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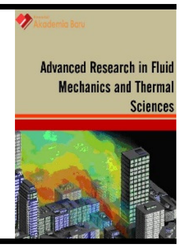

Surface Finish and Mechanical Properties of FDM Part After Blow Cold Vapor Treatment

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ABSTRACT

Fused deposition modeling (FDM) is a 3D printing/additive manufacturing (AM) technology that creates a part layer by layer. However, the printed parts have poor surface finish and staircase effect, which is the inherent characteristics of FDM printed parts. This contributes to poor quality of the final components. Thus, in this paper, post process treatment on 3D printed part by using blow cold vapor has been made. The parts were fabricated by using the open-source 3D printer with acrylonitrile-butadiene-styrene (ABS) material. Then, after the treatment, the surface finish and the mechanical properties of the parts were analyzed. The cold vapor treatment using chemical agents, namely acetone and methyl-ethyl-ketone (MEK). A comparison was made between the parts before and after treatment. It is found that the proposed method is able to improve the surface finishing of FDM parts. However, the method has affected the tensile strength where there is a slight decrease in the strength value.

1. Introduction

Additive manufacturing (AM) or 3D printing may revolutionize how we manufacture products in the future [1]. In 3D printing, parts are created layer by layer according to computer aided design (CAD) data [2]. One of the 3D printing technologies is fused deposition modelling (FDM). It is a 3D printing technique in which a plastic material extruded from a nozzle that point out onto the part cross geometric layer by layer. The most widely used materials are thermoplastic, *acrylonitrile butadiene syterene* (ABS) and *polyactic acid* (PLA) [3]. Since FDM is one of the popular AM technologies for various applications in engineering scope, thus the quality of processed part is the main concern to consider. Due to poor surface finish of 3D printed parts, recently, researchers have

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explored many ways to improve mechanical properties and surface finishing of the printed part using various methods, design, techniques and concepts [4-10]. Some of the researchers used pre-processing and post-processing assisted with secondary process. In order to reduce the staircase effect and improving the surface roughness of 3D printed parts, this study introduced a new method called blow cold vapor treatment process. The proposed method is practically safe as it does not involve any heat along the treatment process compared to hot vapor smoothing immersion.

ABS is a thermoplastic material that easily reacts with other chemical finishing agents when it is exposed to chemicals, vapor and coatings. The chemicals that are widely used to improve ABS parts for FDM are acetone, thinner and methyl ethyl ketone (MEK). The chemicals react with ABS and able to produce smooth outer layer of the surface part by dissolving the rough surfaces and producing strong bonding between the layers [11]. This can improve the surface roughness of the ABS printed parts by chemical rolling treatment and others [12]. One of chemical that widely used as the cleaning agent is acetone. It is used for polishing and finishing the products because it has good surface peeling characteristics. Acetone dipping is one of the chemical finishing methods that can help in improving surface finishing using acetone solution [13,14]. Generally, acetone dipping method as post-processing technique can improve the flexural strength, wear resistance and water tightness, but 1% of shrinkage and it may affect the part's accuracy but it was neglected [15,16]. Optimization on acetone dipping for finishing on biomedical micro device applications was also being done to get the optimum conditions or the method [17].

A vapor smoothing technique using acetone is used as a remedy to treat the surface roughness of the ABS printed part especially for FDM technique where the chemical is heated in an enclosed system [18]. In a chamber, the solvent is heated and the chemical vapor dispersed surround the parts. Thus, it allowed the vapor to condense and penetrate on the ABS surface before it smoothen the outer layer [19,20]. The parts can also be improved using coating method by another chemical agent and improved the surface finishing as well as its mechanical strength [21,22]. The vapor smoothing is usually conducted using hot vapor and it can be conducted for the complex shape such as medical appliances [23,24].Chemical vapor acts as a solvent to smooth the outer layer of the parts and improves the surface finishing especially on ABS parts [25]. Various analysis to find the optimum setting for several parameter conditions of vapor smoothing including quantitative analysis using central composite design (CCD's) experiment, design of experiment (DOE) using Taguchi and experimental design between the parameter settings for FDM and vapor smoothing conditions were conducted [11].

The current vapor polishing techniques, however, have some drawbacks to consider. Hot treatment via boiling the acetone solvent in a crackpot or similar chamber the presents of fume and fire hazards, thus it required a hand-on process and safety factors are essential elements when handling this procedure. Using cold treatment via slow release of solvent from paper towels in an enclosed containers method was excessively time consuming and the users cannot observe the parts during the process. Another method was by using the spray technique. But, the spray canned solvent aerosol onto part produced inconsistent surfaces finish while dipping parts directly into liquid solvent created an unpredictable or inconsistent finish and only affects smaller portion of the parts. The post-processing technique using chemical agents such as acetone was proved to be highly effective, fast and economical to improve the surface finish however, the method of vapor smoothing may be dangerous to some safety issues. Thus, in this paper, a new implementation of vapor smoothing (VS) using cold vapor was introduced. The technique does not involve any heating elements and produces consistent surface finishing through the parts.

2. Methodology

In this study, low cost 3D printer machine is used to fabricate the specimens using ABS material of dogbone specimens using ISO 527:207 standards (ASTM D638). The selected process parameters from FDM settings are tabulated in Table 1. The build direction was constant at horizontal plate. After the part was fabricated, it was treated using cold vapor treatment. The process setting is tabulated in Table 2.

Table 1
FDM parameter for 3D printed part fabrication

Parameter	Specification
Layer thickness (mm)	0.18
Infill density (%)	30
Raster angle (º)	90
Infill pattern	Line pattern

Table 2
Blow cold parameter conditions

Descriptions	Specification
Power Supply (V)	5
Exposure time (min)	5 to 180
Solvent	Acetone / MEK
Volume (ml)	20

The setup of experiments is shown in Figure 1. In this method, the specimens were placed inside the container on top of aluminum foil, as well as glass jar that have been filled up by the solvents with 20 ml volume of acetone and MEK respectively. On top of the glass jar, an electric fan was being attached to the glass cover where it was connected to the power supply. The glass jar covers have a small hole so that the solution can be vaporized. The fan functioned as a medium to blow the solution so that the vapor can be produced. This process was practically applied for the post-process after the part was fabricated. Since acetone and MEK were highly flammable, it was not recommended to expose the chemical to the hot surfaces, open flames or spark. Cold vapor treatment was introduced since there was no heating element needed for the process. The minimum time to expose the acetone to the environment was 5 minutes, whereby, the maximum time for exposure time was 3 hours because the samples started to destroy if it was exposed more than that.

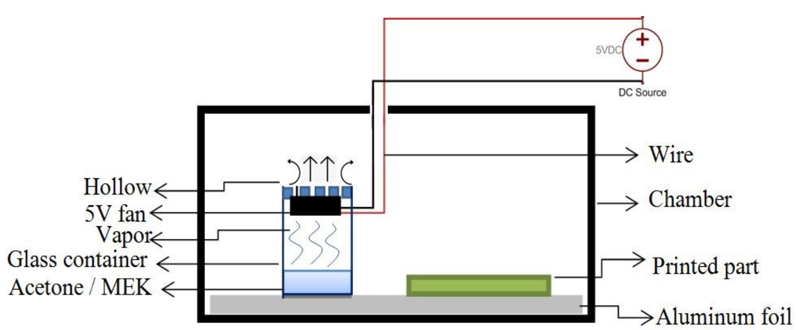


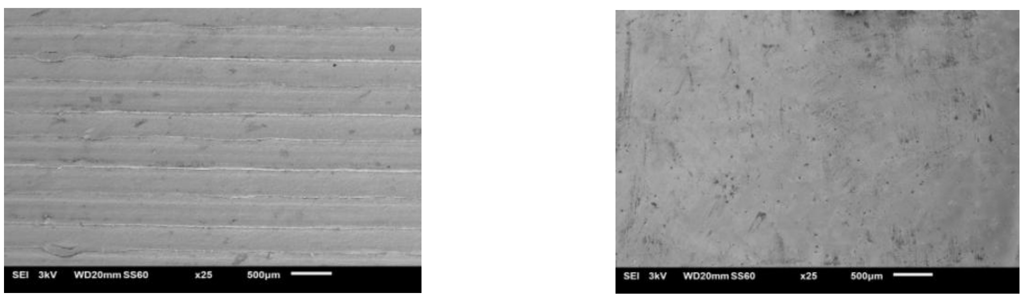
Fig. 1. Schematic diagram on cold vapor setup experiment

After the part was vaporized accordingly, the surface roughness of the sample was taken using a Mitutoyo profilometer, with 0.5 mm/s, GAUSS filter, 800µm range, R-speed of 2.0 mm to measure the value of average roughness (Ra). Then, the tensile strength of the sample was conducted using INSTRON 8872 with the velocity speed of 5 mm/s and 50 maximum load capacity. The results were compared between treated with untreated samples on the surface roughness and tensile strength. The top and cross sections image were taken using scanning electron microscope (SEM) in order to observe the surface before and after the treatment.

3. Results and Discussion

3.1 Surface Roughness

Figure 2 compares the top sections on the surface roughness of 3D printed part when observed using SEM before and after the post-processing. Figure 2 (a) shows the line of deposited filament which were well arranged at the raster angle of 90º during printing. Whereas Figure 2(b) illustrated the surfaces of the same surfaces after being exposed to cold vapor treatment. By comparing these figures, it shows that the cylindrical shape of the ABS filaments has dissolved by the chemical vapor to become a smooth surface after being exposed to the vaporization process.



(a) Before treatment (b) After treatment

Fig. 2. Top surfaces of non-treated and treated sample

3.2 Surface Roughness Results with Acetone

Using acetone vapor to treat ABS 3D printed part was an extremely effective way to create parts with shiny, smooth surface and porcelain-looks-like product. By applying the acetone with a brush, or dipping the parts without a proper adjustment of parameter and condition settings, generally results showed that the part may be destroyed or completely melted due to excessive acetone and exposing time to the solvent. However, by using acetone vapor technique, it can help to preserve parts with the proper amount of solution applied and exposing time to acetone vapor. It also helped in preserving details while giving a smooth and shiny surface finish.

Figure 3 indicates the effect of cold acetone vapor on the surface roughness as the exposure time of the 3D printed part to acetone vapor is increasing. The surface roughness of non-treated parts was 12.00µm. When the part exposed at 5 minutes, the roughness started to improve. The process produces a smooth surface finish of the outer layer of plastic as the acetone broke the secondary bonds between the ABS polymer chains. This allowed chains to slide past each other and moved to more stable positions. The solvent was vaporized in the container and the chemical vapor dispersed around the parts, thus, making it condensed and penetrated on the ABS surface before it flattened the outer layer. The cross section of SEM images on ABS parts are shown in Figure 4.

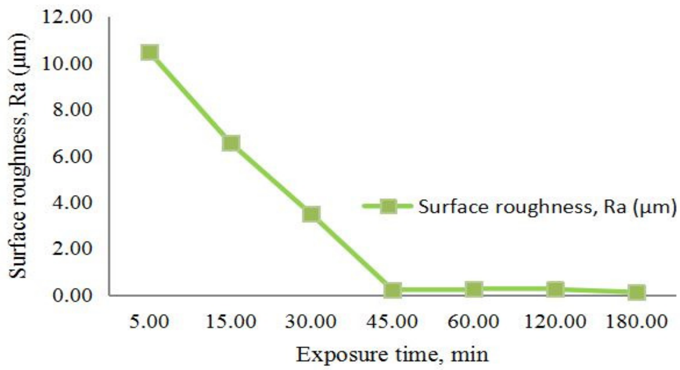
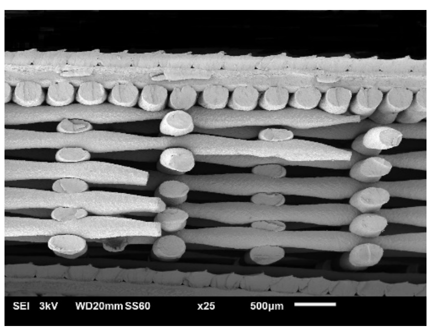
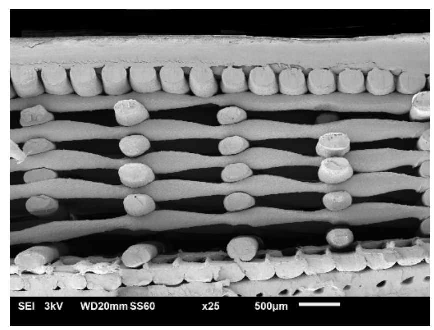


Fig. 3. Effect of acetone vapor process on surface roughness

FDM fabricated part through deposition of filament layer by layer, thus, the cylindrical shape of the filament was made up between the continuous layer to form the bond. When acetone evaporated, the surface tension of the cylindrical shape that form the layer was affected and produced smooth structure of the outer layer. As a result, a well bonded of continuous layer was produced. Generally, by increasing the exposing time for the parts to acetone vapor, a very smooth surface roughness is produced. However, when the exposing time was more than 3 hour, the part was completely destroyed. In this experiments, the solution was placed inside a glass jar instead of plastic container since the acetone could not be exposed to plastic material because there is a possibility for the acetone to dissolve it.



(a) Before treatment



(b) After treatment

Fig. 4. Cross section of printed part after the treatment using Acetone

3.3 Surface Roughness Results with MEK

ABS polymers are synthesized from three monomeric chemicals which is acrylonitrile, butadiene and styrene from which the acronym is derived. For every monomeric, it has different properties that form ABS plastic with good durability and resilience as well as mechanical strength. In addition, these thermoplastic polymers demonstrate a favorable combination of thermal, electrical and mechanical properties. The difference properties may be selectively enhanced for specific applications by modifications of the composition or relative proportion of the components [25]. The usage of MEK, which acts as the solvent gives a shiny surface finish for ABS surface's part.

Roughness reduction of approximately 99 percent is obtained for both types of solvent. The surface line between the neighboring layers cannot be longer observed through naked eye as it was dissolved by the used of the solvent. The use of cold vapor MEK can also reduces the influence of staircase effects in 3D printing. For MEK, the very best surface finish recorded at the exposure time, 3 hr. The duration of the exposure time cannot be too long because it may affect the accuracy of the part and dimensional changes might be occurred. Figure 8 showed the cross section of ABS printed part for MEK meanwhile Figure 5 shows the effects of MEK vapor on surface roughness.

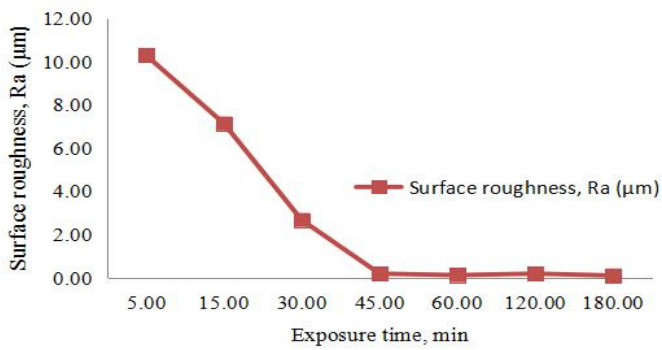
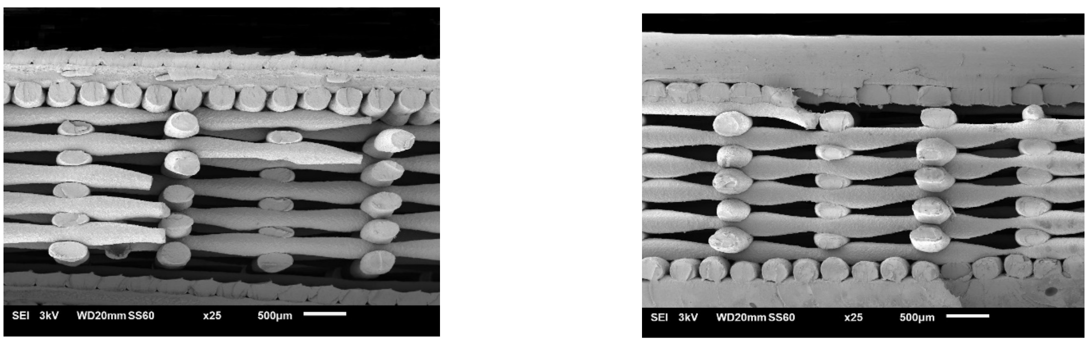


Fig. 5. Effect of MEK process on surface roughness



(a) Before treatment (b) After treatment

Fig. 6. Cross sections of treated ABS printed part using MEK

3.4 Mechanical Properties

The tensile testing was performed with an Instron 8872 mechanical testing machine. All tensile specimens were tested for mechanical properties a minimum of 24 hr after smoothing to allow vapors to fully evaporated, as the specimens were initially soft after the treatment and hardened as the vapors evaporated. The tensile test showed that there were slightly linear decrease in the maximum tensile strength with increasing treatment times which agreed with the findings from Galantucci *et al.,* [7,8]. The observation from the graph showed there was a slightly decrease in the value of tensile strength as the exposure time increased. Existing research explored that, the effect of anistrophy and build orientation affected the mechanical properties in AM process. Figure 7 showed the effects on acetone and MEK on tensile strength, MPa value.

Therefore, by treating the ABS specimens with acetone vapor, the strength is affected. Acetone vapor smoothing of the outer layer of specimens caused a permanent chemical change which affect its strength. Based on the cross sectional view of SEM images, it is clearly indicated that the treatment did not penetrate deeply into the subsequent layer, but only penetrate on the part's surface. The acetone also weakening the material structure and affects the mechanical strength of the parts as the exposure time increase. From the experiments, as the part exposed to acetone and MEK vapor for 180 min, the surface roughness of the parts increases drastically. The fine layer of the part's surface is totally dissolved as shown in Figure 4b. When acetone vapor evaporated, the plastic part returns to its original hardness, increase toughness but reduce the strength. The testing suggested that vapor treatment has a minor effect on the strength of the stress concentration sample. As the treatment time increased, strength decreased and elongation to failure increased. This showed that, the material properties of ABS itself became tough after being exposed to the chemical vapor due to the absorption of the vapor to the ABS surface.

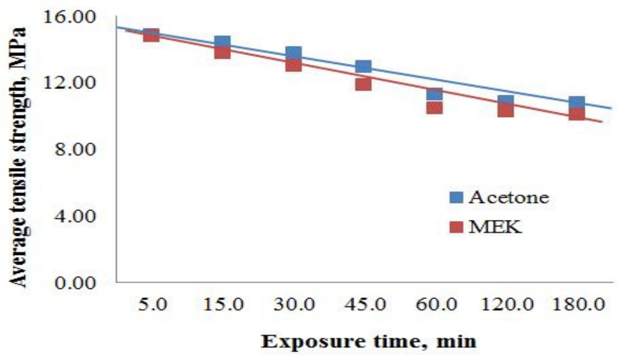


Fig. 7. Effect on acetone and MEK vapor treatment on tensile strength

4. Conclusions

The FDM process is a unique process which produces functional parts in shortened time from CAD data. However, the parts are inferior in terms of surface roughness and its strength. This study proposed a new method to enhance the surface finishing of FDM parts using cold vapor treatment. Based on the findings, the post-processing treatment using blow cold vapor treatment resulted in a dramatic improvement for surface roughness as it improves the surface finishing by 99 percent and reduces the staircase effects. However, the strength of the parts treated with this method produces a lower part strength. Hence, sound judgement is necessary is balancing between the surface roughness and strength in applying this technique for any specific application.

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