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The Study and Development of Factor Affecting the Smoothness in 3D Printed Part Surface Treatment via Acetone Vapor

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Abstract. Fused Deposition Modelling (FDM) has been extensively used in low-cost printers. However, the fundamental working principle (layered manufacturing) is resulted in the poor quality of the surface texture, the dimensional inaccuracy of fabricated parts, the limits its domain all issues often take place in precision industrial applications. In this paper, initially FDM based acrylonitrile butadiene styrene (ABS) model have been fabricated. In the post-processing stage, the vapor of acetone has been applied to the specimen. Then the changes in the surface finish and surface roughness have been investigated. The study highlighted that the post-processing of ABS specimen with acetone vapor treatment resulted in dramatic improvement of surface finish. Finally, parameter setting that gave the acceptable results while considering all the responses simultaneously.

Introduction

The technological development of additive manufacturing and 3-D printing has been substantial, fueling rapid growth in commercial rapid prototyping as it has proven useful for both design and small batch production [1-6]. The great spread of these technologies has driven the manufacturers and the hobbyists in machine and process improvements. One of the most commonly used technologies is fused deposition modeling (FDM). The main advantages of this technology for industrial machines include a good variety of materials available, easy material change, low maintenance costs, quick production of thin parts, a tolerance equal to ±0.1 mm overall, no need for supervision, no toxic materials, very compact size and low temperature operation [7]. Annual unit sales of rapid prototyping systems using FDM technique worldwide grew by an estimated 13.9% [8]. The technological evolution of the 3-D printers, widespread internet access and inexpensive computing has made a new mean of open design capable of accelerating self-directed sustainable development [9].

FDM possesses many advantages that include the ability to fabricate complex and intricate geometries easily with low operating, fabricating and maintenance cost [10]. Despite of various advantages, the FDM fabricated components suffers from poor surface quality and dimensional inaccuracy due to stair-stepping effect and chordal error [11-12]. This was mainly due to the slicing and conversion of CAD model into STL file which approximated the surface as a net of triangles. It simplifies the part geometry but part losses it resolution as now only triangles, represent its outline [13]. It is not possible to eliminate these effects completely.

The literature review reveals that FDM input parameters, namely build orientation and thickness of the layer influences the stair case effect significantly, which ultimately affects the surface quality of the fabricated parts. Also, the chemical vapor smoothing process seems to be a promising technique for enhancing the surface finish of FDM parts with respect to time consumed and the cost incurred. So, in the present work, investigations have been performed on surface finish of ABS specimen by integrating the FDM and chemical vapor smoothing process. Further, the combined optimization has been performed in order to obtain the parameter level that gives the acceptable results when all the responses have been considered simultaneously.

Experimental Procedure

Materials and equipment. The rectangular specimens were produced on the industrial system using a Tier time UP300 with filament of ABS-P400 material with diameter of 1.75 mm and a density of 1000 kg/m3 [14]. ABS material is widely used by FDM technique for industrial and other application parts manufacturing due its characteristics and being non-toxic. Default settings of extrusion temperature and speed were used as recommended by the manufacturer. The specimens were designed in cubic shape with surface area 2000, 5000 and 8000 mm^2 as shown in Fig. 1. The relationship between cubic dimension and surface area excluding bottom surface was shown in Eq. (1).

The 3D printed part has been placed in 8000000 mm^3 PU plastic chamber. The liquid acetone was vaporized by ultrasonic transducer. The excess air was excreted via the exhaust channel through the water as shown in Fig. 2.

$$Surface\ area = 5d^2 \tag{1}$$

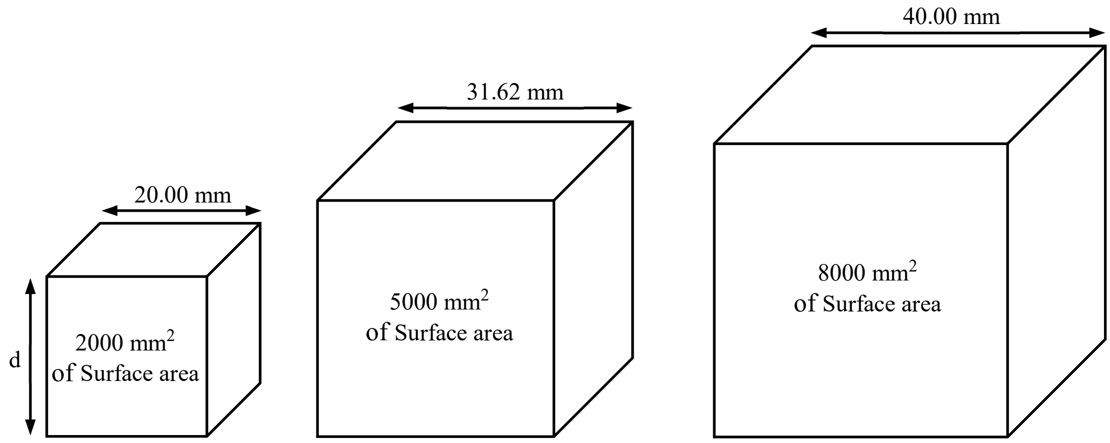

Fig. 1 Cubic shape specimen in 2000, 5000 and 8000 mm^2 exclude bottom surface.

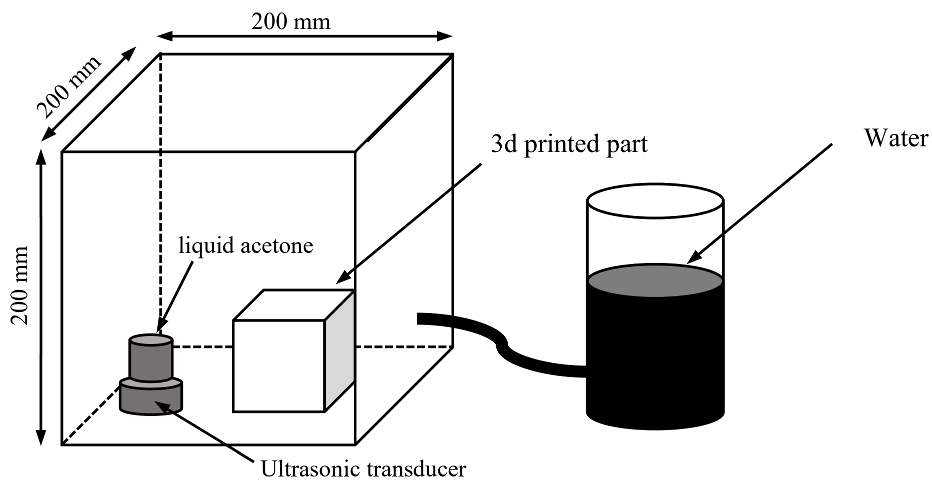

Fig. 2 Cubic shape specimen in 2000, 5000 and 8000 mm^2 exclude bottom surface.

Surface roughness. Surface topography and roughness were determined from the Olympus LEXT Laser Measuring Microscope OLS4000. It was used a 405 nm laser light to capture the direct distance to the surface of the object. Fig. 3. were show the 3D printed part before (a) and after (b) surface treatment via acetone vapor experiment. Based on the specimen 20 pcs., the mean of surface roughness before improving surface was 14.63 µm. and after improving the surface was 0.12 µm as shown in Fig 4.

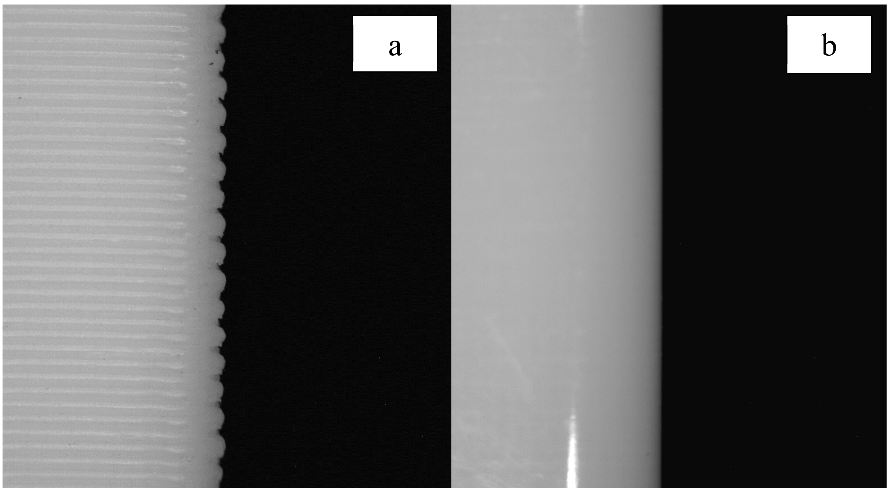

Fig. 3 3D printed part before (a) and after (b) experiment.

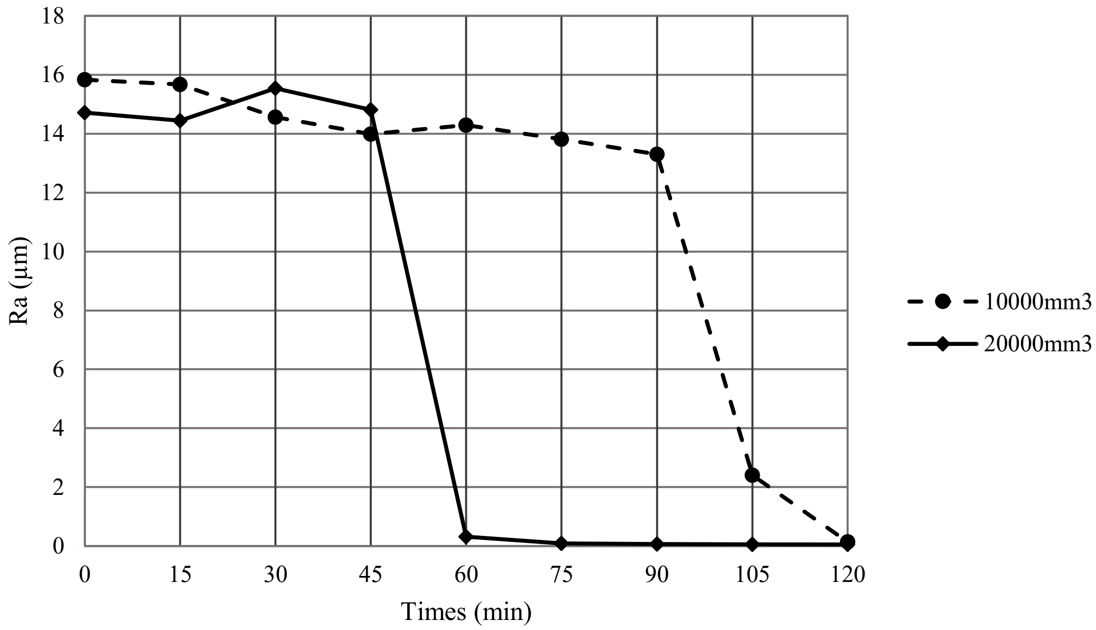

Fig. 4 Effect of surface with 10000 mm^3 and 20000 mm^3 of acetone.

Design of experiments. A 3^k full factorial DOE was utilized to collate the data in a controlled way. The associated variables period times, acetone volume and surface area were listed in Table 1, Also it had double replication, for the total of 27 experiments. A very simple cubic shape of the specimens was used to facilitate their dimensional measurements: d_1 = 20 mm with surface area 2000 mm^2, d_2 = 31.62 mm with surface area 5000 mm^2 and d_3 = 40 mm with surface area 8000 mm^2

Table 1 Full factorial design of experiments.

Experiment no.	Surface area (mm^2)	Period time (min)	Acetone (mm^3)	R_a	
				Replications 1	Replications 2
1	2000	50	10000	5.912	6.524
2	2000	50	15000	0.360	0.295
3	2000	50	20000	0.135	0.186
4	2000	75	10000	5.328	5.490
5	2000	75	15000	0.101	0.150
6	2000	75	20000	0.079	0.084
7	2000	100	10000	3.260	3.128
8	2000	100	15000	0.099	0.087
9	2000	100	20000	0.072	0.067
10	5000	50	10000	7.916	7.136
11	5000	50	15000	0.416	0.397
12	5000	50	20000	0.237	0.230
13	5000	75	10000	6.601	6.305
14	5000	75	15000	0.230	0.287
15	5000	75	20000	0.098	0.095
16	5000	100	10000	5.300	5.797
17	5000	100	15000	0.130	0.144
18	5000	100	20000	0.093	0.090
19	8000	50	10000	11.356	10.730
20	8000	50	15000	0.521	0.597
21	8000	50	20000	0.382	0.362
22	8000	75	10000	9.520	9.604
23	8000	75	15000	0.441	0.407
24	8000	75	20000	0.159	0.174
25	8000	100	10000	7.975	7.160
26	8000	100	15000	0.181	0.170
27	8000	100	20000	0.122	0.142

In this research, the 3^3 factorial design was used to analyze the surface roughness of ABS specimen with acetone vapor resulted in dramatic improvement of the surface finishing. In the 3^3 factorial design, surface area, period times and acetone volume were considered as the main factors which each factor had three levels. Each experiment was double replicated. Initially, a variance analysis was carried on the experiments and the results were analyzed. The final ANOVA result was given in table 2.

Table 2 Analysis of variance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Surface Area	2	23.441	11.720	258.77	0.000
Times	2	10.815	5.408	119.40	0.000
Acetone	2	543.578	271.789	6000.82	0.000
2-Way Interactions	12	52.321	4.360	96.27	0.000
Surface Area*Times	4	0.614	0.154	3.39	0.023
Surface Area*Acetone	4	37.875	9.469	209.06	0.000
Times*Acetone	4	13.832	3.458	76.35	0.000
3-Way Interactions	8	1.021	0.128	2.82	0.021
Surface Area*Times*Acetone	8	1.021	0.128	2.82	0.021
Error	27	1.223	0.045		
Total	53	632.399			

Results and Discussion

The effects of the main factors. According Table 2, It was shown that the main factor significantly affected of surface roughness. The effect of surface area and time explained as a result of surface roughness. According to Fig. 5 when the surface area was increased the surface roughness also increasing.

The Effect of acetone quantity could be explained as a result of surface roughness. According to Fig. 5, it showed that the acetone quantity with 10000 mm^3 gave the worst surface roughness in 6.95 Ra., For acetone quantity with 15000 and 20000 mm^3 gave the same surface roughness in 0.28 Ra and 0.16 Ra respectively. The proper acetone volume for improving surface of specimen is 15000 mm^3 that could be achieved the good surface roughness (surface roughness acceptant).

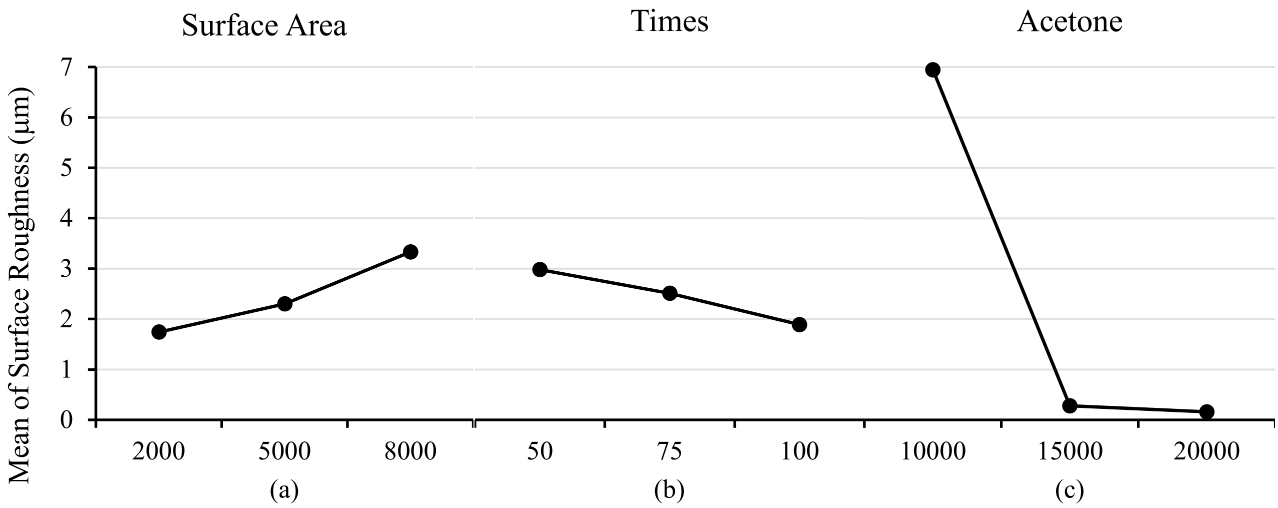

Fig. 5 Main effects plot for surface roughness.

An interaction graph between surface area and acetone volume was given in Fig. 6 (a). It was shown that the acetone volume with 10000 mm^3 got a large impact with surface roughness. It was mean surface roughness value more than Ra 5 μm at surface area with 2000 mm^2, 5000 mm^2 and 8000 mm^2 but using acetone volume with 15000 and 20000 mm^3 got the similar surface roughness which were less than Ra 0.5 μm. For all surface area shown in Fig. 6 (b), the interaction between period time and acetone quantity shown that the acetone volume with 10000 mm^3 has a large impact to surface roughness gaining more than Ra 5 μm. The interaction graph between surface area and acetone volume was showed that the acetone volume of 10000 mm^3 was not affected in the surface area.

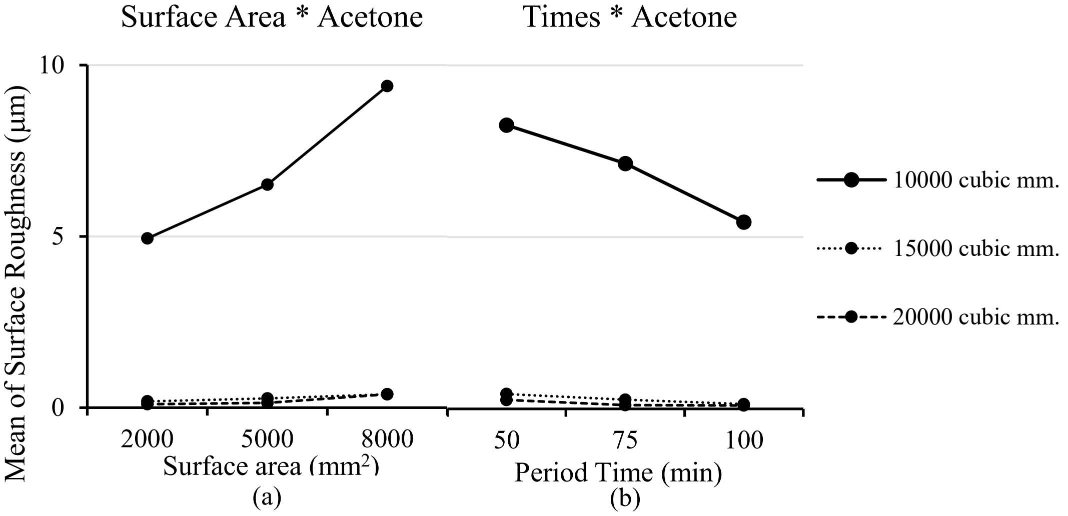

Fig. 6 The interaction plot of surface area and aceton volume , period time and acetone volume.

The effects of the surface area and period time. According to table 2, all the interactions except the surface area on the period time are ineffective factors on the percentage of the removal rate with 21% significant level (p-value = 0.021). The interaction graph between surface area and period time was given Fig. 7. A maximum interaction to the best surface roughness (the less number is good) was obtained on the period time by 100 min at 2000 mm^2 surface area. The trends lines of interaction between surface area and period time were correlation. This means that the improving surface is going to increase follow size of specimen.

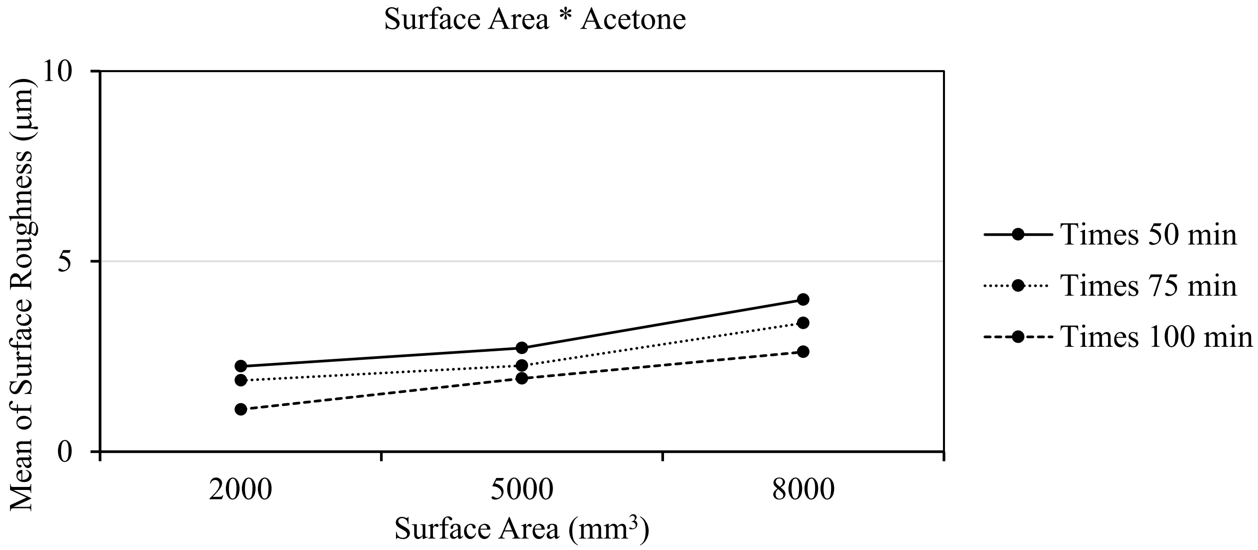

Fig. 7 The interaction plot of surface area and period time.

Summary

According to the results of the experiment, to improve of 3D printed part surface treatment, the parameter should be given.

- Acetone quantity should not be used less than 15000 mm^3. The quantity will be affected on the surface roughness.
- The effects of the surface area and period of time were not significantly affect to each other. However, it took more time to obviously notice when there is more surface area.

The factors affecting the smoothness of the finishing parts using acetone vapor treatment in ABS from 3D printer were surface area, acetone volume and time. The most affecting factor on the surface roughness is acetone volume. The recommendation volume is greater than or equal to 1500 mm^3

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