Analysis of the influence of chemical treatment to the strength and surface roughness of FDM

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Abstract. The applications of Additive Manufacturing (AM) technology have a greater functionality and wider range of application beyond an intention of prototyping. AM is the process of joining materials to form objects from Computer-Aided Design (CAD) models via layer upon layer process. One of AM technologies is the Fused Deposition Modelling (FDM), which use an extrusion method to create a part. FDM has been applied in many manufacturing applications includes an end-used parts. However, FDM tends to have bad surface quality due to staircase effect and post treatment is required. This chemical treatment is one of a way to improve the surface roughness of FDM fabricated parts. This method is one of economical and faster method. In order to enhance the surface finish of Acrylonitrile-Butadiene-Styrene (ABS) FDM parts by performing chemical treatment in an acetone solution as acetone has very low toxicity, high diffusion and low cost chemical solution. Therefore, the aim of this research is to investigate the influence of chemical treatment to the FDM used part in terms of surface roughness as well as the strength. In this project, ten specimens of standard ASTM D638 dogbone specimens have been fabricated using MOJO 3D printer. Five specimens from the dogbone were tested for surface roughness and tensile testing while another five were immersed in the chemical solution before the same testing. Based on results, the surface roughness of chemically treated dogbone has dramatically improved, compared to untreated dogbone with 97.2% of improvement. However, in term of strength, the tensile strength of dogbone is reduced 42.58% due to the rearrange of material properties and chemical effects to the joining of the filaments. In conclusion, chemical treatment is an economical and sustainable approach to enhance the surface quality of AM parts.

1. Introduction
Additive manufacturing (AM) is a group of techniques used to fabricate quickly a scale model of a physical part using a CAD system. It describes the technology of generative production processes. According to the ASTM definition, AM is the process of joining materials to create a part from the CAD model by layer upon layer. One of famous technologies of AM is Fused Deposition Modelling (FDM). FDM is solid-based manufacturing system that utilizes solids as the primary medium to create parts, which uses extrusion to from parts. FDM can consider as AM by laying down material in layers that use Acrylonitrile-Butadiene-Styrene (ABS) in the form of plastic filament using molten material system [1].

Moreover, FDM technology has expanded not only to be used as prototype, but as well as functional applications as the end-used parts. Therefore, the strength and surface finishing of FDM is important considerations to assure the quality and usability of FDM product with satisfactory physical and mechanical qualities.
In order to attain a good surface finish, researches had been done to recognize the parameters, which can give obvious effect to the surface roughness of the parts produced, include built orientation, slicing height and chemical treatment [2]. In this report, the parameter that will discuss in detail is chemical treatment. It is used to enhance the surface finish of ABS fused modelled part by chemical dipping that yielding significant improvement of the roughness of the treated [3]. Although the implementation of the chemical treatment on the FDM part will gives effect on the tensile strength of the part, the proposed chemical post treatment will be fast, economic and easy to be conducted method to improve the surface finish of the ABS parts [4][5][6].

Therefore, this research focuses on the chemical surface treatment method to eliminate the irregularities on the surface of parts produced via FDM by chemical smoothing reaction observed the improvement of the finishing as well as the behaviour of the finishing. This led in investigating the effect of the chemical treatment to the FDM parts on surface quality and mechanical strength as well maintaining the original dimension without degrading the quality of the parts.

2. Experimental procedure

The experiment works was done to investigate the effect of the chemical treatment on the surface roughness as well as the tensile properties of the FDM used part. Hence, this will include the fabrication of specimens by FDM machine using ABS material. Specimens of dogbone are fabricated in way to carry out analysis of surface roughness and tensile test. Figure 1 show the flow chart of studies.

![Flow chart of the project](image)

Figure 1. Flow chart of the project

In this study, the dogbone specimens of size and material were created according to Standard Test Method for Tensile Properties of Plastic, Type I ASTM D 638-01. The material of test specimens for this experiment is ABS, which is a rigid plastic. ABS is one of types of thermoplastic that deformable and recyclable. For the mechanical properties, ABS is the toughness and impact resistance. It affects
resistance will not fall drastically at low temperature. Figure 2 shows the standard dogbone specimen size and its dimension are presented in table 1.

![Figure 2. Standard specimen for plastic parts](Source: ASTM Standard, D638-02)

**Table 1.** Detail dimension of ASTM 638-01, Type I dogbone test specimen. (Source: ASTM Standard, D638-02)

| Specimen of D638-01, Type I | Dimension (mm) |
|-----------------------------|----------------|
| L₀  Overall length       | 165            |
| W₀  Width overall       | 19             |
| W   Width of narrow section | 13            |
| L   Length of narrow section | 57             |
| R   Radius of fillet     | 19             |
| h   Thickness            | 3.2            |
| l₀  Gauge length        | 50             |
| D   Distance between grips | 115           |

The fabrications of the parts use the MOJO™ system, which use the FDM technology to build models from CAD STL files. It creates parts layer by layer via extruding engineering grade thermoplastics such as ABSplus model material and SR-30 as support material through print heads. In this machine, it has some control parameters that expected to affect the quality of the parts when produce especially in surface quality. Therefore, in this project, fabrication variables were decided as a constant variable throughout the fabrication. Table 2 show the fabrication variable has been decided.

**Table 2.** Constant Process Variable.

| Process Variable | Value  |
|------------------|--------|
| Orientation      | Horizontal |
| Support Style    | Sparse  |
After the dogbone specimen have fabricated, the specimens are subjected to a chemical treatment process. Acetone was chosen as the chemical solution for this experiment because it has very low toxicity, high diffusion and low cost chemical solution. This chemical solution has a low reticulation degree, including Nitrile functionality having a weak reaction with polar solvent on this chemical. This Acetone was selected according to ABS material [7]. Then the surface roughness of specimen been investigated using surface roughness tester while the strength of has been test using tensile strength analysis using Universal Tensile Test. Figure 3 shows the flow chart of experiment that has been designed as a main method.

![Figure 3. The design of experiment](image)

2.1 Chemical treatment

For the chemical treatment process, Acetone was used as a solution to increase the surface roughness due to it properties towards ABS material. However, there are some difficulties while using acetone, which the chemical is too strong for solvent. Due to that, the chemical solution is added with water with the volume of 90% dimethylketone and 10% water during the process of immersion. All of the 5 dogbone specimens were immersed into the acetone solution for 300 seconds as shown in figure 4. All of the ready specimens were observed and measured in terms of surface roughness values.

![Figure 4. An Example of the Specimens Immersing in Acetone Solutions.](image)

2.2 Surface roughness analysis

All the specimens of dogbone were analysed before and after been treated with chemical. The surface roughness of the treated and untreated specimens had been measured using precision measuring instrument, which is Mitutoyo Suetest SJ 301™ as shown in figure 5. The recorded profile display capability allows surface texture measurements to check instantly with prior to print out.
2.3 Tensile testing

Mechanical properties use in this study to identify the strength of the parts and focus on to the tensile properties. Tensile properties designate the material behaviour will respond to the forces been applied in tension. Therefore, the tensile test is the mechanical test that been done in this research. To conduct a tensile test, the test specimen is gripped at the end and pulled apart until the specimen is broken. In order to minimize the damage on the specimen due to the clamping force, the specimens are designed to have their narrower centre part than the ends as shown in figure 6. The data from the testing includes Young Modulus (E), Maximum Force ($F_{\text{max}}$), strain and tensile strength. Tensile stress is defined as force per unit area of the original cross section within the gauge length. It is usually expressed in megapascal (MPa). The formula is as below

$$\sigma = \frac{F}{A}$$  \hspace{1cm} (1)

Where:
\begin{itemize}
  \item $\sigma$: tensile stress (MPa)
  \item $F$: Force applied (N)
  \item $A$: Initial cross sectional area of the specimen (mm$^2$)
\end{itemize}

Figure 5. Mitutoyo Sueftest SJ 301

Figure 6. Tensile Test Experimental Setup
3. Result and discussion

In this section, the influences of the chemical treatment of acetone on the build parts of FDM will be described. The surface roughness of the parts build is analysed for both treated and untreated parts. The tensile strength of the parts also had been recognizing the effect of chemical treatment to the AM parts. Figure 7 shows the dogbone specimen after printed using MOIO™ FDM machine and before it been treated into acetone. While figure 8 shows the dogbone specimen that has been immersed in acetone in 300 seconds. By visual observation, It shows that the surface finish of the specimens after treated were smooth and shiny compare to untreated specimens.

![Figure 7. Dogbone Specimens before Immerse in an Acetone](image1)

![Figure 8. Dogbone Specimens after Immersed in Acetone](image2)

Surface roughness is a component of a surface texture which quantified by the normal vector of the real surface in ideal form. To check the surface roughness of the treated and untreated parts of FDM was using Mitutoyo Surftest SJ 301. Table 3 shows the value of surface roughness, $R_a$ for treated and untreated dogbone specimens.

| Treated /Untreated | Specimen | Surface Roughness, $R_a$ | Mean Roughness Average, $R_a$ |
|--------------------|----------|---------------------------|-------------------------------|
| Untreated          | 1        | 12.84                     |                               |
|                    | 2        | 12.71                     |                               |
|                    | 3        | 12.85                     | **12.736±0.164**              |
|                    | 4        | 12.82                     |                               |
|                    | 5        | 12.46                     |                               |
| Treated            | 1        | 0.27                      |                               |
|                    | 2        | 0.42                      |                               |
|                    | 3        | 0.37                      | **0.350±0.054**               |
|                    | 4        | 0.35                      |                               |
|                    | 5        | 0.34                      |                               |
Figure 9. Graph of comparison of the surface roughness of the treated and untreated specimens.

Based on figure 9, the mean surface roughness, $R_a$ for untreated dogbone specimen is 12.736µm while treated is 0.35µm. The surface roughness of specimens treated with acetone has better surface roughness compare to the untreated with the improved 97.25%.

Besides, to know the surface roughness of AM part, the test has been taken for these specimens. The tensile strength of material is the maximum amount of tensile stress that it can take before failure. The table 4 show the tensile strength and its Young Modulus after tensile test experiment.

Table 4. Mechanical Strength Data of Treated and Untreated Specimens

| Treated / Untreated | Specimen | Tensile Strength (MPa) | Mean Tensile Strength (MPa) | Young Modulus (MPa) | Mean Young Modulus (MPa) |
|---------------------|----------|------------------------|----------------------------|---------------------|------------------------|
| Untreated           | 1        | 36.54                  | 36.012                     | 7.00                | 6.5±0.500              |
|                     | 2        | 36.60                  |                            | 6.50                |                        |
|                     | 3        | 35.52                  | 36.012                     | 7.00                | Article I.             |
|                     | 4        | 36.12                  |                            | 6.00                |                        |
|                     | 5        | 35.28                  |                            | 6.00                |                        |
| Treated             | 1        | 18.84                  |                            | 4.57                |                        |
|                     | 2        | 17.28                  |                            | 5.00                |                        |
|                     | 3        | 26.30                  | 20.678                     | 5.63                | 4.69±0.432             |
|                     | 4        | 23.98                  |                            | 5.00                |                        |
|                     | 5        | 16.99                  |                            | 4.50                |                        |
Based on figure 10, it shows clearly that all tensile strength of the treated specimens has low strength compared to the untreated specimens. The reduction of mean tensile strength was from 36.012MPa to 20.678MPa or 42.5% in percentage value. This can conclude that the specimens that chemically treated with acetone will affects the tensile properties of the parts. Suggested that this may due to the joining of the subsequent filaments affect the arrangement of the atom internally during and after the reaction with the acetone solution.

In addition, the Young Modulus undergoes plastic deformation where the shape of material will not back to original shaper after the force is removed. According to figure 11, all treated specimens also have a lower modulus of elasticity compared to the untreated specimens. This means that there are decreases in term of stiffness after the part immersed into the acetone. In terms of reduction in average, the Young Modulus has dropped from 6.5 to 4.96 or 23.7% in percentage value. This may due to the joining effect of filaments after reacting with acetone.
4. Conclusion

As the conclusion, the main aim of this project is to investigate the influences of chemical treatment to the FDM part in term of surface roughness and mechanical properties has been achieved. The findings of this study generally suggest that chemically treated parts have very good surface finish. However, this will affect the mechanical properties of the parts with reduction of tensile properties. The result from both tensile strength and Modulus of Elasticity, the mechanical properties generally has reduced suggested due to the reaction to the chemical which creating isotropy after chemical treatment. These results can be explained by the joining effect of the filaments after the penetration of Acetone along the structure of the part itself. These show that the treated specimens have improved 97.2% in surface roughness analysis. On the other hand, chemical treatment was able to improve significantly the surface finish of ABS part. Moreover, this chemical treatment is one of the economical and fast methods to enhance the surface quality of the additive manufacturing parts in future manufacturing industry.

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