSTRACT

Additive manufacturing (AM) has the benefit being capable to create very complex geometries, which could be impossible with traditional methods or fabricated at a high cost. For material cost properties, the cost of AM parts is mostly related to the size of the product. The project used polymer-based material specifically acrylonitrile butadiene styrene (ABS). However, the FDM technique suffers from poor surface roughness, restricting it application on some areas requiring high surface integrity. Therefore, a post processing is required to improve the surface roughness of the FDM printed part. In this study, an acetone vapor post process employed to improve the surface roughness of the part but the scope of the study will focus on the effect of mechanical properties of the printed part. Mechanical anisotropy behaviour of the specimen investigated via tensile test, flexure test and surface finish. The results of an implementation of acetone vapor as post processing of FDM printed part are compared to the original printed part in term of its mechanical properties.

1. Introduction

Fused deposition modeling (FDM) is the most diffused rapid prototyping techniques which are low maintenance cost and quick production of complex parts. There are many choices of materials can be used for FDM process. One of the materials is acrylonitrile butadiene styrene (ABS) which the composition of the material was provided by the company that produced the material. However, the fluctuations of temperature during production lead to delamination and high surface roughness of the printed part [1- 7]. The printed part that suffers from poor roughness restricting its application in some areas requiring high surface integrity. Therefore, it is required a post-processing stage for the printed part in order to improve the surface finish, thus will affect the mechanical properties of the

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part. The mechanical properties for finished printed part are important in order ensure the part produced with a good quality and can undergo any stress or deflection at a certain range of conditions and also to avoid malfunction of RP when using on long period of time [8 - 12]. There are many post-processing solutions can be applied for improving the mechanical properties of the printed part. Therefore, it can differentiate the mechanical properties of the original part of the part that undergo post-processing process.

To improve the mechanical properties of a printed FDM part, it is necessary to perform the work study needed precisely and accurately so that an improvement of mechanical properties for an FDM printed part can be obtained. The purposes of this research writing are to study the effect of acetone vapor on mechanical properties of FDM printed part, conduct a test in order to differentiate the mechanical properties of the original printed part with the acetone vapor part and also improve the mechanical properties of the printed part [13 - 16].

2. Research Methodology

2.1 Specimen Preparation

In this research, two sample tensile specimens and two sample flexure specimens have been built for original and four different vaporing times using ABS material. ABS has high mechanical strength, is low cost and is convenient for fabrication and AM. The mechanical properties of the ABS are given in Table 1. The substrates were built by adding ABS layers that were 0.20 mm thick. The specimens were fabricated using a UP Plus 2 3D Printer machine. The 3D specimens were modeled in Solidworks 2016. The outputs exported as STL files that were imported by the FDM software.

Table 1
Mechanical properties of ABS

Tensile strength	37 MPa
Tensile modulus	2.320 MPa
Tensile elongation	3 per cent
Flexural strength	53 MPa
Flexural modulus	2.250 MPa
IZOD Impact, notched	106 J/m

Thus, the process proceeded with the printing of the specimens with some parameter setting.

2.2 Tensile Test

Tensile strength test was conducted using Instron Universal Testing Machine equipped with a 50-kN load cell. Tensile strength tests were performed according to ASTM D638 (plastics: determination of tensile properties) with 5 mm/min crosshead speed. Figure 1 shows the shape and dimensions of the test specimens [7]. The specimen was gripped with Wedge Action Grips. An extensometer was used to determine the elongation and tensile modulus of the part.

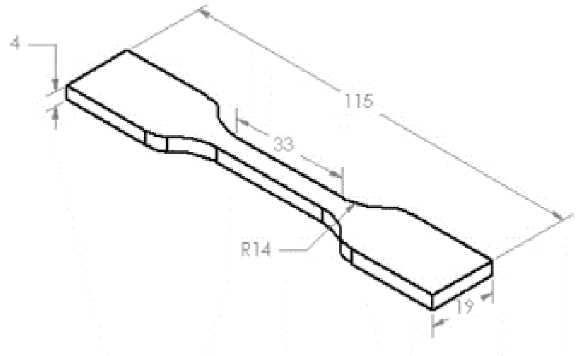

Fig. 1. Test specimens, all dimensions are in mm
tensile test specimen

2.3 Flexure Test

The flexural strength at yield was determined according to the ASTM D790 (plastics: determination of flexural properties) standard for the specimen shown in Figure 2. The specimen is held by two supports and loaded in the middle with a force until the test specimen fractures by using Static 3 Point Flexure Fixture. The distance between the supports is 60 mm. The loading nose is a spherical tool with a 5 mm radius. The tests were performed at room temperature with a constant crosshead speed of 2 mm/min and measured at 5% deformation or strain of the outer surface.

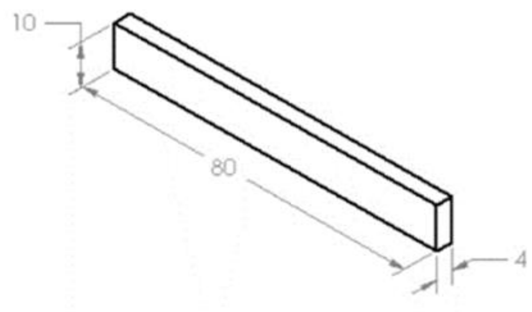

Fig. 2. Three-point flexure test specimen

2.4 Surface Finish Appearance

The surface finish appearance checked was conducted using a measuring microscope. The specimen used for the surface finish check was the same specimen for the tensile test or flexure test as the process just need the prepared surface of the material without considering it shapes. The important was the surface of material specimen that had undergone the vaporing process as the vaporing process would affect the structure of the specimen's surfaces.

3. Result and Discussion

The objective of this study is to analyze the effects of acetone vapor on the mechanical properties of parts produced by the FDM process.

3.1 Tensile Test

A tensile test was conducted to measure the tensile strength of the specimens. Each specimen was gripped at both ends before pulled until it breaks or meets the failure. The results showed the maximum load applied and ultimate tensile strength of the material for each specimen so that it can be compared.

Figure 3 below shows the graph of maximum load versus specimens. Based on the graph, the highest value for maximum load that to be compared with the original part was the specimen of sample 1 for 45 minutes vapored part with the value of 657.8956 N.

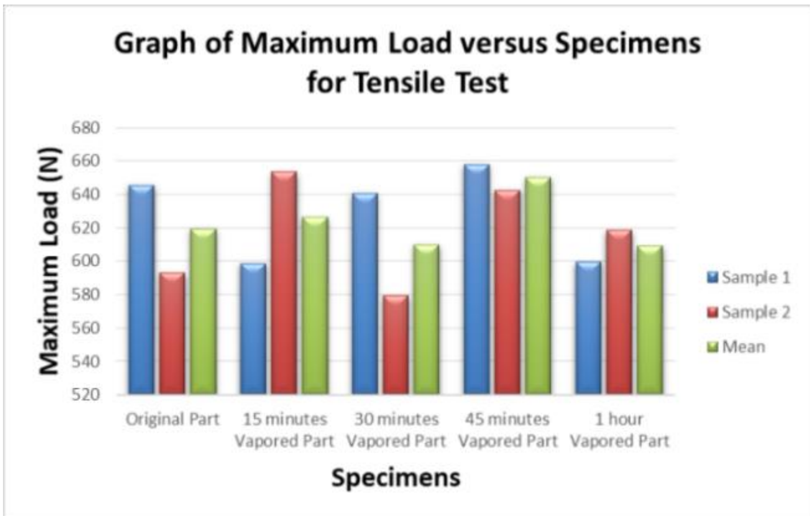

Fig. 3. Graph of maximum load versus specimens for tensile test

Meanwhile, the lowest value for maximum load was the specimen of sample 2 for 30 minutes vapored part valued 579.2352 N. There were two samples for each part. Therefore, the mean or average of the value for those two samples was required for further analysis. The highest average value for maximum load was 45 minutes vapored part with the value of 650.3140 N. Specimen of 15 minutes vapored part was the second highest value of average maximum load with 626.0480 N and followed by specimen of 30 minutes vapored part that valued 609.9648 N. The lowest was specimen of 1 hour vapored part with value of 608.8999N. All the specimens value were acceptable for further analysis as the increasing and decreasing percentage was below than 10 percent.

Figure 4 below shows the value of tensile strength for each specimen. The highest tensile strength that to be compared with the original part was the specimen of sample 1 for 45 minutes vapored part at 27.412 MPa. Next, the specimen of sample 2 for 15 minutes vapored part gave the second highest value with 27.232 MPa and followed by sample 2 for 45 minutes vapored part with 26.772 MPa. The fourth highest value of tensile strength was a specimen of sample 1 for 30 minutes vapored part with 26.696 MPa and continued with a specimen of sample 2 for 1 hour vapored part valued 25.594 MPa. Meanwhile, the specimen of sample 2 for 30 minutes vapored part gave the lowest tensile strength that valued 24.135 MPa followed by a specimen of sample 1 for 1 hour vapored part as second lowest with the value of 24.883 MPa and sample 1 for 15 minutes vapored part valued 24.934 MPa as third lowest of tensile strength.

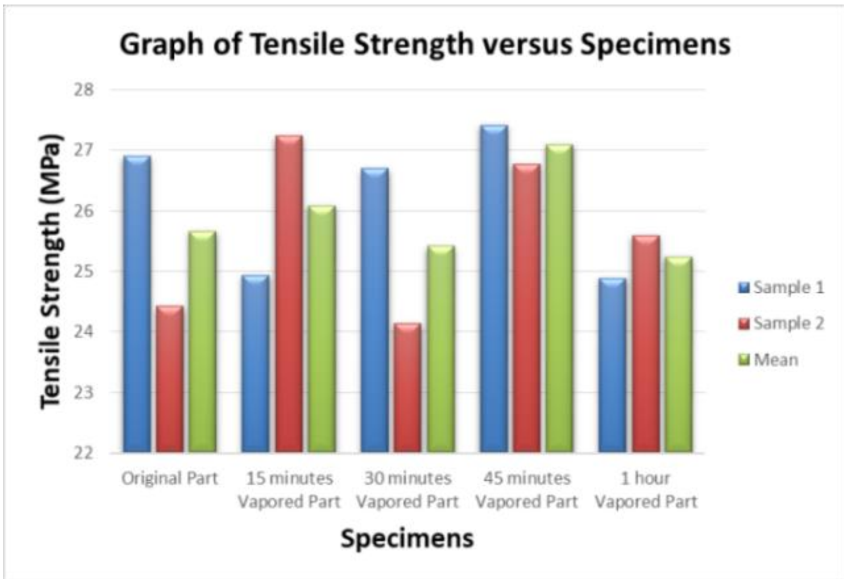

Fig. 4. Graph of tensile strength versus specimens

Figure 5 below shows the graph of average tensile strength versus the type of part. As the test conducted for each type of part was performed with two samples, the average of the values was required for further analysis and to compare with the original part value. Based on the graph, the 45 minutes vapored part gave the highest value of tensile strength with the value of 27.092 MPa. Next, the 15 minutes vapored part gave the second highest tensile strength valued 26.083 MPa followed by 30 minutes vapored part with 25.415 MPa. Meanwhile, the 1 hour vapored part resulted as the lowest tensile strength with a value of 25.238 MPa.

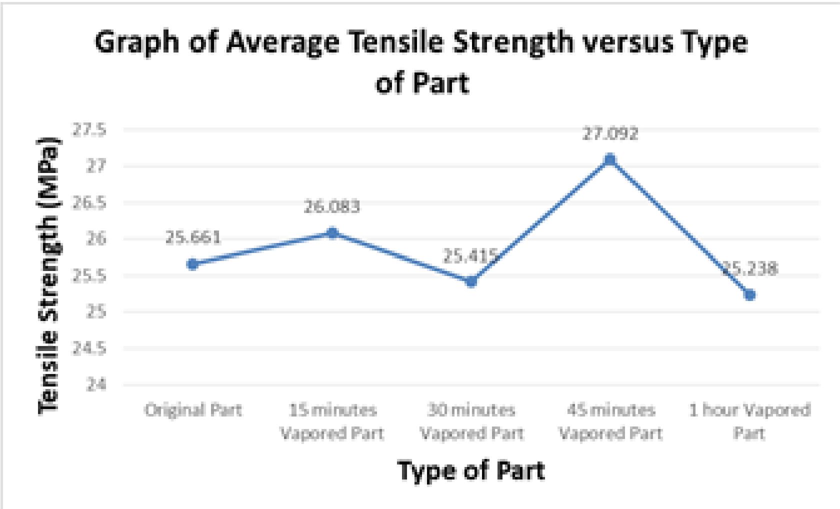

Fig. 5. Graph of average tensile strength versus type of part

Therefore, based on the results, the original part gave the average tensile strength of 25.661 MPa. As compared with the original part, the 45 minutes vapored part gave the higher value with 27.092 MPa. Besides that, the value of 15 minutes vapored part also gave the higher value than the original part and as the second highest compared to 45 minutes vapored part with the value of 26.083 MPa. Thus, it shows that the implementation of acetone vapor with the duration of 45 minutes and 15 minutes had improved the tensile strength of the material.

3.2 Flexure Test

Flexure test is frequently applied to a brittle specimen. The test was conducted by bending the specimen to fracture with three point loading technique. At the point of loading, the top surfaces of the specimens were placed in a state of compression, while the bottom surfaces were in tension state. The stress at fracture for flexure test is known as flexural strength or modulus of rupture which considered as the important mechanical parameter for brittle material.

Figure 6 below shows the graph of the maximum load against ten specimens. The maximum load means that the force that used to bend the specimens during the testing to meet the 5 percent of strain. The highest value for maximum load that to be compared with the original part was the specimen of sample 1 for 45 minutes vapored part with the value of 92.62290 N. Meanwhile, the lowest value for maximum load was the specimen of sample 2 for 1 hour vapored part valued 85.07919 N. Based on the average values of each part, the results gave the specimen of 45 minutes vapored part as the highest maximum load valued 90.80477 N to be compared with original part. The results followed by 30 minutes vapored part with 89.51199 N, 15 minutes vapored part valued 89.40279 N and the lowest was 1 hour vapored part with 86.67410 N.

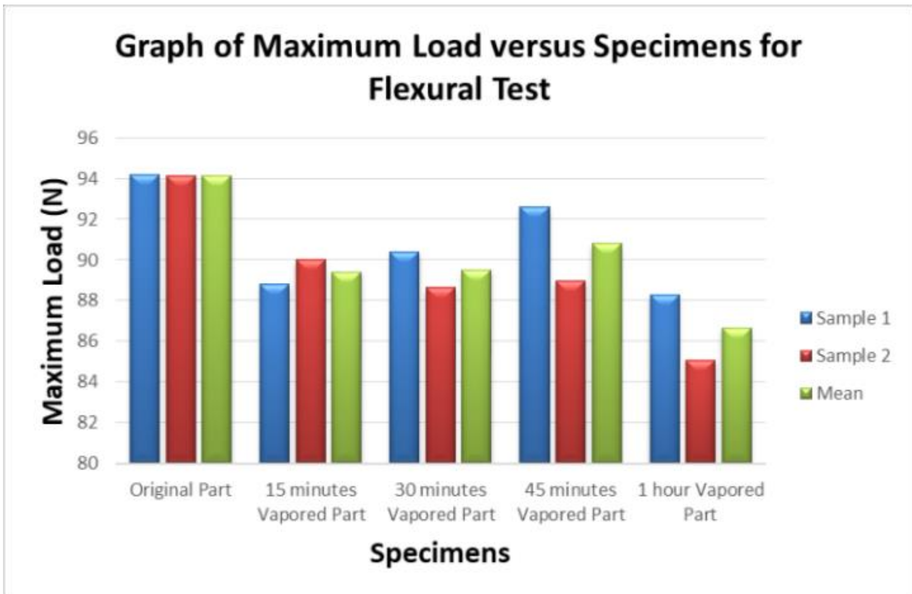

Fig. 6. Graph of maximum load versus specimens for flexure test

Graph in Figure 7 below shows the flexural strength for each specimen. The uppermost flexural strength to be compared with the original part was sample 1 for 45 minutes vapored part valued 52.10038 MPa followed by sample 1 for 30 minutes vapored part with 50.84479 MPa, sample 2 for 15 minutes vapored part gave the value of 50.62673 MPa. Then, sample 2 for 45 minutes vapored part resulted as the fourth uppermost value of flexural strength valued 50.05499 MPa, continued with sample 1 for 15 minutes vapored part valued 49.95141 MPa and 49.85620 MPa for sample 2 of 30 minutes vapored part. Meanwhile, both specimens for 1 hour vapored part gave the lowermost values of flexural strength with sample 2 valued 47.85704 MPa as the lowest and sample 1 valued 49.65131 MPa as second lowest.

The line graph shows in Figure 8 below shows average flexural strength versus type of part. As the test conducted for each type of part was implemented with two samples, so that the average of the values was required for further analysis and to compare with the original part value. As referred to the graph, the 45 minutes vapored part gave the highest value of flexural strength valued 51.07768

MPa. Then, the 30 minutes vapored part gave the second highest flexural strength with 50.35049 MPa and continued with 15 minutes vapored part that gave the value of 50.28907 MPa. Meanwhile the 1 hour vapored part resulted as the lowest flexural strength with value of 48.75418 MPa.

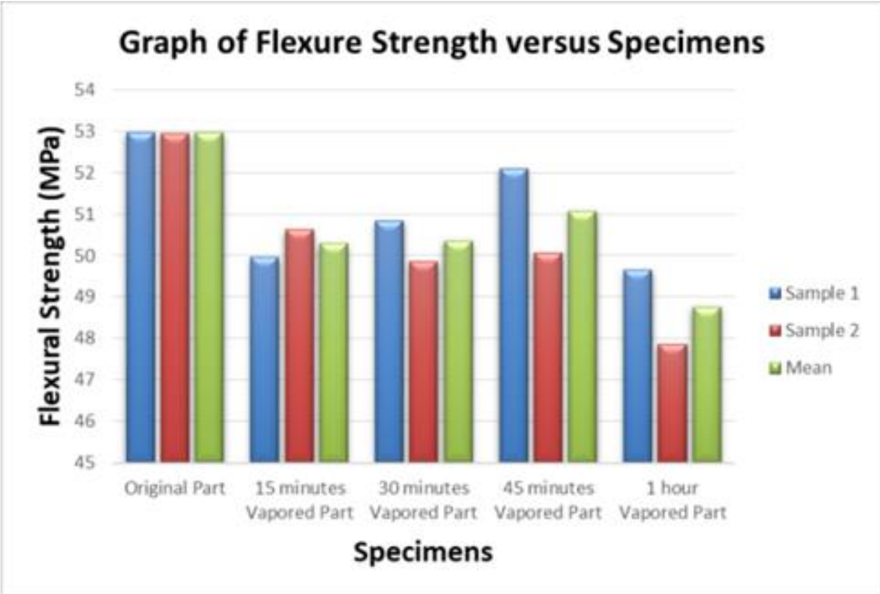

Fig. 7. Graph of flexural strength versus specimens

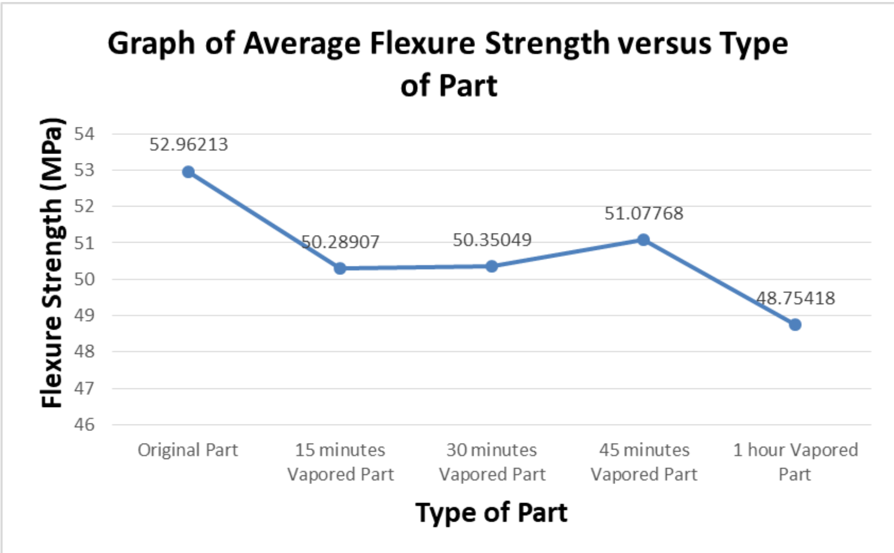

Fig. 8. Graph of average flexural strength versus type of part

So that, as resulted in the graph, the average flexural strength of the original part was 52.96213 MPa. All the parts gave the lower flexural strength of the material as compared to the original part. The 45 minutes vapored part gave the highest value among the other three type of parts with value of 51.07768 MPa. Thus, the 30 minutes vapored part ranged as second highest valued 50.35049 MPa followed by 15 minutes vapored part with 50.28907 MPa while the lowest value was 1 hour vapored part gave the value of 48.75418 MPa. Therefore, the implementation of acetone vapor had decreased the flexural strength of the material instead of improving.

3.3 Surface Finish Appearance

The surface finish was checked to see the appearance of the material structures after undergo the vaporing process. Theoretically, the part on the material surface would melt as exposed to acetone vapor in order to produce a smooth and shiny surfaces. Therefore, the melted part was effected the structure arrangement of the material on the surface. The surface finish checked was performed to differentiate the image of structure for the original part compared to the acetone vapored parts.

Based on Figure 9, its show the surface finish appearance of the original part and acetone vapored parts. Figure 8 shows the surface finish appearance of the original part with the smallest size of the structure among others. As the parts had undergone vaporing process with acetone, the structure of the material had also changed. Therefore, Figure 10 below shows that the sizes of surface finish appearance of the material become bigger than the original part's structure. In addition, the size of the structure become larger with the increasing of vapored time as shown in Figure 11, Figure 12 and Figure 13. The increasing size of the structure varies with the increasing time of vapor as the acetone vapor reacted with the parts by melted the material. So that, it had effected the structure of the material.

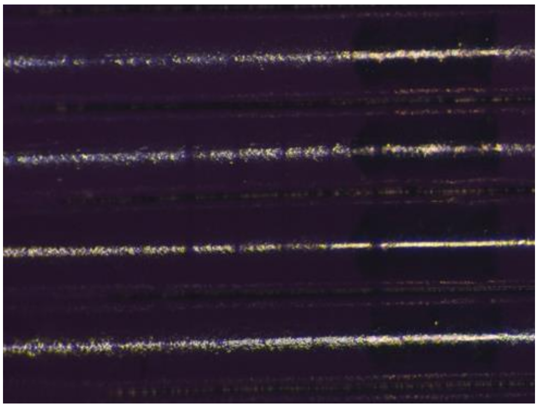

Fig. 9. Surface finish appearance of the specimens; original part

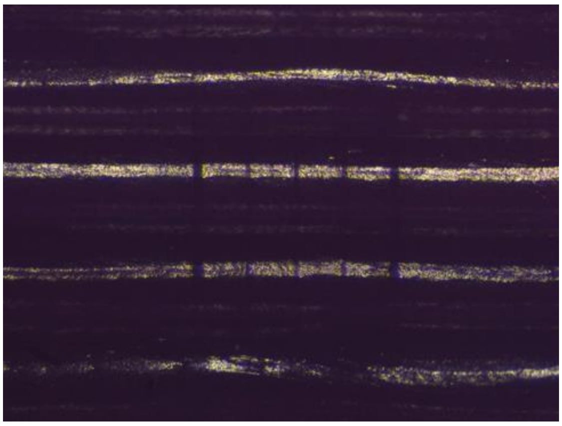

Fig. 10. Surface finish appearance of the specimens; 15 minutes vapored part

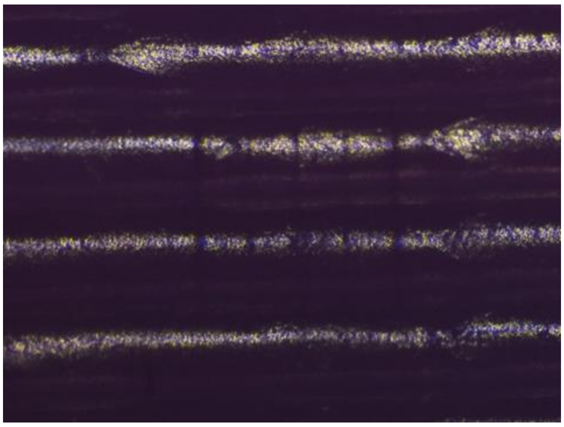

Fig. 11. Surface finish appearance of the specimens; 30 minutes vapored part

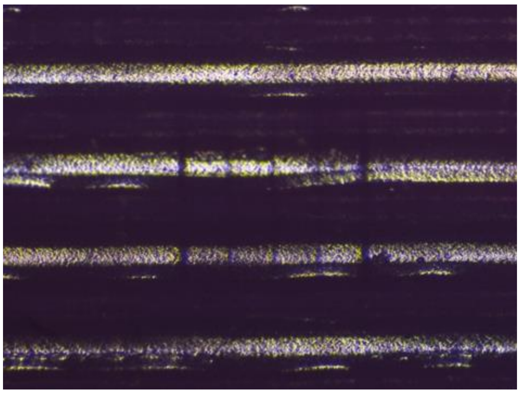

Fig. 12. Surface finish appearance of the specimens; 45 minutes vapored part

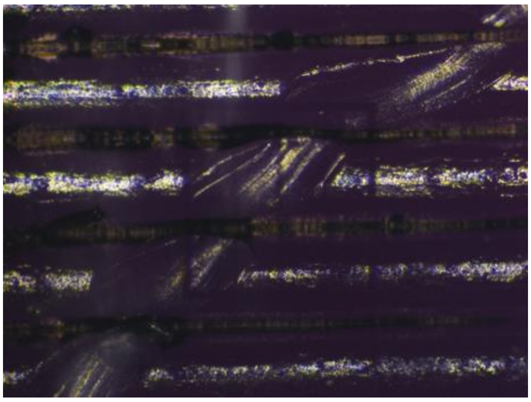

Fig. 13. Surface finish appearance of the specimens; 1 hour vapored part

As the final of all the analysis that had been done, the effect acetone vapor on mechanical properties of FDM. ABS printed part were identified. The mechanical properties that involved were tensile strength and flexural strength with surface finish of the material.

The tensile strength of the material was improved by undergo the acetone vaporing process in the duration 45 and 15 minutes of time compared to the original part. This showed that the vaporing process had improved the tensile strength of the material but in the range of time that had been identified.

Meanwhile, the flexural strength of the material was decreased as part undergo vaporing process. All the set of duration vaporing times resulted to lower the flexural strength. As the results, the effect of the acetone vapor had decrease the flexural strength of the material. The material could undergo the vaporing process but at the best time that had been identified in order to prevent the decreasing of flexural strength. The best set of time to maintain the flexural strength was 45 minutes as the results showed that it was the best time that gave the highest value of flexural strength among others. Reducing of flexural strength of the material as it undergoes vaporing process was because of the increasing of brittleness for the material, made it easily to fracture.

Besides that, for the surface finish appearance, the results showed that the reaction of acetone vapor had enlarged the size of the structure for the material. The increasing of vaporing time had increased the enlargement of the structure size. The longer the duration of vaporing process time, the larger the structure size would be.

Each duration of vaporing process was tested with two sample of specimens that had gave a slightly different values. Therefore, the average value was required. The different values could be caused by the technique of printing or vaporing the parts. However, the differences could be acceptable as the increasing or decreasing values was not more than 10 percent.

4. Conclusion

As conclusion, acetone vapor had effected to the mechanical properties of FDM printed part. As mechanical properties studied, tensile strength had been improved by implementing the acetone vapor meanwhile not for flexure strength. However, it is still can be considered as the vapored part flexure strength did not differ much compared to the original part. The best duration of vaporing time is 45 minutes for both mechanical properties

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