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Mechanical Properties of 3D Printed Surface under Influence of Chemical Post Processing

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ABSTRACT: The emergence of additive manufacturing has introduced fused deposition modeling (FDM) as one of the popular technology in fabricating desired prototypes. This is due to its capability to fabricate 3D part effectively, economically and more user-friendly. However, the yield of the product was poor in surface finish and it produced staircase effect resulted from the layer by layer deposition process. The staircase issue on the fabricated part impaired the finishing of the product due to the deposition process which contributed to rough surface finish. The chemical treatment is one of the methods that employed widely to treat 3D printed part and improve its surface topography. Hence, this research is focusing on the chemical post-processing treatment for surface finish of ABS printed part and the influences of the chemical towards ABS strength and porosity. The methyl ethyl ketone (MEK) was used as a solvent to the ABS to dissolve the thermoplastic to form a new structure of printed part in order to reduce the surface roughness. The amount of the MEK was applied with a designed applicator at different volume. It was discovered that MEK treatment can be used to produce better surface finish. The roughness was reduced as much as 94.2% with the use of the designed applicator. While the strength of printed ABS was strengthened as much as 8.4% and the porosity was improved a little about 10.2%

KEYWORDS: Additive Manufacturing (AM); Chemical Post Processing; Methyl Ethyl Ketone (MEK); Surface Roughness.

1. INTRODUCTION

Fused deposition modeling (FDM) is one of the methods in additive manufacturing that able to fabricate object layer by layer from CAD data [1].

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Additive manufacturing or also known as 3D printing may revolutionize the way of manufacture things in the future due to its capability to fabricate parts in a shortened time [2-3]. It becomes one of the techniques that can be applied as a necessity of domestic in future especially for hobbyist and researchers due to its ability which can be adopted to fabricate desired part without particular tooling besides it can be used in work environment with ease handling procedure [4-5]. However, most of additive manufacturing/3D printing gives adverse effect to its surface finish and produces the stair stepping effect due to the deposition process that brings to the printed part less in surface quality and also affecting its dimensional accuracy [1-6].

According to Galantucci et al, this problem can be reduced via several methods such as optimizing printing parameters and employs chemical post treatment as a medium to improve surface roughness and the mechanical properties [7]. Consequently, the strength and the porosity of printed part also can be improved by both of these methods. In addition, Lee et al. stated the parameters that required to produce better surface finish were layer thickness and printing angle. These parameters were able to enhance finishing of printed object with the proper adjustment of parameter setting [8]. It was supported by Bual et al. which discovered there were four types of approaches in the improving surface finish in FDM which were i) optimizing printing orientation ii) layer thickness strategy ii) parameters optimization in fabricating 3D part iv) post processing treatment [9]. Other than that, Habeeb et al have shown the relationship between strength and porosity of PLA in 3D printing that stated the highest tensile strength was influenced by layer height parameter and the low layer height resulted to the low porosity of sample [10]. The development technique of pressing successfully invented by Majid et al where the porosity of printed part was improved by using an integrated roller to exert pressure on the semi-solid filament which consequently filled up the porous structure and reduced porosity. The tensile strength slightly increased due to the compression that made the bonding of ABS particles holding

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tightly between one layer to another [11]. However, Jin et al discovered that chemical treatment was a method that can be adopted to attain better finishing which cannot be avoided via optimizing parameter [12].

The usage of chemical like dimethyl ketone (aceton) solvent can be used to react with ABS in order to improve the surface finish and strength under consideration of several control factors in printing parameter such as build orientation, raster angle, raster width and layer thickness [13-14]. One of the methods for post-processing techniques was vapor polishing that was used as surface treatment by coating the printed part evenly without affecting the dimensional accuracy significantly. The treatment made the solvent reacted with ABS layers, which it fused together and reformed a new structure that produced a smooth surface finish. This also can increased cohesion between layers and affects the mechanical properties of ABS [15-19]. Hence, in this research, MEK was applied on 3D printed surface as post processing treatment and its influence on ABS mechanical properties for instance surface roughness, tensile strength and porosity were studied. The new method was proposed in this experiment which an applicator was being used to apply the MEK on top of the ABS printed part evenly.

2. METHODOLOGY

Specimens were fabricated using ABS thermoplastic by following ISO 527:2007 standard (ASTMD638) on low-cost 3D printer (Mendel Max). The samples were constantly built up with XY direction with printing speed of 30mm/s. The temperature for nozzle and bed were set at 240˚C and 100˚C respectively. The parameters setting is shown in Table 1.

Table 1: Parameter setting for 3D printing

Volume, ml	1	2	3	4	5	6	7
Layer thickness, mm	0.2						
Fill angle,˚	90						
Infill pattern	Line						
Infill density, %	30						

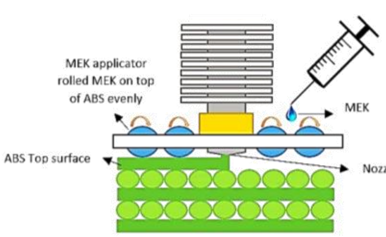
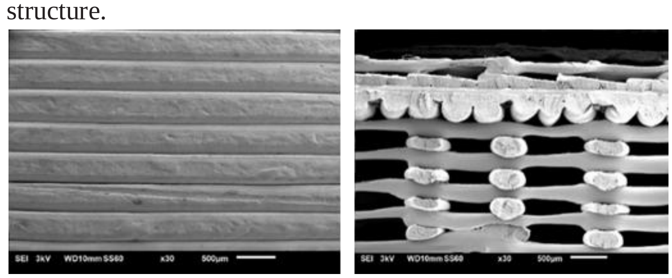


Figure 1: The schematic diagram of integrated applicator in FDM

An applicator was designed to apply the injected solvent on the ABS surface evenly. The application of MEK volume was made using 20ml syringe. Each of samples was rolled with various amount of MEK. The purpose was to investigate the optimum volume that produced the best surface roughness. The samples were cured for five days in order to solidify the ABS structure completely. This experiment was carried out for three times and the average reading of the results of the testing was taken. The surface roughness of all samples were taken using Mitotuyo profilometer to measure the surface peaks and valleys. The initial roughness for the untreated sample was recorded at 12.093 µm. The tensile strength test was performed using INSTRON 5969 model with 50kN (11250lb) maximum load capacity and 5mm/s for the speed velocity testing. The untreated tensile strength data was collected at 13.058 MPa and it was being compared with MEK treated samples. The scanning electron microscope (SEM) was used to observe the surface. The porosity analysis was performed by using ImageJ software in order to compare the percentage before and after post processing-treatment.

3. RESULTS AND DISCUSSION

The initial reading of surface roughness and tensile strength for untreated samples were acquired at 12.093 µm and 13.058 MPa respectively. The SEM images were captured as shown on Figure 2 a) and b). Based on Figure 2, both of the pictures have shown that the surface topography of the untreated ABS was coarse and bumpy. The cross section of the sample also appeared jagged and with the top view of the sample, the printing line which resulted fromdeposition process can be seen clearly. The air gap of ABS prominently showed that the porosity was high and can tend to low in tensile strength. Figure 3 represented the result of porosity illustration by ImageJ software where it was found about 45% of porosity for the air gap of the ABS structure.



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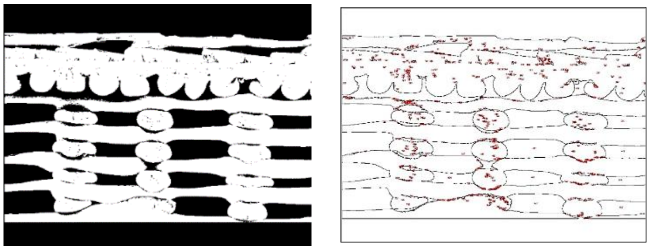
(a) (b)

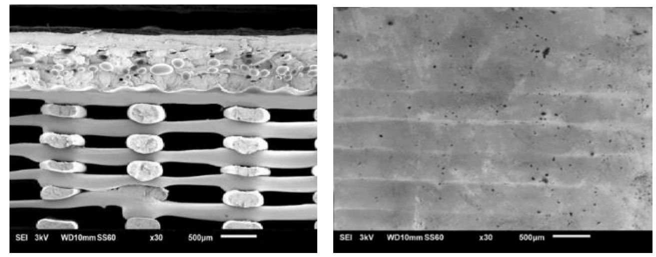
Figure 2: SEM of untreated sample a) Top view b) cross section



(a) (b)

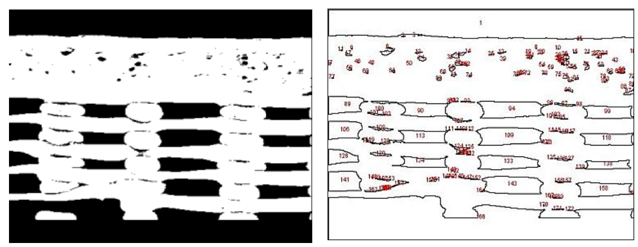
Figure 3: Porosity image a) black and white image of porosity b) particle image analysis

Based on the data obtained, using chemical treatment as post-processing improved the roughness and strength at a certain amount of volume. The volume of chemical played significant role in determining the roughness of the ABS. Figure 7 indicates that the roughness has reduced from Ra= 12.093 µm to Ra= 0.703 µm when 1 ml of MEK applied on ABS. In addition, 94.2% of improvement was achieved and the perceptible glossy effect of the sample was noticed for the exterior surface of ABS. The MEK dissolved the ABS surface and formed a strong intermolecular bond as the MEK evaporated and created cohesive bonding on ABS structure. As a result, the distance of printing line became closer and the molecular structure of the reactant bonded each other as shown in Figure 4 b). The surface roughness worsened when the volume of MEK increased. This has shown that the high volume of MEK may increase the surface roughness where Ra = 6.02 µm was recorded for 7 ml MEK. Figure 4 a) showed the cross section when the reactant has filled in the air gap in between the deposition line and increasing the compactness of ABS structure with the present of tiny bubbles that might affect the percentage of porosity. The porous structure was reduced a little compared to the untreated sample where 40.4% for MEK specimen and 45% for the untreated specimen. The satisfactory strength was recorded at 14.163 MPa for 1 ml of MEK and it was drop off to 10.759 MPa as the volume increases to 7ml. Figure 7b) has shown the trend line of tensile strength mean for treated samples that reduced as volume of MEK increased. The error bars become inconsistence in the distribution point as the volume increases due to the structures changes on the ABS surface that absorb the MEK chemical in different rate which caused the uneven fragile area. The Figure 8 b) shown the improvement between the treated and untreated tensile data right after 1ml of MEK was used on the ABS samples.



(a) (b)

Figure 4: SEM of treated sample a) cross section b) top view



(a) (b)

Figure 5: Porosity image of sample treated with MEK a) black and white image of porosity b) analyse particles image

Figure 4 a) showed the cross-sectional view of ABS where the reaction between MEK and ABS plastic produced a reactant that filled in the air gap of the sample. This made the molecular chain of ABS broken down and slide over each other and reformed a new secondary bond with the presence of MEK solvent. At this stage, the intermolecular forces between MEK molecules were weak and the vapor pressure was relatively high due to the lower boiling point of MEK compound and the molecules evaporated easily at room temperature. As a result, the new form of ABS structure was produced with glossy effect on its surface. MEK has low viscosity liquid and is highly volatile with 70mmHg (9.5kPa) vapor pressure at 20˚C temperature. Thus this liquid vaporized easily at room temperature and the sample treated using this chemical must be fully cured. The low chemical resistance property of ABS has made its random structure to absorb chemical easily and destroy its secondary bond if the

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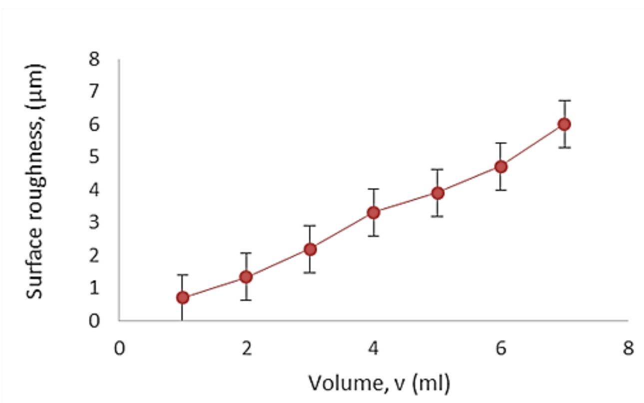
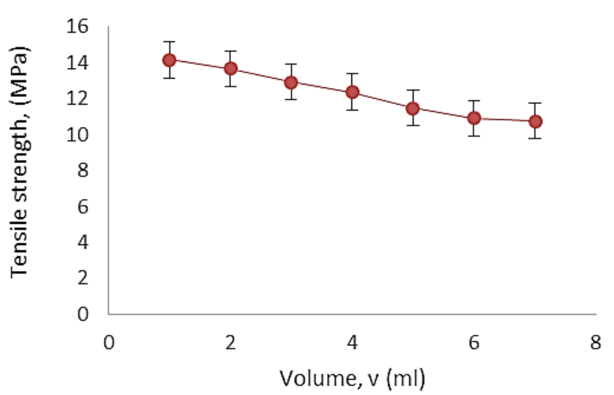
usage amount of the chemical was not being controlled which would then lead to the poor in roughness and produce a brittle material structure. For the MEK treatment, it was observed that the amount of the chemical was very important in order to produce high quality of surface finish besides increasing the strength and reducing the porosity of ABS part. The interaction of ABS and MEK material showed significant improvement in its mechanical properties. Compared to related study, it was reported that other researchers have conducted cold vapor and dipping treatment for surface treatment of ABS, this method is difficult to be controlled and the longer exposure to the chemical may cause the structure of ABS damage [12].

The consideration of concentration and time exposure must be taken into account in optimizing and obtaining a better result for the treated part [7], [13-14], [20], [21]. However, by this research approach, the volume control become another factor which is an important element that can be used with the application of integrated roller with additional material [22]. This has proven that MEK is a solvent that can be used to enhance the mechanical properties [23] of ABS printed part at the suitable amount [24].

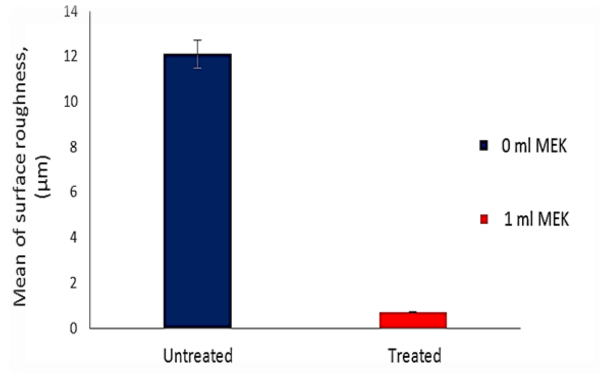


a)

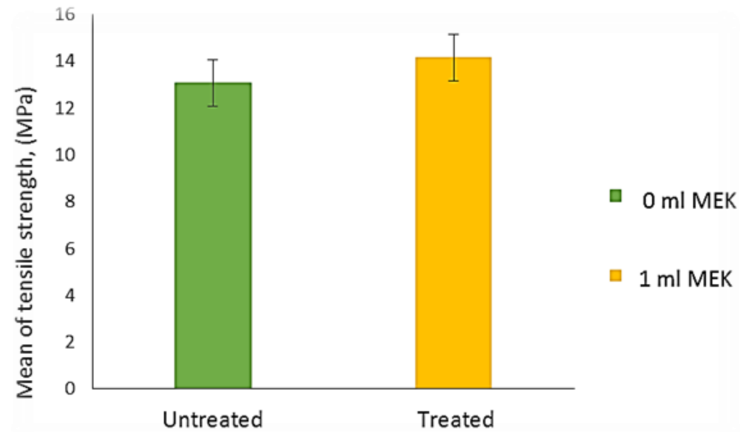


b)

Figure 7: Influence of MEK a) Mean of surface roughness b) mean of tensile strength



a)



b)

Figure 8: Comparison of treated (at 1ml) and untreated sample a) mean of surface roughness b) mean of tensile strength

4. CONCLUSION

FDM has a high potential in various application but the quality of printed parts needs to be improved. The drawbacks of FDM in its mechanical properties has led to the introduction of various methods in improving FDM parts. This research indicates that application of MEK as post-processing method on 3D printed topography enables the surface roughness to be improved significantly besides it gives impact on the tensile strength and the percentage of porosity. This process is much easier and economical. However, the amount of MEK applied on the surface need to be controlled to ensure the required roughness can be obtained and the molecular structure of the ABS part can be

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improved with the right amount of MEK. This shows that the treatment of ABS by using MEK gives positive impact to the tensile strength and the porosity of treated part.

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