# A Review on Post Additive Manufacturing Techniques to Improve Product Quality

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**Abstract** Since past three decades, direct printing of parts for various applications by the use of 3D-printing technology has gathered a lot of attention. However, many issues remain with the widespread applications of 3D-printed materials such as regulatory issues, sterile environment for part production, and the improvement of material properties with the desired structure. This article focuses on review of various post additive manufacturing processes to improve mechanical properties such as storage modulus and Young's modulus and surface roughness. A heat treatment process after 3D printing was also discussed as potential method to achieve better mechanical properties by optimizing the crystalline structure of material. It was also reviewed that traditional AM technique produces products at a rapid rate and with minimum waste of materials and post processes could improve the surface finish as well as structure with higher strength in three dimensions.

**Keywords** Additive manufacturing processes · 3D printing · Mechanical property · Surface finish heat treatment

## 1 Introduction

Additive manufacturing (AM) technologies are nowadays have importance in industries (construction, prototyping and biomechanical) and in research field. Rapid prototyping which involve possibility of realizing objects of complex shapes is shifting conventional manufacturing techniques to produce customized products. 3D manufacturing system has benefits over conventional techniques in terms of overproducing products with complicated profile, high precision and accuracy, material savings, design flexibility and personal customization. Fused Deposition Modeling (FDM) is one of the most common AM methods due to user handy, economic and able to use conventional thermoplastic polymers such as PLA, ABS, and Nylon [1]. Three-dimensional (3D) printing technology has also potential to use products

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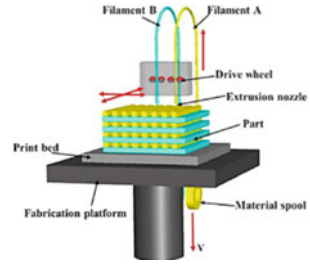
in biomedical field including engineering scaffolds, implants, printing tissues and
organs, etc. The 3D printing has reduced the additional expenditure involved in
the process of developing a product. FDM method is very common method of 3D
printing which uses a continuous filament of a thermoplastic polymer to print layers
of materials (Fig. 1a).

The filament is heated at the nozzle so that material will convert into semi-liquid
state and finally extruded on the platform in a manner of layer by layer deposition
to transform into final product. Material should be having higher degree of thermo-
plasticity so that it could fuse easily during printing. The main process parameters
which affect the printed part's mechanical properties are thickness of the layer, width
and filament orientation and air gap (in between or even the same layer). FDM
process is economic, rapid and simple process but having disadvantages such as
poor mechanical properties and poor surface quality. This paper reviews the various
researches done to improve the mechanical properties and surface finish after 3D-
printing process [2].

## 2 Temperature Effect on 3D-Printed Parts

Perfect 3D-printing temperature for material used such as PLA (polylactic acid) does
not exist and various trial and errors are carried out to achieve the perfect PLA print
temperature. Printing temperature impacts on the quality and effectiveness on 3D-
printed product. An optimal range of temperature should be selected before starting
3D-printing process. Coppola et al. [1] investigated the prominent effects of temper-
ature in the 3D printing of PLA/clay nanocomposites in additive manufacturing
applications.

The two specimen names as Dog-bone and prismatic specimens were manufac-
tured using the technique of fused deposition modeling at three varying tempera-
tures. The temperature was increased in certain range from melting temperature to
higher temperature as (185–200–215 °C) for PLA 4032D and (165–180–195 °C) for
PLA 2003D as raw materials. The specimens were further tested for tensile strength
according to the varying nozzle temperatures. The other mechanical properties such
as young's modulus ($E$), elongation at break ($\varepsilon b$) and tensile strength ($\sigma$) were also
measured. It was found that the samples with nanocomposites have higher modulus

of elasticity as compared to pure samples of polyacitic acid (PLA) for all the printing temperatures in his experiments. An embrittlement was found to be increased as nozzle temperature increases in given range for both PLA/nanocomposite specimens printed by FDM technique. Storage modulus variation was studied in defined range of printing temperature of PLA 4032D and PLA 2003D. The study revealed that storage modulus starts to decrease with rising print temperature for PLA 4032D while increases at increased temperature. The study revealed that printing temperature should be selected in correlation with the melting temperature [1].

It was also observed that the perfect adhesion of any printed sample to its printing bed was also affected by temperature variation and was achieved by heating the printing bed to temperatures slightly above the TG of the filament material for materials such as PLA. The simple reason behind this was that when the temperature is increased above the filament's TG it leads to a reduction of the surface tension between the printing bed and the printing material apart from it larger contact area is created which gives better adhesion between the bed and the filament. Strong increase in the adhesion force was also reported as printed bed temperature increases. It was observed that higher printing temperature generates a contact angle of low value as compared with the samples at lower temperature which results in more adhesion [3, 4].

## 3   Reason of Porosity and Affective Measures

In additive manufacturing density is defined as the pores development during the layering of the product. Although maximum number of products produced generally attain a density over 99.5% after 3D printing but repeatedly obtaining same density in manufactured products is undoubtedly challenging. The problems occurred due to porosity in a material was that it adversely affected the strength and reduced the resistance to impact of the product manufactured. Apart from it due to high porosity cracks, it generates or propagates faster whenever stress are generated during the life cycle of the product leading to its complete failure. Therefore porosity is a negative factor for finished product in 3D printing. Several researches have been done to minimize the porosity of the material.

Internal pores might be existing in 3D-printed specimen. X-ray computed tomography (XCT) technique might be useful to find out the details such as size, shape, and porosity. It was evident that the main parameters that were influenced the porosity of 3D-printed products were the thickness of the wall of specimen and extrusion thorough nozzle and G-code optimization of these parameters. It was found that larger the extrusion multiplier the porosity reduced significantly consistently. Whereas Wall thickness in the 3D-printed process allowed for an diagonal internal filling.

Further in some studies, the effect of porosity and crystallinity was studied in 3D-printed samples. It was found by specimen morphology that the pores intensity is more in the top and middle layer of 3D-printed specimen. It was suggested that thinner

samples in conjunction with low build temperature lead to improved mechanical properties with higher degree of orientation [5].

Porosity is equally important in additive manufacturing or 3D printing of biomaterials as porosity along with size of pore of biomaterial scaffolds are crucial parameters which affect the quality and rate of bone formation. Lower porosity stimulates the process of osteogenesis by reducing cell proliferation phenomena and enhancing cell aggregation. Enhanced porosity tends to improve the growth in bone. Size of the pore shows its affect on the progression of osteogenesis due to vascularization, major experimental results show that small pores favored hypoxic conditions and induced osteochondral formation before osteogenesis and on the other hand large pores had been well-vascularized lead to direct osteogenesis without osteochondral formation [6].

Increased porosity in controlled manner of 3D-printed parts may be beneficial in case of biomedical implants. Minas et al. [7] incorporated large pores on top layer which resulted in better healing process. 3D-printed biocomposites consisting of higher porosity introduces a hygroscopic property which increases to retain the water.

## 4    Surface Roughness Affects and Measures

Surface roughness is defined as the variance or irregularities in a surface topology. Surface roughness details and specifications are important and crucially required information in any engineering design as it determines the life of the product and usability. Metal Additive Manufacturing (AM) processes although takes some care of the surface roughness but usually fails to meet the precise surface roughness requirements. This makes it necessary for some expensive post-processing techniques such as machining or polishing. Surface roughness capabilities of metal AM, post-processing techniques and their associated time and cost should be considered to select the optimal manufacturing workflow.

Surface roughness of Metal AM parts have three major contributors that are

- Surface irregularities due to layering effects and low process resolution,
- Granular micro-surface textures from melting and binding powder feedstocks,
- Support structures and the remnants and surface marks left by their removal.

The main process parameters that generally affect the surface roughness of AM product are speed of printing, power, built part, and cooling rates.

Several studies show that the layer height with wall thickness is critical factors to be selected for optimum surface roughness. The surface roughness is decreased when height of the layer and product wall thickness are increased simultaneously or individually in FDM technique. It was recommended to use lower levels of layer height, staircase effect and also wall thickness to reduce surface roughness. The parameter selection should be also based on the size of the nozzle extruder [8].

Improving the surface roughness can be really easy and can be done without making any major changes in the main processing or post-processing techniques simply by optimizing the design which includes geometry and orientation of the parts and supports. Therefore implementation and making of most optimized design is the most effective way to control surface roughness.

A new post-processing method has been reported for 3D-printed thermoplastic parts which are also called constrained remelting. The improvement in the surface roughness and mechanical strength of the 3D-printed parts was reported. A 3D-printed PLA sample was inserted in a profiled mold insert with a negative shape and was then heated to near the melting temperature with additional thickness. Remelting conditions, the remelting temperature and initial thickness were investigated in terms of the surface roughness and tensile strength. The results showed that remelting at 160 °C along a 4.0 mm thickness could improve surface finishing. [9, 10].

## 5   Warping

The major effect of wrapping is the upliftment or rising of the deposited metal at the ends this is caused due to rapid cooling of the material. During rapid cooling the material contracts quickly and results in the above problem. Warping also results in formation of cracks in the print. The main reason for this problem is that the temperature difference between the layers of extruded product is significantly large, which creates tension within the product and consequently the lower layer start to lift up or drag. Easy solution to this problem is to just keep the entire printed product at the same temperature. But this is a nearly impossible task therefore several ways have been devised to overcome wrapping such as adjusting bed temperature, using bed adhesion tools, and setting optimum enclosure temperature.

Alsoufi and Elsayed [11] found that extruded PLA + filament deposited onto the non-heated platform by moving a printing head in a user-defined pattern, such as to achieve the desired final 3D shape. It was evident that the optimum value for temperature of the nozzle was nearly 220 °C with minimum warping deformation of 4.77 ± 0.12 mm at 15 mm/s printing speed. The accuracy of arrangement resulted in a small percentages error of about 4.55%. The result of the validation process showed that there was a significant improvement in warping deformation in each case by reaching 0.4% error.

It was also found that the printed products with 90° edge also showed less wrapping deformation. Another study says that it is found effective to use a enclosure or enclosed 3D printers. Although it makes it a little costly but helps prevent defects like wrapping and clogging of nozzle therefore properly maintaining the enclosure temperature should be considered as a crucial step.

Heating bed during printing is also one of the main solution to eliminate wrapping completely. The core idea is to keep the first layer heated and not let them cool quickly. This helps the initial layers to remain in contact with the build plate thus avoiding warping [12].

## 6 Quality Methods

Since roughness and layer line are mostly present of the FDM-based products therefore for smooth surface post-processing becomes crucial. Some of the post-processing techniques not only adds strength to prints but also helps to reduces the anisotropic behavior of it. One of the common methods is to annealing the produced part. Slavković et al. [13] studied the mechanical properties of 3D-printed polylactide acid SMP material. Annealing treatment and printing directions were considered and found to have significant impact on elastic modulus and ultimate strength of material. Annealing at 75 °C increased tensile and compressive strength compared to as-printed SMP tested at room temperature. It is probably due to annealing effects resulting in residual stress relief and crystallinity stronger layer bonding which causes changes in the properties of 3D-printed products.

Electrode position-based AM technique improves the deposited metal qualities and eliminates limitations and improving horizontal and vertical resolution. Electrode position has the quality of producing films in vertical resolution at a sub-nanometer range [14]. Electroplating is also considered as a good post-processing technique as it can improve the strength of the product but also gives a fined surface finish enhancing the look of the final product. Materials that can be easily electroplated include ABS.

It was found that if titanium alloy is produced using 3D printing in traverse direction as compared to longitudinal direction then mechanical properties such as tensile strength and ductility could be improved [15–17]. Same observations were identified for alloys, ceramics and polymers [17–19].

## 7 Crack Detection in 3D-Printing Process

Cracking is caused due to deformation in higher layers after printing process. The stress caused between two layers tends to deform the layers due to which crack is initiated in the object.

Patterson AE [20] studied the most affected areas on which cracks could initiate and hence grow in 3D-printed materials.

(1) Cracking caused by faulty print process.
(2) Cracks initiate in the shell and proceeds toward relatively low dense areas of 3D-printed part. The other attributes caused of cracking is also due to rapid material cooling and residual stresses induced.
(3) Cracking and delamination of parts have been also reported which are printed into full density parts. This is generally caused by residual stresses and concentrations in the part after printing. Effect of residual stresses on full density parts is prominent more severely than partially filled parts.

Materials having higher rates of shrink develop more cracks after cooling. It was also found that the cracks stay without further escalation till any external source
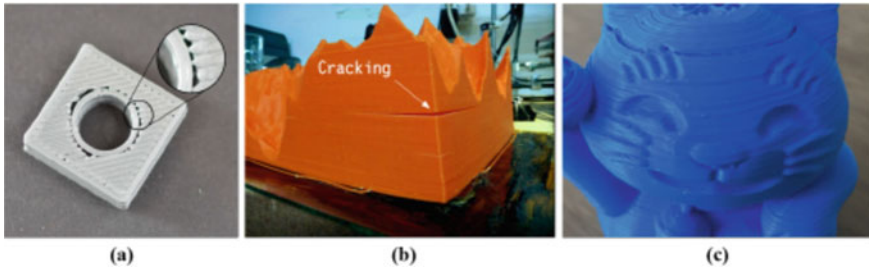
**Fig. 2** **a** Surface defect crack. **b** Shell defect crack. **c** Delamination [20]

acts or imparts energy on the product. Zolfagharian [21] did experimentation using centrally positioned notches with Nylon 12 filament and PA12 nylon powder to produce 3D-printed specimens. This printing technique was found to be effective for improving tensile behavior. MJF (multi-jet fusion) and FDM (Fused Deposition Modeling) was compared in terms of structural integrity, elongation and toughness. FDM process was found to be most suitable as compared to MJF considering all mechanical properties.

Layer height should be 20% smaller than the nozzle diameter selected as reported in one study. If the layer height exceeds the limit then improper bonding of each layer of plastic may result. For avoiding cracks during 3D-printing process print temperature should not be too low and print speed should be controlled properly as it should not be in higher range [22] (Fig. 2).

## 8 Material Selection

The applications of additive manufacturing are widespread and escalating at a rapid rate; therefore, the choice of material for different application becomes important for a efficient three-dimensional printing process. Generally, 3D-printing process begins with melting of the metallic feedstock for which usually an electron beam or a laser beam is used and after that a solid part is obtained layer by layer. Many materials such as alloys of steel, aluminum, magnesium, cobalt, nickel and titanium along with pure titanium are considered good for a 3D-printed product. Titanium and its alloys are used widely in many industries and workplaces such as aerospace and biomedical fields because of its high performance but the machining cost of titanium is high. Various steels such as austenitic stainless steels, precipitation harden able stainless steels, maraging steels are commonly used in AM. These alloys are used to obtain high strength and wear or scratch resistance that is hardness conditions. Aluminum compared to titanium is used very less in 3D manufacturing but they are easily machinable and cheaper compared to titanium. Due to high thermal conductivity of aluminum, the residual or internal thermal stresses are reduced that allow faster production. Further, magnetic properties are required in areas like aerospace, etc.;

therefore, such material are also prepared in 3D printing, and studies are being done on magnetic alloys such as NiFeV and NiFeMo. Although a vast variety of metals and their alloys are being used in this printing, majority of the alloys do not fit good in the process of 3D printing due to melting and rapid solidifications. Additive manufacturing is now also used in the construction process but here it depends on a large nozzle size and concrete properties like good extrusion strength and cohesion among concrete particles. Although a vast variety of material are used in AM process, polymers are most widely used. In general Metals and alloys are used in aerospace, automotive. Polymers and composites are used in Aerospace and Automotive, Sports, Medical, Architecture, Toys and biomedical. Ceramics in chemical industries and aerospace and concrete in infrastructure and construction [2, 23, 24].

## 9    Conclusion

3D-printing technique has various advantages over the convention methods like faster production, less tool requirement, accuracy and it is much economic to use. Although FDM generally used ceramics as printing ink but nowadays metals, alloys and even concrete are used for the same. The process suffers from main disadvantage of poor mechanical properties and surface finish. It was found that printing temperature was playing a important part to attain higher mechanical properties such as Young's modulus ($E$), net deformation at break ($\varepsilon b$), and elastic or tensile strength ($\sigma$). Even selecting a temperature higher than the TG of the material resulted in a better material and bed adhesion which is desiray. If larger extrusion multiplier values (sometimes as large as possible) are used then porosity could be reduced. In 3D printing, internal diagonal filling should be allowed in wall thickness. Some research recommends a low or reduced value of wall thickness, a decreased height and stair casing effect reduce surface roughness. Remelting is another post-processing method which has been found to improve the surface roughness and mechanical strength of the 3D-printed parts. Several methods such as adjusting bed temperature, using bed adhesion tools, and setting optimum enclosure temperature have been found to overcome wrapping problem. Annealing treatment and printing directions were found to be vital important for improving mechanical properties such as elastic modulus and ultimate strength of material. The various research conducted focuses on to improve the surface and mechanical properties of 3D-printed product. Future research could lead to a stage where we can perform AM in a manner without producing the common defects and even eliminating processes like heat treatment which will definitely reduce the cost of production and eventually reduce the production time. But for now, working with metals, ceramics or alloys is still a challenge with the present technology of AM.

# References

1. Coppola B, Cappetti N, Maio LD, Scarfato P, Incarnato L (2018) 3D Printing of PLA/clay nanocomposites influence of printing temperature on printed samples properties. Materials 11:2–17. https://doi.org/10.3390/ma11101947
2. Ngo TD, Kashani A, Imbalzano G, Nguyen KTQ, Hui D (2018) Additive manufacturing (3D printing): a review of materials, methods, applications and challenges. Composites B 143:172–196
3. Spoerk M, Gonzalez-Gutierrez J, Sapkota J, Schuschnigg S, Holzer C (2017) Effect of the printing bed temperature on the adhesion of parts produced by fused filament fabrication. Plast Rubber Compos 47(1):17–24. https://doi.org/10.1080/14658011.2017.1399531
4. Sun H, Wang SQ (2012) Shear and extensional rheology of entangled polymer melts: similarities and differences. Sci China Chem 55:779–786
5. Liao Y, Liu C, Coppola B, Barra G, Maio LD, Incarnato L, Lafdi K (2019) Effect of porosity and crystallinity on 3D printed PLA properties. Polymers (Basel) 11(9):1487. https://doi.org/10.3390/polym12010142
6. Karageorgiou V, Kaplan D (2005) Porosity of 3D biomaterial scaffolds and osteogenesis. Biomaterials 27:5474–5491. https://doi.org/10.1016/j.biomaterials.2005.02.002
7. Minas C, Carnelli D, Tervoort E, Studart AR (2016) 3D printing of emulsions and foams into hierarchical porous ceramics. Adv Mater 28(45):9993–9999
8. Pérez M, Medina-Sánchez G, García-Collado A, Gupta M, Carou D (2018) Surface quality enhancement of fused deposition modeling (FDM) printed samples based on the selection of critical printing parameters. Materials (Basel) 11(8):1382. https://doi.org/10.3390/ma11081382
9. Cho KL, Liaw II, Wu AHF, Lamb RN (2010) Influence of roughness on a transparent superhydrophobiccoating. J Phys Chem C 114:11228–11233
10. Kim HC, Kim DY, Lee1 JE, Park K (2017) Improvement of mechanical properties and surface finish of 3d-printed polylactic acid parts by constrained remelting. 8(12):1199–1203. https://doi.org/10.5185/amlett.2017.1686
11. Alsoufi MS, Elsayed AE (2017) Warping deformation of desktop 3d printed parts manufactured by open source fused deposition modeling (FDM) system. Int J Mech Mechatron Eng 17(4):7–16
12. https://manufactur3dmag.com/common-problems-in-3d-printing-how-to-resolve-them-part-i/
13. Slavković V, Grujović N, Dišić A, Radovanović A (2017) Influence of annealing and printing directions on mechanical properties of pla shape memory polymer produced by fused deposition modeling. In: 6th International Congress of Serbian Society of Mechanics Mountain Tara, Serbia, pp 1–8
14. Braun TM, Schwartz DT (2016) The emerging role of electrodeposition in additive manufacturing. Electrochem Soc Interface 25(1):69–73
15. Carroll BE, Palmer TA, Beese AM (2015) Anisotropic tensile behavior of Ti–6Al–4V components fabricated with directed energy deposition additive manufacturing. Acta Mater 87:309–320
16. Mühler T, Gomes CM, Heinrich J, Günster J (2015) Slurry-based additive manufacturing of ceramics. Int J Appl Ceram Technol 12(1):18–25
17. Niendorf T, Leuders S, Riemer A, Richard HA, Tröster T, Schwarze D (2013) Highly anisotropic steel processed by selective laser melting. Metall Mater Trans B 44(4):794–796
18. Cooke W, Tomlinson RA, Burguete R, Johns D, Vanard G (2011) Anisotropy, homogeneity and ageing in an SLS polymer. Rapid Prototyping J 17(4):269–279
19. Guessasma S, Belhabib S, Nouri H, Hassana OB (2016) Anisotropic damage inferred to 3D printed polymer using fused deposition modelling and subject to severe compression. Eur Polymer J 85:324–340
20. Patterson AE (2016) Crack propagation in 3-D printed PLA: finite element modeling, test bed design, and preliminary experimental results. A Technical Report, University of Illinois at Urbana-Champaign

21. Zolfagharian A, Khosravani MR, Kaynak A (2020) Fracture resistance analysis of 3D-printed polymers. Polymers 12:302. https://doi.org/10.3390/polym12020302
22. https://www.gearbest.com/blog/how-to/how-3d-printing-fills-the-gap-between-the-outline-2992
23. Wach RA, Wolszczak P, Adamus-Wlodarczyk A (2018) Enhancement of mechanical properties of FDM-PLA Parts via thermal annealing. Macromol Mater Eng 303:1800169
24. Song Y, Li Y, Song W, Yee K, Lee KY, Tagarielli VL (2017) Measurements of the mechanical response ofunidirectional 3D-printed PLA. Mater Des 123:154–164