A Review on surface enhancement approaches for thermoplastics developed through Fused Deposition Modeling

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Abstract

As the Demand of low cost, tailor-made products are increasing in the contemporary industries, the research and development of different material processing techniques has been intensified. Fused deposition modeling (FDM) is most successful and popular additive manufacturing technique which used thermoplastic polymers as raw materials. This paper aims to study and analyze the fundamental working process, applications, limitations and challenges for FDM technology in present and future. Poor surface finish, which is one of intrinsic defect of this technology, has been considered as major barrier against implementation in critical application areas. Various chemical, mechanical and pre-processing techniques are elaborated along with detailed literature review. The impact of finishing operations in materials properties and overall cost of product has also been discussed in detail. The study also discussed the current and future challenges along with remedies which would help this technology to sustain in competitive environment.
Keywords: 3d printing, FDM, surface finish, mechanical properties, thermoplastic

1. Introduction

Fused deposition modeling (FDM) is the additive manufacturing process nowadays which is widely used in the industry. This technique also known by a name of fused filament fabrication and material extrusion in few countries. As the demand of the additive manufacturing is increased at the same pace the demand of FDM is also increased due to its easy and user friendly operated system.

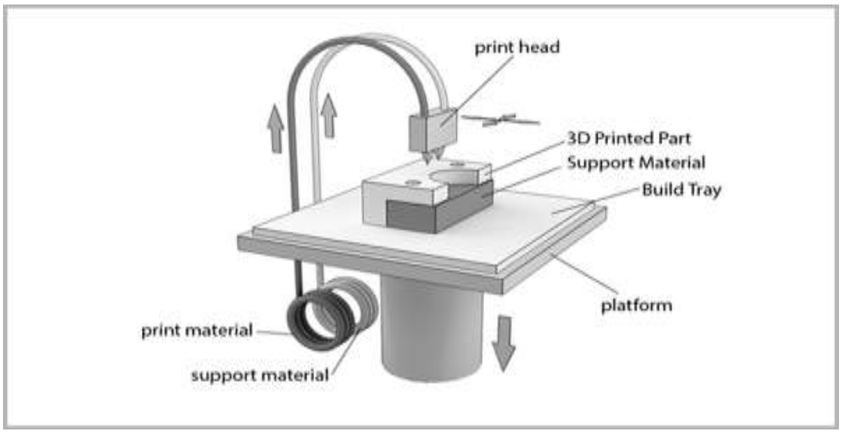

Figure 1 Schematic of FDM process

This technique contains mainly two type of material one is for to make the final product and other to hold or support the material during manufacturing of product so we can say that second type of material is act as a scaffold to the final product [1]. Most common material used for the FDM technique is thermoplastic as it having a property to regain it shape when heated up and become solid when heat is extract from it. The plastic filament in the FDM technique is wound in wires coils and these coils of wire are fed into the nozzle where it is heated up and then extracted from the nozzle tip in liquid state in a layer over the surface of the finished product [2]. The working principle of the FDM is shown in the Figure 1.

2. Applications of FDM technology

This technique of manufacturing gives a wide spectrum to part manufacturing as it having great ability to make complex part and have a great flexibility. This technique is mostly used in automation industry and many textile and paramedical product is to be manufactured by this technique also few examples are given below.in present scenario the FDM manufacturing is used almost every field right from tiny to tiny needle to giant airplane parts most common application of the FDM technology is shown in following Figure 2.

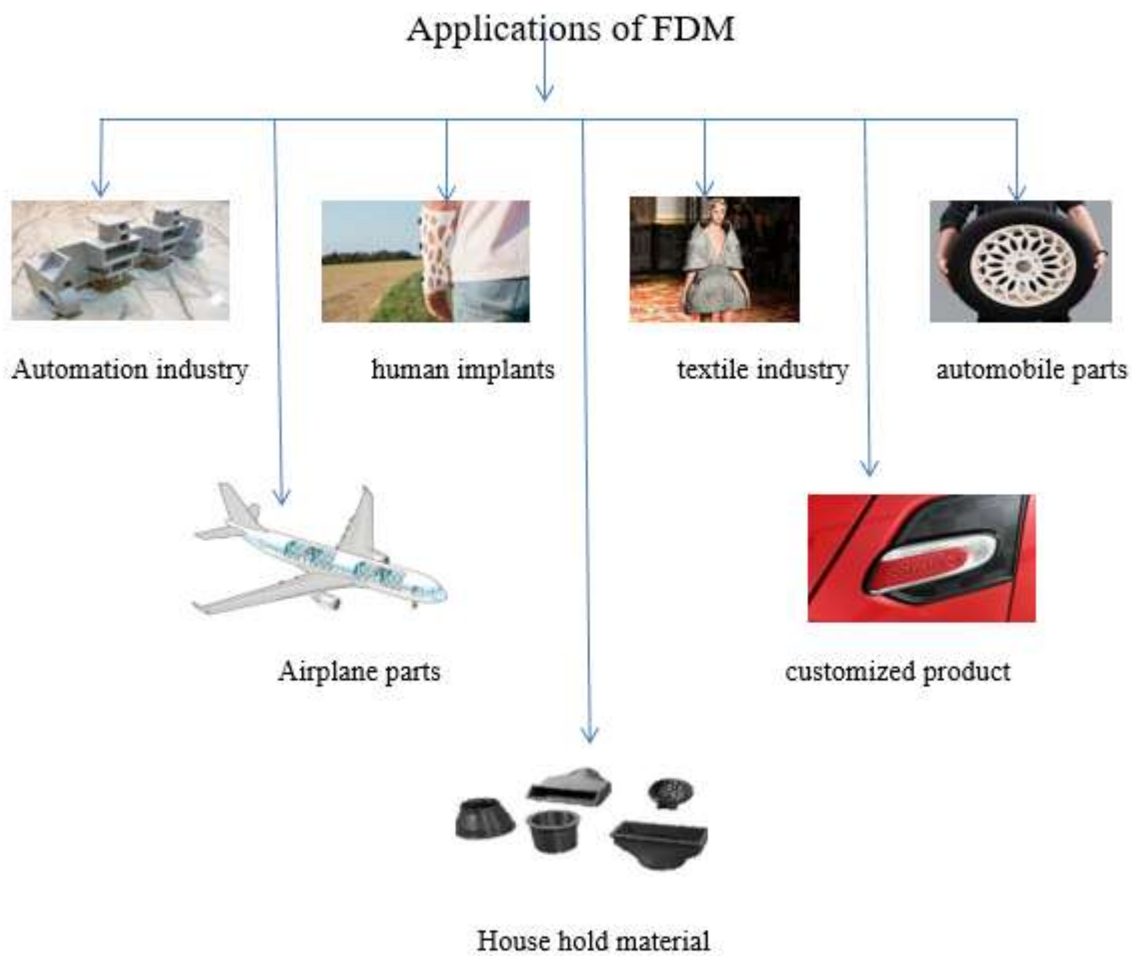

Figure 2 Application areas of FDM

3. Limitations of FDM technique

Although the FDM technique is used in each and every industry in the present scenario as it easy to use and flexible properties and many more advantages over other manufacturing techniques. But it also is having some limitation that makes the researcher to do some more work on it so that to make this technology to optimum level. This technique is making each part in layers. That is one over another the molten metal is poured and solidified material becomes the final product. This final product is having mostly staircase effects. The Staircase effect is nothing but the layering of material which overlaps one over another as shown below in steps so these steps shown on the final product. These marks are called staircase as shown in Figure 3.

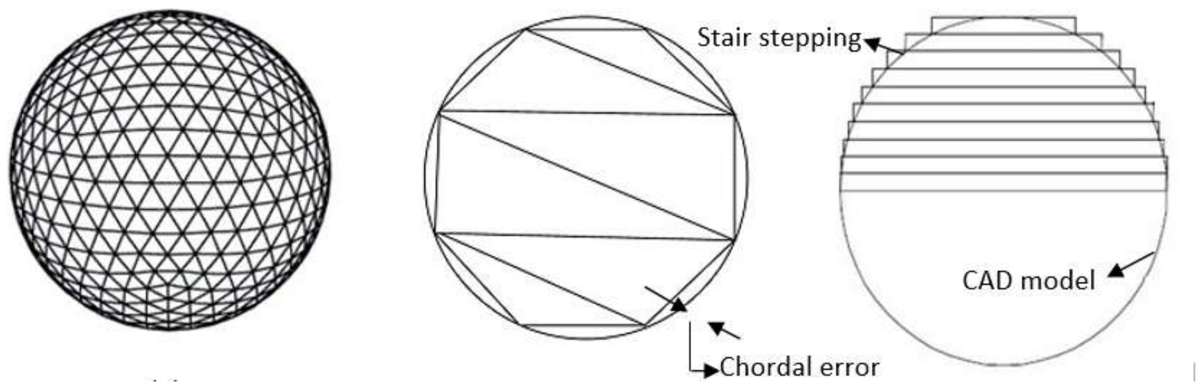

Figure 3 Surface defects produced on FDM parts

Figure 3 shows the surface roughness and stair case effect produced in the FDM products. Another important drawback of FDM manufacturing technique is the surface finish of the final products. The fused deposition modeling is having roughness that decreases its surface finish the surface finish of this technique is poor to overcome this problem many methods are adopted by researcher and numerous type of techniques are used now days and this technique also termed to be after processing technique to upgrade the surface quality of the final product, few mostly commonly used method are as discussed below,

4. Approaches for Surface Enhancement

There is lots of investigation is to be done by researcher how to improve and decreases the surface roughens of the final product. The numerous types of methods are available which can improve the surface quality of final product if we classify the method on broadly sense then it divide into two main types that is chemical method in which many chemical or solvent are used to improve the surface finish like painting or many resigns. And mechanical methods in which different mechanical process are used to remove the surface roughness of the material. These two method are then sub-divided into many part which classified as below:

4.1 Chemical Methods: the process in which the chemical solvent or other chemical process is to be made to make the surface finish better and the improved version comes under the category of chemical method. Followings are the chemical method which is used to increase the surface quality of the product. The few investigators analyze that the chemical method [2] has a great potential for improving the quality of the product. So to prove that investigators analyze the post processing treatment by cold vapor of acetone generally known as dimethyl ketone for parts manufactured by abs material with FDM technique, in this technique researchers focus on the three parameter viz. surface roughness of the part, uniformity and the time taken for the treatment. And take the full range of roughness of the product and apply two different methods for treatment one is termed as backward and other called facing and treated on many others interaction treatment methods and found that 98% of the roughness has been reduced by this method. Moreover it has been found that backward treatment is more effective in absolute final roughness and uniformity whereas the facing treatment is effective for time taken for the process. Few investigators are also studying that the FDM modeled part of abs material not required the human intervention in chemical treatment [3] it can be improved by just modified some prototype size. The investigator found that the raster width and slicer height are most influencing parameter for surface roughness. whereas the tip diameters have little consideration for the surface roughness.

Few researchers examine that the use of vapor smoothing method on fused deposition modeled parts of abs has given good surface finish with appearing minimal dimension affected. The researcher performs two different tests on parts which are manufactured on FDM. tallying a changed interpretation of a T.A. Grimm and Associates test part used extensively in industry in precision tests and run time examination, were used to assess the effects of vapor smoothing on surface quality and dimensional changes. As a rule results demonstrated that dimensional changes realized by the vapors smoothing process were irrelevant while considering both pre-smoothing estimations and CAD estimations as evaluated using an encourage assessing machine, the parts showed surface quality updates that are discernible from optical pictures. Future examinations will focus on performing accurate assessment to assess the dimensional precision changes. Additionally, features present on the test parts will be analyzed autonomously to choose whether certain shaped features are slanted to higher dimensional changes on account of vapors smoothing. Surface brutality upgrades will in like manner be estimated by obtaining Ra regards when vapors smoothing. This method of vapor smoothing although improves the surface quality by reducing the staircase, ridges and waviness, the FDM parts having plenty of flaws that can be reduced by this method and improving surface aesthetic value but it should not be able to completely remove the flaws. To achieve the surface quality nearer about injection molding the FDM end part should be process on direct digital manufacturing (DDM)

Few investigators examine surface finish for fused deposition models that can be upgraded by dipped or immersed on the parts on the chemical solvent dimethyl ketone- water solution. And study about the treated and untreated parts and their mechanical properties like bending and tensile strength approximately 200 test is to performed and then verified the properties with marine turbine blades manufactured by FDM, Mechanical properties of FDM models treated with 90% of dimethyl-ketone and 10% water have been breaking down. This technique is significantly increasing the surface quality of ABS models. In states of diminished harshness, a minor decrease of the elasticity was found yet a more prominent flexibility was found. Additionally, bending test uncovered improvements of the bending quality, most likely because an alternate activity of the arrangement on surfaces worked with various examples as well as an alternate response of used filaments to footing and pressure. These two cases show the edge of the filaments does not affect much on the mechanical properties, most likely because better isotropy can be achieved when treatment is completed.

Similarly, in one industry case study, the turbine blade is inspected with three-point bending test that indicated no change in mechanical properties yet a decreased harshness. More investigations are required, to inspect a few different perspectives, for example, the distinctions in the flexible conduct of test, or depend upon the time taken between treatment and for the test.

Some researchers have been examining AM-fabricated parts uses for fluid pressure application but this technique is not so famous or applied due the porosity and not so optimized building variable parameter (e.g., orientation of build and properties of materials). With an end goal to broaden the utilization of AM in various applications including liquid weight, parts fabricated with Fused Deposition Modeling (FDM) were fixed with an assortment of sealants and under tension they are tried. Eleven sealants with differing substance properties were applied to numerous geometries of FDM-created pressure tops through brushing or vacuum invasion. The tops were introduced on pressure vessels and along these lines tried while wellbeing precautionary measures were taken to maintain a strategic distance from calamitous disappointment (i.e., detonating) brought about by pressure differentials [6]. Assembling finished parts utilizing FDM is not feasible for liquid weight applications because of porosities present in parts, air holes, and voids. Removing such form deformities may permit FDM innovation to be utilized applications where liquids are applied at low weights including hermetic lodgings for biomedical products, for example, pacemakers and funnels/covers for thermodynamic frameworks, for example, heat exchangers. Vacuum invasion and brushing were investigated with the utilization of six sealants [5] (DEFT Clear Brushing Lacquer, Minwax Sanding Sealer, Minwax Oil Based Polyurethane, PRO Finisher Water-Based Polyurethane, Thompson's WaterSeal Multi-Surface Waterproofer) [6] that are promptly accessible to purchasers at home improvement shops and six modern sealants (IPS Weld-On 3 Cement, BJB TC-1614 A/B, Hysol E-30CL, Stycast W19 + Catalyst 9, West Marine Penetrating Epoxy, West System 105 Resin + 209 Hardener epoxy)[5] that are fundamentally utilized by mechanical organizations for particular assemblies and attachment of the products.

Some of the researcher works on the various parameters to decreases the surface roughness and improve the surface quality by controlling various parameter like time exposure to the material, concentration of the solvent and initial surface roughness of the material and interaction of material and temperature using different chemical applying by design of experiment method and examine it[7]and they found that the surface roughness of the end product of FDM can be optimize by controlling the concentration of solvent, time exposure and initial roughness of the material and temperature in solvent bath by adopting ANOVA technique [7]. In this research they took two different chemical solvent one is dimethyl ketone also known as acetone and other one is methyl ethyl ketone also known as MEK. When they applied the Anova technique of the above said parameter they found that in acetone bath the concentration of the solvent, concentration temp. Interaction and initial surface roughness of the material play a vital role in the surface quality of the finished product. Whereas in MEK it found that the parameter viz concentration of material, concentration – temperature and time interaction is play an important role to the surface quality but surprisingly for MEK the starting stage roughness and time of exposure have very little effect on the process [7]. The presence of the completed parts is practically identical to plastic shaped parts, the parts have reflexive completion and the most extreme restoring time is around 2 to 4 hours. This procedure is conventional and contradicts the market scenario that is for good productivity the time for one part should be Minimum as it takes more time.

Further investigations can be done to popularize this procedure to make it accessible in the market at a reasonable cost.

Some of the research is work on the FDM part manufacture product, how to decrease the overall cost to improve surface quality and focus on the ideal build direction of prototypes to acquire the best possible surface finish on explicit surfaces [8]. To achieve the goal of the research the researcher perform approximately 100 test on surface roughness parameter like tensile strength and elastic properties of chemical immersed manufactured part dipped in a dimethyl ketone(acetone)with90% concentration -10 % water based solution experimentally And also examine that the compressive strength of the material. They found that significantly improved the surface completion of ABS models, appearing to increment tractable flexibility yet in addition to marginally bring down stiffness. In addition, twisting tests uncovered a general improvement of the flexural quality, most likely because of an alternate activity of the arrangement on surfaces worked with various examples as well as an alternate response of treated fibers to footing and pressure. The investigation has been finished in the current examination with pressure tests that concurred with going before contemplates, bringing about expanding compressive quality. All in all, the outcomes accomplished point out the viability of the proposed completing medications that are to be utilized with drenching times up to 300 sec to diminish roughness up to 90%, keeping mechanical properties now and again better than the non-treated parts.

Some researcher study on the different raw material and modern and machining process to improve the surface quality of the product they found that if the different material and different technique are used with strategy like different parameter like Abrasive size, HCM feed rate, flow rate of abrasives, chemical concentration and Laser power [9] etc. are chosen according to need and the requirement the optimal result can be found.in this study they almost take all possible material that are used as filament for FDM technique like metal, ceramics and polymers.

Some researcher also investigate on the chemical solvent/ vapor polishing and analysis there effect on the mechanical properties of extrude abs parts in this research the research work to measures the surface roughness change and furthermore assesses the impact on hermeticity and mechanical property, and find the impact of acetone vapor-polished ABS tensile specimens of 1, 2, and 4 mm thicknesses of extruded FDM parts by examine closely they found that Fume cleaning demonstrates to diminish the force thickness for surface roughness highlights bigger than 20 μm by a factor of 10X, and shows huge improvement in hermeticity dependent on both per fluoro carbon net break and weight spill tests. Nonetheless, there is insignificant effect on mechanical properties with the slight examples giving some expansion in stretching at break yet diminished versatile modulus. A bi-exponential dispersion rot model for dissolvable vanishing recommend a thickness free and thickness lesser time required with the last supporting a plasticizing impact on mechanical properties.

Some researcher is study and examine that as the FDM method is having poor surface finish and ABS parts are manufactured by FDM technique which is having very low or poor surface finish to overcome this drawback many user apply chemical solvent generally acetone vapor which is toxic in nature to make this solvent user friendly researcher develop and suggest desktop vapor polisher with acetone vapor absorption mechanism [10]. This method overcomes the drawback by providing sealing to the process so that the toxic solvent never interacts with the environment and gives a feasible reasonable economical process to add water into it. It is having other benefits such as modular design and induction heating method [10]. The other benefits of this are environment friendly design, less costly so economy saving as well as energy and user friendly. And induction heating provides the design more heat effectiveness and safety

4.2 Mechanical Methods

In mechanical methods the surface roughness of the product is removed by mechanical means. That is the mechanical machine or other mechanical tool such as a vibratory bowl. Hand finishing with file and other tools like sand paper etc. here we discuss the different methods used to increase the surface finish of rapid manufacturing machining by using mechanical method there use and benefits and which type of material are used.

Some of the investigators work on Ciba-Geigy XB5081-1 and XB 5143 resins [11] on vibratory automatic surface finishing. As discussed, the surface finish of the 3 dimensional printing or additive manufacturing parts are having low surface finish to improve that surface finish on curve parts which contain convex and concave parts. Which difficult to increase the quality of surface finish on the edges to improve the surface finish at the edges the investigator analysis on two different mechanical surface finish techniques viz vibratory bowl abrasion and Ultrasonic Abrasion method which are validate by initial microscopy electron scanning and topography analysis that give that the both technique have an ability to improve the surface finish.in vibratory bowl abrasion Parts made from XB5143 are more receptive to surface completing strategies than XB5081-1which gives off an impression of being unsuited· to the majority of the grating procedures because of its brittleness. Both Vibratory Bowl Abrasion and Ultrasonic Abrasion have represented that they are potential procedures for deburring polymer Stereolithography leaves behind empowering results at short period of times.

Some of the investigators work on advancement of abrasive flow machining and streolithography process and try to reduce the time frame for the manufactured prototype by applying statistical technique. In this research they found that the media grit size, media pressure, orientation on work and resign type of flatness. Table 1 different material used and process used on FDM effect on mechanical properties.

Table 1 Different studies performed for surface finishing of FDM test parts

S. No	Materials used	Parameters	Methodology	Findings
1.	PET –G [12]	PET-G materials with different printing filling structures (rectilinear, triangular, full honeycomb) at processing speed of 50 mm/s	standard (TS 138-A) tensile test samples used	Rectilinear structure have more tensile strength compare to other two; Shore D hardness and surface roughness value are closed to each other; Pet-g material is more suitable with rectilinear filling method then other two method
2.	ABS, PET and PLA [13]	Different temp ranges for different material ABS at 380˚C – 430˚C For PLA(300˚C-400˚C)	All filaments which are used kept in a dry place for 24 hours, Thermogravimetric Analysis (TGA) in temp range of f 20˚C	All thermoplastic filament contain dangerous VOC such as styrene, butanol, cyclohexanone, ethylbenzene, and others; concentration of formed organic vapors is not much dangerous as it

		For nylon above 390 DTG peak at 422°C And pet temp range Is 432 [30]	– 550˚C and Heating rate has been equal to 10˚C min-1, VOC(volatile organic compounds.) Emissions Testing Procedure	used in well insulated room; VOC emission largely depend upon the temp.; PET and nylon had a great thermal stability over a PLA and ABS
3.	ABS, PLA, PEI, PEEK, PC, PA [14]	Layer thickness/height, nozzle diameter/bead/road width, flow rate, deposition speed, infill, raster orientation/angle, raster pattern, air gap	Study all parameter which effects mechanical properties of materials and deep study and physical properties	FDM technique product is dogged by the filament bonding. this thermally driven process and all variables are influenced; tensile strength can be improved by using minimum values for layer thickness and raster width; negative raster angle help to improve the mechanical properties; All parameter like raster angle, thickness consider to be standardized parameters
4.	**ABS** [15]	Raster angle 45, thickness of layer 0.15mm nozzle speed and bed tempertature40mm/sec and 100 degree respectively	Compared two different chemical solvent acetone and Dichloroethane and check the mechanical properties	The surface roughness value & maximum tensile strength diminishes with an expansion in the immersion time; higher tensile strength was obtained for acetone-treated samples compared with dichloroethane-treated samples; reduction in the surface asperities tend to decrease in tensile strength, but an improve elongation to the material.
5.	ABS	Different concentration ratios of acetone and finishing time	ASTM Standard D638– 10[16]	vapor polishing largely affects thinner segments by expanding strain to the limit of failure and quality yet diminishing the elastic modulus; with increase of thickness upto 2 mm show quiet improvement in ductility and ability to resist penetration with a quiet decrease in elastic modulus

Few investigators work on the profilometric analysis as the average of surface roughness is not predictable to the actual roughness of the prototype in this they study each and every parameter which is responsible for the surface roughness and their characteristic which is obtainable and profilometric analysis. In this they make a hypothetical 3D profile model as a component of procedure parameters and the shape of the parts. A reasonable geometry was structured and prototyped for approval. Information was estimated by a profiler and supplemented by infinitesimal investigation. A philosophy dependent on the proposed model was applied to streamline model creation in two down to earth cases. In this study they found that the profile is effective in portraying the smaller scale geometrical surface of combined affidavit displaying models. The third measurement empowers the count of sufficiency, spatial and half breed of roughness parameters A constraining part of FDM is the surface nature of delivered parts. The proposed model permits to know the achievable 3D profile ahead of time contingent on process factors. This allows the definition of all unpleasantness parameters acquired by a profiler investigation. The trial, performed on appropriately structured examples in ABS, confirms the model speculation and profile shape. Various displayed unpleasantness parameters have demonstrated extraordinary understanding with the deliberate ones. The microscopic examination called attention to the wonders influencing the morphology of the filament area prompting model constraints. At the item advancement stage, this model is helpful to conform to structure specifications. Additionally, in the process arranging it very well may be applied to decide fabricating procedures. A temporary examination demonstrated the capacity of the best approach to manage helping the structure period of a thing by addressing the possible surface roughness. Other logical examinations showed the feasibility of the strategy to choose ideal part course in order to meet in any occasion one particular. The imaginary model was verified on various materials. Taking everything into account, the machine, the method boundaries and the mechanical properties of the materials are extremely one of a kind, results confirmed the model authenticity. Consequently, we can reason that the proposed model remains against the combination of material and assembling machine. The impact of different surface finishing approaches on mechanical strength og FDM part is shown in Table 2.

Table 2 Literature review on investigation of different mechanical properties of test parts

Authors	Parameters	Properties of mechanical material	Materials
Mahmood and Qureshi, 2017 [17]	Infilled density, thickness and width (3 levels each)	Strength under tensile load	ABS
Ransey, 2017 [18]	Orientation of building, infill (3 levels each)	Strength under tensile load	ABS
Dizon, , 2017 [19]	Raster (45/-45; 30/-60; 15/-75; 0/90), building orientations (flat, on- edge, up-right); process parameters constant but different between printers	Axial strength, endurance , Lateral to longitudal ratio, modulus of elasticity	ABS
Alvarez.kC, 2016 [20]	Infill parameter vary from 0 to 100 with 5% increment	Tensile strength, toughness of material	PLA
Hernandez, R., Slaughter 2017 [21]	5 building orientation on various angle	Axial, compressive, and bending strength	PLA
Torrado, A. R, 2016 [22]	Pattern of raster three different level	Inflexibility capability	PLA
Mahmood, S., Qureshi, 2017 [23]	Different parameter like width, thickness, no of specimens density of infill on (3 levels each)	Tensile strength	PLA

Raney, K., Lani, 2017 [24]	Infill and orientation of building in 3 levels each	Capacity of resist tensile load	PLA
Dizon, J. R. C, 2017 [25]	Raster (45/-45; 30/-60; 15/-75; 0/90), building orientations (flat, on- edge, up-right). Parameter taken same for machine but change for printer	Capacity of resist tensile load, point of failure, Poisson ratio, modulus of elasticity	PLA
X. Liu, M. Zhang, 2017 [27]	Orientation of deposit material, thickness of layer, method to deposition material, variation in raster and distance of raster (3 levels each)	Capacity of resist tensile load, bending strength, toughness of material	PLA
A. Bagsik, V. Schoeppner, 2017 [28]	On three different level select feed rate, building orientation and 4 layer thickness parameters	bending strength, capacity to resist tensile load	PLA
W. Wu, P. Geng, 2015 [29]	Three different level value taken for layer thickness material and for raster angle	compressive strength, flexural strength and axial load wearing capacity	PEEK AND ABS
K.P. Motaparti, 2016 [30]	Orientation of building, angle for raster, air gap and infill material at particular level of (2,2,3,2 simultaneously for parameter)	Capacity to wear compressive load under compression	PEI
R.J. Zaldivar, 2017 [31]	Location of chamber and different building orientation of material	Mechanical and thermal behavior	PEI
S. Xiaoyong, C. Liangcheng 2017 [32]	Variation of temperature according to bed position 3 value is taken for each position, ratio to filling	Strength to tensile load	PEEK
Dong H, Moys MH, 2018[33]	Printing parameter like temp, speed of print, layer to layer thickness and filling of material on 3 level each	Tensile strength, modulus of elasticity, elongation or strain	PEEK
F. Knoop, V. Schoeppner, 2016 [34]	All used material like zortrax, z-glass etc are examine by 5 set of sample	Strength of material under tensile load	Zortrax proprietary materials
K. Szykiedans, W. Credo, 2017 [35]	Printing parameter like orientation and plane and thickness of material layer by layer	Capacity to wear load under tension and compression, and strength of material under these condition	Zortrax proprietary materials

5. Conclusions

In this paper, different chemical and mechanical techniques are identified and studied which are used for surface enhancement of thermoplastic parts made by FDM. The surface finishing techniques are broadly divided into two types i.e. pre-processing and post-processing. Since pre-processing are only limited to process planning and parametric optimization, the latter is most popular and effective as compared to former. Post processing approaches are further classified into two types i.e. chemical and mechanical techniques. A comprehensive literature review has been presented where impact of process parameters on surface quality and mechanical behaviour of FDM test components is analyzed. The successful implementation of effective surface treatment technology can improve the surface quality of FDM parts.

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