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Journal of Mechanical Engineering Research
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ARTICLE

An Experimental Study of Surface Improvement in FDM Parts by Vapor Treatment Process

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ARTICLE INFO

Article history
Received: 1 February 2020
Accepted: 21 March 2020
Published Online: 31 March 2020

Keywords:
FDM
Vapor chemical process
Surface quality
Design of experiment

ABSTRACT

Fused deposition modeling is one of the most adaptable additive production method as a result of the value-effectiveness and environment-friendly nature. However, FDM technique nevertheless possesses primary problems in phrases of negative surface best due to including layer by using layer production method for the prototypes. It is acceptable to explore an efficient method for FDM elements to enhance the bad surface first-rate and dimensions precision. In the present research paper, an effort has been made to decorate the surface better and optimize the vital processing parameter of FDM based benchmark the use of vapor smoothing procedure (VSP). A comparative experimental take a look at has been completed by layout of experiments, Taguchi technique to analyse impact of input layout parameters at the floor finish of benchmark FDM parts. The outcomes of prevailing research display that VSP treatment improves the surface excellent of FDM components to micro stage with negligible dimensional variation. It is observed that improved floor excellent is observed in the 1,2, -Dichloroethane chemical at 90° component construct orientation, 0.25 mm layer thickness, 10% fill density and 90 sec Exposure times.

1. Introduction

Additive manufacturing (AM) process is gaining great importance and industrial demands to because of increase in complexity of product geometries. In this process conceptual model is made in a short span of time, economically with good characteristics [1]. The great spread of AM technologies has progressed as a fabrication method for fast tooling or rapid manufacturing products in low volume industrial applications [2]. Fused deposition modeling is one of the most widely used AM technologies. In the FDM technology, prototypes are built up by the data obtained from 3D CAD files and virtual model is converted into Standard Triangulation Language format [3]. The FDM also is known as 3-D printing layer-based manufacturing process, as extruding semi-solid thermoplastic materials solidifies in the form of thin slices on a fixtureless table [4]. The support material at the same time must be extruded, which acts as a support for the hanging fragments which can be detached later by manual cleaning or post-processing [5]. The use of AM technique for the different application is still possessed major difficulties in terms of poor surface finish. The poor surface finish limits the functionality of AM parts, and the reason

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  DOI: https://doi.org/10.30564/jmer.v3i1.1681

lies behind is the building strategy, layer thickness, orientation of the part, the geometry of enclosing surface, etc [6]. These drawbacks lead to dimensional inaccuracy and outweigh the advantages in FDM parts [7].

Many studies have been reported in the open literature to develop the quality of FDM parts since the origin of this technology. Galantucci et al. [8] investigated the FDM machining parameters on acrylonitrile butadiene styrene prototypes surface finish by chemical post-processing treatment has been investigated and yields a significant improvement of the Ra of the treated specimens. A dimensional accuracy of ABS specimens through post chemical treatment. It is naturally increases the surface finish and dimensional accuracy by Jayanth et al. [9]. J.S. Chohan et al. [10] revealed that, ABS specimens are manufactured by FDM and optimized vapor smoothing (VS) process for biomedical applications.Yifan Jin et al. [11] examine that chemical reaction mechanism during the treating process is analysed surface roughness for polylactic acid parts in FDM. R. Singh et al. [13] founded the surface finish of FDM based benchmarks through acetone exposure by using vapor smoothing station technique improving the surface finish nano-level with negligible dimensional deviations using a design of experiments technique. R. Singh et al. [14] inspect; surface hardness of ABS components has been improved through the HVS process by using acetone as smoothening media by scanning electron microscopic-based characterization of the components were carried out. Garg et al [15] search that, the simultaneous effect of part building orientation and raster angle on surface roughness, tensile strength, a flexural strength of ABS material. Lalehpour A. et al. [16] study the effect of the smoothing parameters on the resulting surface roughness of the final FDM products. The smoothing parameters are divided into the number of smoothing cycles and the cycle duration.

The use of FDM parts in different areas is till doubtful as the final part undergoes from rough geometrical roughness and a smaller amount geometrical tolerances in contrast to other AM technologies. However, various investigators have completed several experiment and investigation to evaluate the surface roughness and dimensional features of FDM parts by optimizing the input parameters.

The present study work, the authors is concentrated to improve the surface finish of FDM parts by using an alternative, cost effective volatile fluid (acetone, one-two-dichloroethane, butylalcohal). because it necessities marginal human intervention, the cost is very low and curing times are about few minutes. Taguchi L9 OA has been used to investigate the influence of factors such like as density of the parts, layer thickness, surface finish, build orientation and chemical exposure time for treated and untreated PLA samples.

Right now creators explore the connection between the FDM procedure parameters and the surface part of models, concentrating a strategy to improve the surface completion of the items. This technique performs better whenever contrasted with that revealed in refs. [16,17], in light of the fact that it needs minor human mediation, the expense is extremely low and relieving times are around a couple of moments minutes. Figure 1 shows the work process of the present paper. The trial action was done more than two stages, concentrating on autonomous factors in both the FDM procedure and the substance wrapping up. In the main stage, comprising of examples producing

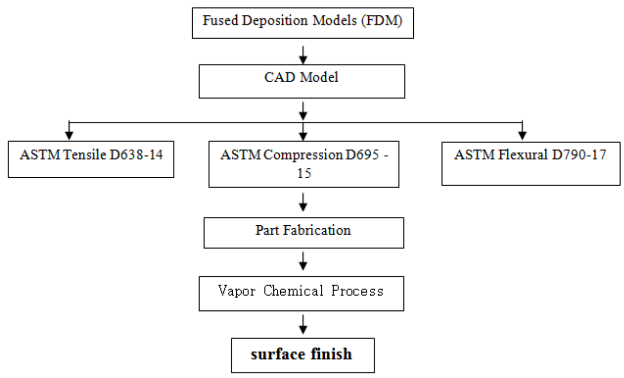


Figure 1. Experiment Strategy

2. Experimental Methodologies

Table 1. Experiment L9 orthogonal array for selected input factors at separate levels

Sr.no.	Layer thickness	Build orientation(°)	Density Fill (%)	Vapourization Time (sec)
1	0.20	0	10	90
2	0.20	90	50	120
3	0.20	90	100	150
4	0.25	90	10	90
5	0.25	90	50	120
6	0.25	0	100	150
7	0.30	90	10	90
8	0.30	0	50	120
9	0.30	90	100	150

To check out the have an impact on of layer thickness, the infill sample and infill percent, we used the Taguchi's L9 DOE. Taguchi's DOE was chosen as it adopts orthogonal arrays. This approach that each parameter has identical weights and may most fulfilling layout with the lowest range of Levels and minimum price. The L9 array calls for only nine Levels, however, for four parameter for 3 levels every, handiest the primary outcomes can be researched and no interactions, consequently, this paintings targets on the main effects. A four foremost parameters are selected for three level of each enter element through literature survey the experiments were designed by using Taguchi L9 orthogonal array in conjunction with independent variables. Table 1 reveals the experimentation elements and degrees.

2.1 Specimen Material

The scholarly CAD programming designer is utilized to make the models of the test examples ASTM D638-14, ASTM D695 - 15 and ASTM D790-17 are utilized for choosing the point by point measurements of malleable, pressure and flexural test examples separately. In the present work, all the examples are assembled utilizing PLA material is utilized to help structure age, while building the test examples. PLA material has the accompanying properties, rigidity = 57.8 MPa, elastic modulus = 3.3 GPa and flexural quality = 55.3MPa. A layer of help material at wanted areas is kept dependent on the art direction and geometric multifaceted nature. In the wake of building the part, the help materials are broken down in a help cleaning station. The models are spared in .stl position for cutting layer age and working of the examples. All examples are worked by saving a layer of 0.20, 0.25, 0.30 mm thickness.

2.2 Chemical Solvent

2.2.1 Acetone

The substantial and compound homes of $(CH_3)_2CO$ are given in Table 2. The substantial places of $(CH_3)_2CO$, alongside high dissipation rate, low thickness, and miscibility with water and various natural solvents make it appropriate to be utilized as a dissolvable. In view of its capability to experience expansion, oxidation/markdown, and buildup responses, CH3)2CO is utilized as a crude texture inside the synthetic blend of numerous business stock.

Table 2. Acetone properties

Molecular weight	Colour	Physical state	Melting Point	Boiling point	Solubility (water at 20°C)	Density-20°C,25°C,30°C	Solubility (organic solvent)
58.08	Colorless	Liquid	-95.35°C	56.2°C at 1 atm	Completely miscible	(0.78998g/ml, 0.78440g/ml, 0.78033g/ml)	Soluble in benzene and ethanol

2.2.2 1,2 Dichloroethane

1,2 dichloroethane is mostly used within the production of vinyl chloride as well as other chemical compounds. The properties of chemical shows in table 3. It is utilized in solvents in closed systems for various extraction and cleaning functions in natural synthesis. It is likewise delivered to leaded gas as a lead scavenger. It is also used as a dispersant in rubber and plastics, as a wetting and penetrating agent. It become formerly used in ore flotation, as a grain fumigant, as a steel degreaser, and in fabric and PVC cleaning.

Table 3 1,2 dichloroethane properties

Molecular weight	Colour	Physical State	Vapour pressure	water partition coefficient
98.96 g/mol	Colorless	heavy liquid that is slightly soluble in water	64 mm Hg at 20°C	1.48(log kow)

2.2.3 Butyl alcohol

1-Butanol is a type of alcohol with four carbon atoms being contained per molecule. Its molecular formula is $CH_3CH_2CH_2CH_2OH$ with three isomers, namely iso-butanol, sec-butanol and tert-butanol. It is colorless liquid with alcohol odor. A table 4 shows the properties detail.

Table 4. butyl alcohol properties

Melting point	Boiling point	Density	vapour density	Solubility
89 °C	117.6 °C	0.81 g/ml at 25 °C (lit.)	2.55 (vs. air)	water soluble

3. Results and Discussion

Surface roughness of FDM revealed PLA samples are measured earlier than and after chemical treatment with acetone, butyl alcohol and 1,2 dichloroethane. The components are fabricated at special element building orientations and their surface roughness, tensile; compression and flexural strength are measured. Measurements are completed for all components remedy and compared to have a look at and examine the impact of the exceptional parameters. Table 2, 3 and 4 indicates the results consequences of floor roughness values after chemical vaporization procedure on PLA specimens.

A story hardness is estimated utilizing a story unpleasantness analyzer (SJ 400) settling on a 0.25 mm cutoff length. Unpleasantness is estimated twice and the normal expense is mulled over and root folks rectangular hardness (Rq) values are estimated each nearby and over the length of the examples. Surface hardness of the segments are estimated close by and over the length of the examples multiple times on level floor and normal floor unpleasantness (Ra) and root recommend Rq values are thought about adaptations of Ra and Rq for each check tests developed at selective direction.

  DOI: https://doi.org/10.30564/jmer.v3i1.1681

The whole manufactured parts are treated by uncovering the test examples to cold fume of $(CH_3)_2CO$, 1,2 dichloroethane and Butyl Alcohol. Because of $(CH_3)_2CO$, 1,2 dichloroethane and Butyl Alcohol harmfulness low or significant expense and worth dissipation pace of $(CH_3)_2CO$, 1,2 dichloroethane and Butyl Alcohol. In any case, the substance response with hot fumes or fluid CH3)2CO is resolved serious and every so often, it got hard to administer the harm of the part surfaces. To diminish harm brief presentation length is decided on warm fume. In any case, it is again found that every one surfaces are not managed consistently. Treatment by utilizing hanging of added substances would require appropriate equalization of (CH_3)-$_2CO$, 1,2 dichloroethane and Butyl liquor worthy surface quality. In any case, the creators noticed that in treatment with hot fumes of $(CH_3)_2CO$, 1,2 dichloroethaneand Butyl Alcohol smoothen the part surface consistently. The holder is kept at a vaporization temperature for at vaporization time. Right now, improvement in surface completion and deviation experienced after fume handling were measured by subtracting the underlying and last qualities by utilizing the accompanying condition

$$= [(\text{Initial value} - \text{Final value})/\text{Initial value} \times 100] \quad (1)$$

Using Taguchi's layout For dimensional analysis, peak of the benchmarks changed into decided on judicially. Mintitab-17 software program package was used to find out the effect of processing of input parameters at the great traits of the patterns. Table No. 2 and no shows the stepped forward fee of surface finish of the patterns , dimensional deviation and their respective signal to noise (S/N) responses. Further ANOVA has been carried out for calculating the proportion contribution of input process parameters in surface roughness and dimensional deviation,

Figure 3 (a) and (b) shows the fundamental impact of S/N proportion on chosen process parameters for surface harshness and dimensional deviation separately. Further ANOVA has been directed for computing the rate commitment of info process parameters in surface hardness and dimensional deviation, appeared in table 2 Parametric reaction of S/N proportion for surface unpleasantness and dimensional deviation is given in table 2.

3.1 Discussion of Surface Roughness Effect of Butyl Alcohol Chemical Vapor

In this section represents the surface roughness improvement by butyl alcohol chemical vapor. The result of Surface roughness (SR) is shown in table 2 and figure 3(a) and figure 3(b) shows the minimum surface roughness is achieved at 0.25 mm layer thickness, 0° build orientation, 100% fill density and figure 4 (b) shows the minimum surface roughness is achieved at 0.25 mm layer thickness, 90° angle build orientation, 10% fill density and 90 sec time duration.

Table 2. surface roughness results With butyl alcohol

Sr. No	Layer Thickness(mm)	Build Orientation (°)	Fill density (%)	Time (Sec)	SR before chemical process (µm)	SR after chemical process (µm)
1	0.2	0	10	90	11.938	13.593
2	0.2	90	50	120	21.824	22.461
3	0.2	90	100	150	5.203	12.471
4	0.25	90	10	90	6.201	2.319
5	0.25	90	50	120	4.365	5.091
6	0.25	0	100	150	5.047	2.644
7	0.3	90	10	90	3.796	1.357
8	0.3	0	50	120	5.861	1.445
9	0.3	90	100	150	8.7963	2.225

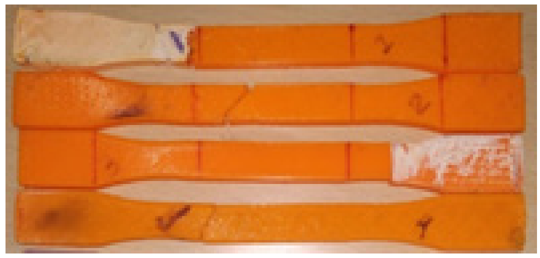
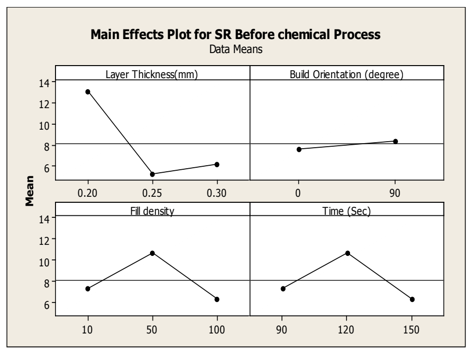
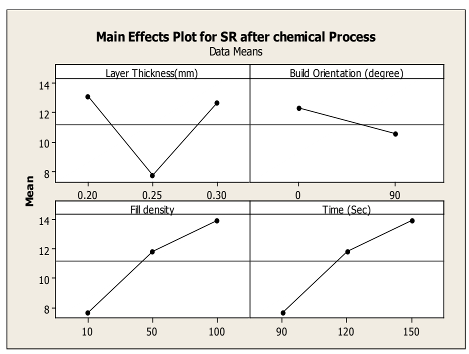


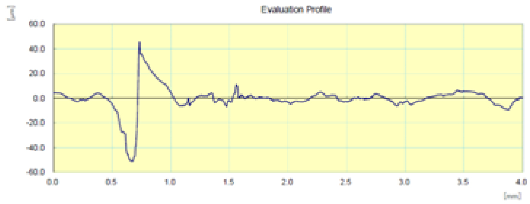
Figure 2. ASTM D638-14 Tensile Specimen



(a) Surface Roughness before chemical vaporization



(b) Surface Roughness after chemical vaporization



(c) Surface Roughness plot before chemical vaporization

(d) Surface Roughness plot after chemical vaporization

Figure 3. Surface roughness result of Butanol or butyl alcohol

In figure 3 (a) shows the surface roughness is very rough at 0.20 mm thickness. This surface finish is very good at the 0.25mm and it is slightly rough at 0.30 mm thickness. The build orientation is not much effect on SR. where, fill density and chemical exposure time same affect on SR. It ia observes that, 100 % fill density and more chemical time exposure gives a good surface improvement this result is vice versa in figure 3 (b).

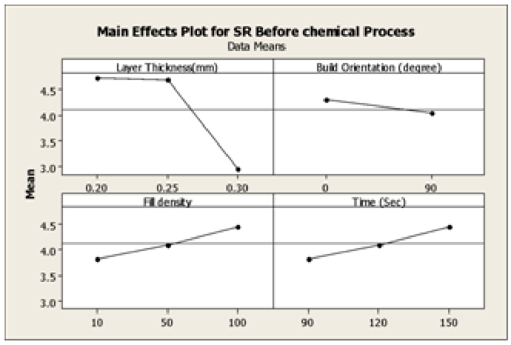
3.2 Surface Roughness Effect by Acetone Chemical Vapor

Surface roughness effect by acetone chemical vapor shown in table 3. A Figure 5 (a) observed that the minimum surface roughness is achieved at 0.30 mm layer thickness, 90° angle build orientation and 10% fill density Figure 5 (b) observed the minimum surface roughness is achieved at 0.30 mm layer thickness, 90° build orientation and 10% and 100% fill density and 90 and 150 sec time duration.

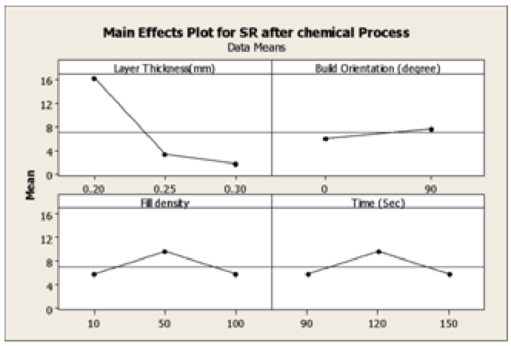
Table 3. surface roughness results with Acetone

Sr. No	Layer Thick-ness(mm)	Build Orienta-tion (°)	Fill densi-ty %	Time (Sec)	SR after chemical process (µm)	SR after chemical process (µm)
10	0.2	0	10	90	13.593	6.710
11	0.2	90	50	120	22.461	19.604
12	0.2	90	100	150	12.471	12.865
13	0.25	90	10	90	2.319	3.521
14	0.25	90	50	120	5.091	2.718
15	0.25	0	100	150	2.644	16.986
16	0.3	90	10	90	1.357	12.826
17	0.3	0	50	120	1.445	13.209
18	0.3	90	100	150	2.225	11.958

Figure 4. ASTM D695 -15 Compression Specimen



(a) Surface Roughness before chemical vaporization



(b) Surface Roughness after chemical vaporization

(c) Surface Roughness plot before chemical vaporization

(d) Surface Roughness plot after chemical vaporization

Figure 5. Surface roughness result of Acetone

DOI: https://doi.org/10.30564/jmer.v3i1.1681

3.3 Discussion of Surface Roughness Effect by 1,2 Dichloroethane Chemical Vapor

Table 4 reveals the SR results of one-two dichloroethane. The minimum surface roughness is achieved at 0.20 mm layer thickness, 0° build orientation and 100% fill density in figure 7(a) and figure 7(b) observed the minimum surface roughness is achieved at 0.25mm layer thickness, 0° angle Build orientation, 100% fill density and 150 sec time duration.

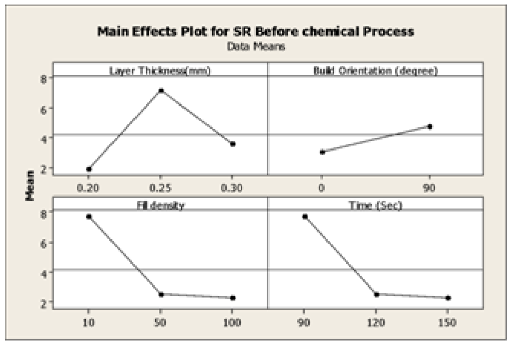
Table 4. surface roughness results with 1,2 dichloroethane

Sr. No	Layer Thickness(mm)	Build Orientation (°)	Fill density (%)	Time (Sec)	SR Before chemical process (µm)	SR after chemical process (µm)
19	0.2	0	10	90	2.144	1.101
20	0.2	90	50	120	1.754	4.198
21	0.2	90	100	150	1.760	0.988
22	0.25	90	10	90	19.172	3.723
23	0.25	90	50	120	0.528	0.576
24	0.25	0	100	150	1.708	1.265
25	0.3	90	10	90	1.937	6.527
26	0.3	0	50	120	5.234	2.172
27	0.3	90	100	150	3.493	0.804

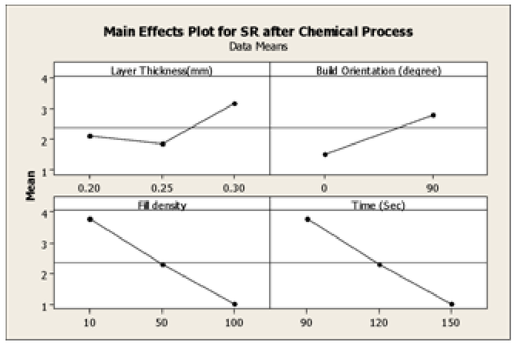
Figure 6. ASTM D790-17 Flextural Specimen

3.4 Discussion on Scanning Electron Microscopy (SEM) Analysis

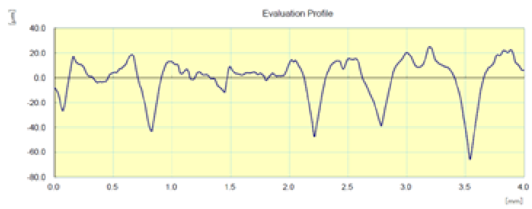
SEM services are used to have a look at surface and particles, concentrated on failure analysis of the additives, visualization of texture and morphology, or contamination of cloth SEM analyses the surfaces of the materials, particles and fibers so that fine information can be measured and assessed via picture analysis. One of the important thing parameters of this look at evaluates the floor roughness of vapor polishing. Figure 8,9 and 10 compares the pinnacle sections on the surface roughness of 3-d printed part whilst determined the usage of SEM before and after the put up-processing. The microscopic image of the untreated PLA sample shown in Figure 8 (a), 9(a) and 10 (a). But from the microscopic images shown in Figure 8(b), 9(b) and 10(b), it is evident that the demarcation due to the 3D-printed raster disappears moderately due to the chemical treatment and the material in the top surface gets dissolved which fills the gap between the raster to form a uniform smoother outer surface, this is in accordance with the 2D roughness profile, i.e. as the immersion time increases, the surface roughness value decreases.



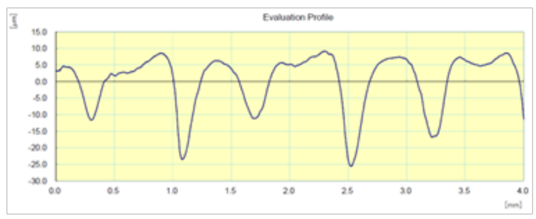
(a) Surface Roughness before chemical vaporization



(b)Surface Roughness after chemical vaporization



(c) Surface Roughness plot before chemical vaporization



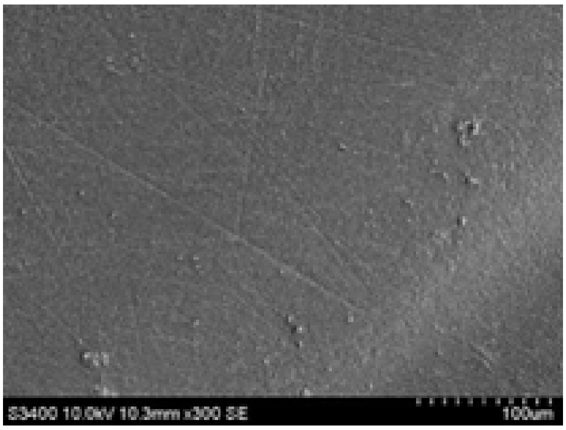
(d) Surface Roughness plot after chemical vaporization

Figure 7. Surface roughness result of 1, 2 dichloroethane

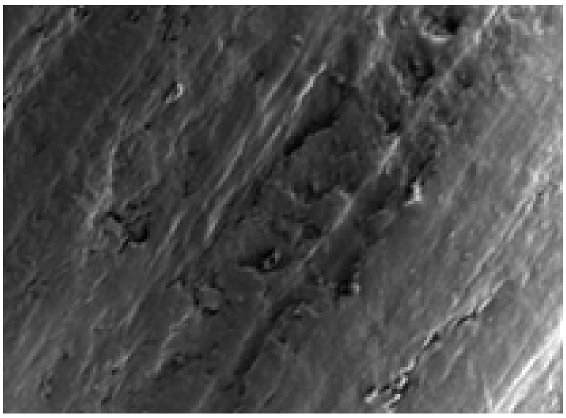
In all the instances the tensile electricity of acetone-dealt with samples is excessive than 1,2 dichloroethane treated samples but a lower floor roughness price is received via using 1,2 dichloroethane. This is due to the fact that PLA dissolves at a better fee in dichloroethane when in comparison to acetone and it makes the samples smoother and softer. From these consequences, a higher surface end is acquired using 1,2

 DOI: https://doi.org/10.30564/jmer.v3i1.1681

dichloroethane. Hence, 1,2 dichloroethane may be used as an opportunity chemical to acetone for better surface finish improvement.



(a)



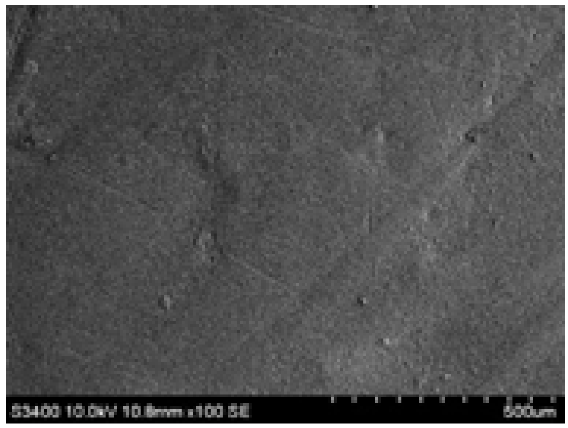
(b)

Figure 8. SEM images of ASTM D695-15 Tensile specimen butanol

Figure 8 (a) shows the line of deposited filament which were well arranged at the raster angle of 90º during printing. Whereas Figure 8 (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.

Figure 8 show the ASTM D695-15 Standard specimen SEM images for improve the surface finish by chemical vapor process PLA parts with acetone chemical. It is observed that the minimum surface roughness is achieved at 0.30 mm layer thickness, 90° angle build orientation and 10% and 100% fill density and 90 and 150 sec time duration is achieved in part number 14.

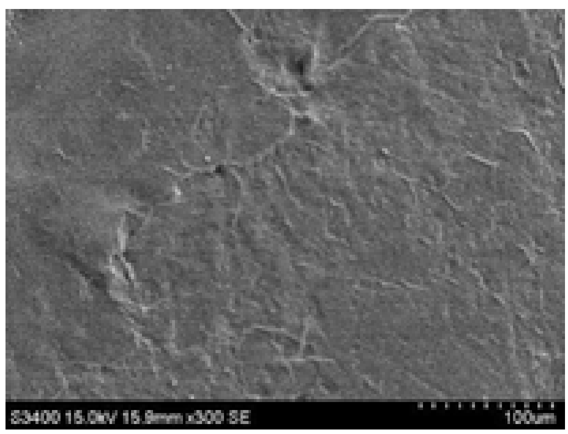
(a)



(b)

Figure 9. SEM images of ASTM D790-17 Flexural specimen with acetone

A flexural ASTM D790-17 Standard specimen SEM images shows in figure 9. It is improve the surface finish by chemical vapor process PLA parts with 1, 2 dichloroethane. The minimum surface roughness is achieved at 0.25mm layer thickness, 0° angle build orientation, 100%fill density and 150 sec time duration and it is good surface finish in part number 22.



(a)

DOI: https://doi.org/10.30564/jmer.v3i1.1681

(b)

Figure 10. SEM images of ASTM D638-14 Compression specimen with 1, 2 dichloroethane

Figure 10 ASTM D638-14 Standard specimen for improve the surface finish by chemical vapor process PLA parts with butanol chemical. A minimum surface roughness is achieved at 0.25 mm layer thickness, 90° angle build orientation, 10% fill density and 90 sec time duration and good surface finish is achieved in part number 1.

4. Conclusion

In this present work, impact of component build, layer thickness, fill density and orientation. Surface roughness of FDM check specimens are investigated. The responses also are measured post constructed treatment by warm vapours of 1,2 dichloroethane, butanol acetone. The roughness of FDM printed elements is analysed process parameters have been shown to influence the Ra. Technique parameters have been shown to have an effect on the Ra. The surface roughness of FDM components constructed at two distinctive part orientations (0° and 90°) with chemical vapour treatment.It has been observed that the optimum surface finish is obtained at 90° part build orientation, 0.25 mm, layer thickness, 10% fill density and 90 second exposure time.

(1) The results are compared based on the results acquired and fractographic studies the following conclusions are:

(2) A butanol chemical vapour conditions of optimum parameters are 0° build orientation, 0.2 mm layer thickness, 10 % fill density and 90 second exposure time

(3) An acetone chemical vapour, the conditions of optimum surface finish are 90° build orientation, 0.25 mm layer thickness, 50 % fill density and 120 second exposure time.

(4) 1,2 dichloroethane chemical vapour experiment gives a rough surface, butanol gives little bit rough surface, while 1,2 dichloroethane gives a good surface finish improvement.

The optimum results of surface finish are 1,2 dichloroethane > butanol > acetone and optimum surface roughness is achieved by 1,2 dichloroethane.

Acknowledgement

The authors would like to thank the CIPET: IPT Ahmedabad for the grant to provide a facility in which to carry out this study.

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