Study of Materials and Process Parameters of 3D Printing

Deep Panchal[a*], Chintan Barelwala[b], Jatin Patel[c]

[a] *PG Research Scholar, Mechanical (CAD/CAM), Gandhinagar Institute of Technology, Gandhinagar, Gujarat, India.*
[b,c] *Assistant Professor, Gandhinagar Institute of Technology, Gandhinagar Institute of Technology, Gandhinagar, Gujarat, India.*

Abstract

Now-a-days, most of the technology are the computer based system. i.e., making an object can be easier in CAD/CAM. Here, there is one technology for making complicated objects is 3D Printing. 3D Printing brings two fundamental innovations: the manipulation of object within the digital format and also the manufacturing of recent shapes by addition of material [Digital + Additive Manufacturing]. 3D Printing is an enabling technology that encourages and drives innovation with unprecedented design freedom while being a tool-less process that reduces prohibitive cost and lead times. The material available for 3D Printing have come a long way since the early days of the technology. Currently, a wide variety of different material types are available like, plastic, nylon, Polyamide, Thermoplastics (e.g. PLA, ABS), Eutectic metals, Edible materials, metal alloy, Thermoplastic Powder, Plaster, Liquid resin, Metal foils, ASA, PVA etc. This paper highlights the materials and process parameters of 3D printing technology.

***Keywords*:** Additive Manufacturing, CAD, CAM, ABS, PLA, PEEK.

1. Introduction

Manufacturing is that the creation or production of fantastic with the assistance of kit, labor, machine, tools and chemical or biological processing or formulation. It is the essence of secondary sector of the economy. The term may ask to range of human activity from handcrafted to technology, but its most typically applied to industrial design, within which raw materials from the first sector are transformed into finished goods on an outsized scale. Such goods could even be sold to other manufacturers for the production of other more complex products (such as aircraft, household appliances, furniture or automobile).

Additive manufacturing, also referred to as 3D printing, rapid prototyping or freeform fabrication, is 'the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies' such as machining. The use of Additive Manufacturing (AM) with metal powders is a new and growing industry sector with many of its leading companies based in Europe. It became an acceptable process to produce complex metal net shape parts, and not only prototypes, as before.

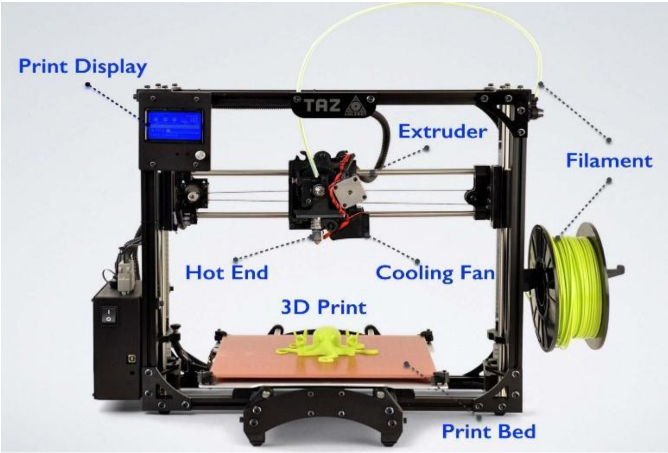

Fig. 1. 3D Printer.

* Deep Panchal
E-mail address: 200120708004@git.org.in

Additive manufacturing uses data computer-aided-design (CAD) software or 3D object scanners to direct hardware to deposit material, layer-by-layer, in precise geometric shape. As its name implies, additive manufacturing adds material to create an object. In contrast, when you create an object by traditional means, it is often necessary to remove material through milling, machining, carving, shaping.

3D printing encompasses many styles of technologies and materials as 3D printing is being used in almost all industries you could think of. It's important to see it as a cluster of diverse industries with a myriad of various applications. Examples: consumer products (eyewear, footwear, design, furniture), industrial products (manufacturing tools, prototypes, functional end-use parts), dental products, prosthetics, architectural scale models, reconstructing fossils, replicating ancient artefacts etc.

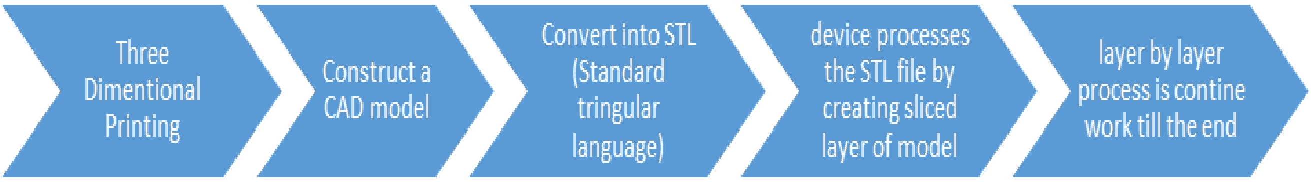

Fig. 2. 3D Printing Technique Basic Steps.

There are several types of 3D Printing, which include:
1. Stereo-lithography (SLA)
2. Selective Laser Sintering (SLS)
3. Fused Deposition Modeling (FDM)
4. Digital Light Process (DLP)
5. Multi Jet Fusion (MJF)
6. PolyJet
7. Direct Metal Laser Sintering (DMLS)
8. Electron Beam Melting (EBM)

Selecting the proper 3D printing process for your application requires an understanding of each process' strengths and weaknesses and mapping those attributes to your product development needs. Let's first discuss how 3D Printing fits within the product development cycle and so take a glance at common types of 3D printing technologies and the advantages of each.

1.1 Stereo-lithography

Vat photo polymerization may be a category of additive manufacturing (AM) processes light-activated polymerization. Stereo-lithography, the first AM process to be patented and commercialized, is a vat photo polymerization technique. Also referred to as stereo-lithography apparatus, optical photo-solidification, or resin printing. Photo polymerization processes make use of liquid, radiation-curable resins, or photopolymers, as their primary materials. Most photopolymers react to radiation within the ultraviolet (UV) range of wavelengths, but some light systems are used furthermore. Upon irradiation, these materials undergo a chemical process to become solid. This reaction is named photo polymerization, and is usually complex, involving many chemical participants.

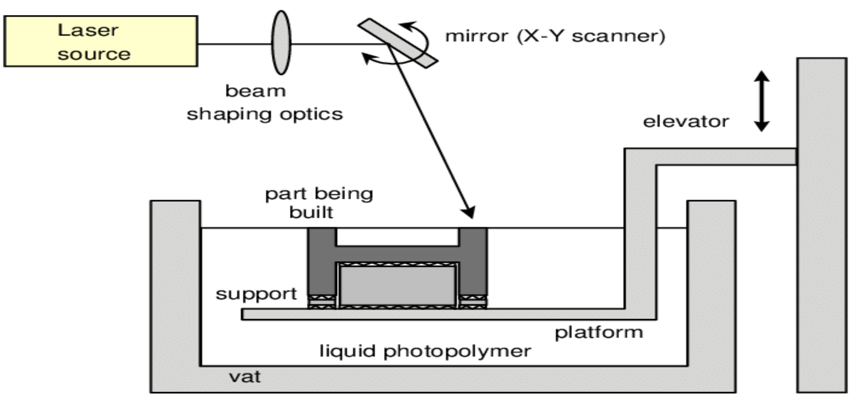

Fig. 3. Stereo-lithography.

Principle: SLA may be a laser based rapid prototyping process which builds parts directly from CAD by curing or hardening a photosensitive resin with a relatively low power laser. Stereo-lithography (STL) is a process for fabricating a solid plastic part out of a photosensitive liquid polymer using a directed laser beam to solidify the polymer. Part fabrication is accomplished as a series of layers, in which one layer is added onto the previous layer to gradually build the required three-dimensional geometry.

1.2 Selective Laser Sintering

Selective laser sintering could be a rapid prototyping process that builds medals from wide variety of materials using an additive fabrication method Selective laser sintering was developed by University of Texas Austin in 1987. The build media for selective laser sintering comes in powder form which is fused together by a powerful carbon dioxide laser to form the final product.
Principle: selective laser sintering relies on the principle that powder of thermoplastic material, metal, composite or ceramics is sintered layer by layer, under the heat generated by CO2 laser to form the part.

1.3 Fused Deposition Modelling (FDM)

Fused Deposition Modelling (FDM) is a common desktop 3D printing technology for plastic parts. An FDM printer functions by extruding a plastic filament layer-by-layer onto the build platform. It’s a cost-effective and quick method for producing physical models. There are some instances when FDM can be used for functional testing but the technology is limited due to parts having relatively rough surface finishes and lacking strength.

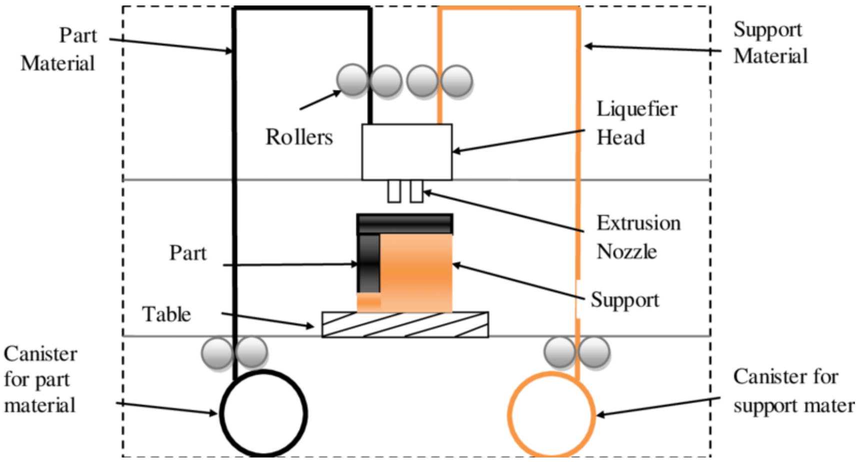

Fig. 4. Fused Deposition Modelling (FDM).

2. Literature Review and Research Gap

By performing various experimental investigation on polymer material, the work done on the material properties like tensile test in the standard size by ASTM D638-03 Specimen. And performance of doing experiment on various polymer material to identify properties of material by changing various process parameters [3]. To changing different parameters like Raster angle, infill density, Layer thickness found different ratio of tensile strength.

2.1 Material

3D printing materials are available in a good array of forms. Most consumer 3D printed products are made of thermoplastics. Designers and engineers prefer creating functional prototypes from 3D printing materials that have the identical or similar material properties as what’s employed in creating the finished product. Plastics are the foremost widely adopted 3D printed material – and it comes in filament, resin, granule, and powder forms. Most thermoplastic 3D printing materials may be employed in home 3D printing technology and professional applications moreover. There are several variable printable materials like PLA, ABS, PVA, NYLON, HDPE, PEEK, RESIN, CARBONFIBRE, NYLON, INCOLE etc.

2.2 Printing Process Parameter

AM consists of the many technologies that create physical parts by the successive addition of materials. Various disciplines like architecture, medicine, engineering, education, and entertainment use AM technologies. To avoid confusion that may hamper communication among different disciplines, this section defines the assorted process parameters supported on ASTM International standards.

1) Raster angle, sometimes called raster orientation, is that the direction of the deposited layers with relevance to the build platform. It always ranges from 0 to 90 [2]. The deposited filaments exiting the 3D printer nozzle form raster's (extrusions) that may be constructed using various angles to fill the inside of the part being manufactured.

2) Layer thickness is that height of every deposited layer within the 3D printed product. A product's height is that the sum of the thicknesses of the stacked layers extruded from the nozzle tip [1]. It depends on the nozzle tip diameter and therefore the filament material.

3) Infill percentage, sometimes called infill density, describes the solidity of the invisible inner structure of a printed part. In other words, it describes the infill volume, which plays an important role in a printed part's strength and mass. Usually, it ranges between 20% and 100%. Infill percentage is taken into account one in all leading parameters that significantly affect the part's mechanical properties [2].

4) Printing speed is that the nozzle's horizontal speed on the build platform during extrusion and deposition. It determines the overall printing time. It depends on the printing technique (stereo-lithography (SLA), selective laser sintering (SLS), and FDM) and also the filament material used. Typically, it ranges from 15 to 90 mm/s. The printing speed influences the material's spread and forming dimension quite all other FDM process parameters [2]. High printing speeds cause to over-extrusion on part edges and reduces extrusion width which winds up in poor dimensional accuracy as additional layers are added before previous layers have completely solidified.

5) Extrusion temperature is defined because the heating temperature for a filament material within the nozzle section during the extrusion process. It varies reckoning on the thermoplastic material type and therefore the printing speed.

3. Material Analysis

3.1 For ABS (Acrylonitrile Butadiene Styrene): Static Tensile Test

In order to determine the mechanical parameters of the tested materials the specimens were printed and extended In static tensile test according the PN-EN ISO 527-1/2012 and PN-EN ISO 527-2/1998 norms.

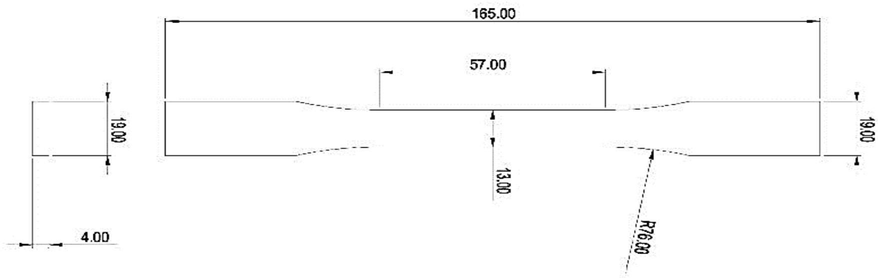

Fig. 5. Material Specimen.

Table 1. Dimensions of Material Sample.

Dimension	Unit
L1	60∓0.5 mm
L2	106-120 mm
L3	≥ 150 mm
B1	10∓0.2 mm
B2	20∓0.2 mm
H	4∓0.2 mm
L0	50∓0.5 mm
L	115∓1 mm

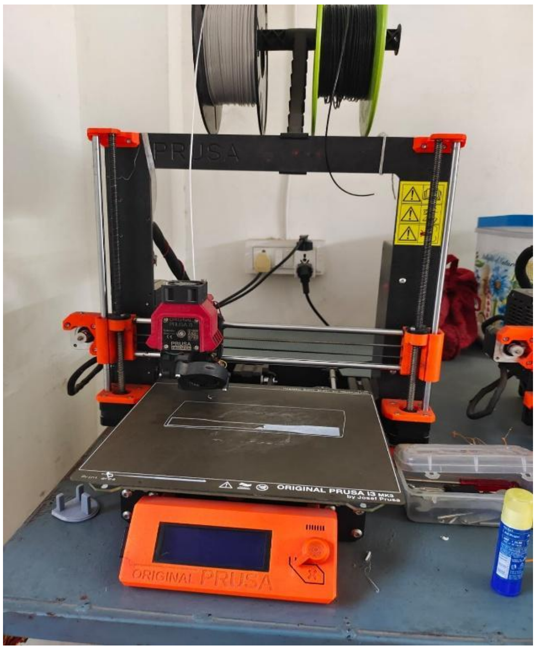

Fig. 6. Printing Material Specimen.

The research was done on standard size specimen (ASTM D638-03) and it was administrated on UTM (Universal testing machine). Machine is provided good sensor 16 md about range of 1000kN load capacity. Program is made for data acquisition. So as to work out the utmost force and values of Young's modulus for the studied materials, orientation and fulfilling, a 3-specimens were examined for a selected configuration. This work presents a comparison of two reasonably materials available on the market. The primary tested material was ABS by Solver and also the second was material named ABS B601 **[1]**. Specimens were printed within the same settings, where *20* means the peak of the paths (0,2 mm), *100* is for chamber temperature (100°), X, Y or Z means the axes orientation and # means the printing fulfilling. The 3D printer default fulfill value is 4. Authors distributed out the research also for value 1 of fulfil.

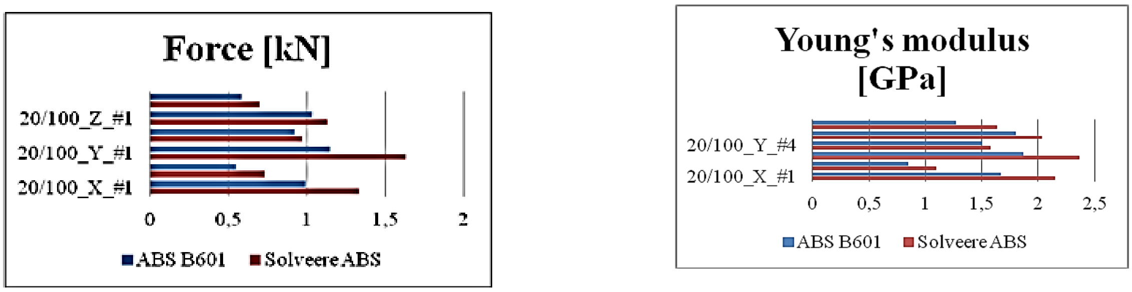

Fig. 7. Maximum strength obtained for the sample and Young's modules obtained for the Sample.

Fig. 8. Specimen Scrap.

The using of 3D printing technology for plastic materials enable rapid prototyping. It reduces the new construction testing time. Reducing the ratio of print fulfil, the printed object stiffness is increasing. Per presented equations, modification in stiffness matrix and mass matrix has a sway on obtained modes. Conducted modal analysis shows that the increasing of tested material stiffness values increase the mods value range [4]. Strength tests shows that ABS by Solve ere material has higher Young's modulus value than the ABS B601 material. Modal analysis enables to avoid the hazardous vibration values of object still in design stage of construction. It's useful gizmo to diagnostic an object construction state.

3.2 For Polylactic Acid (PLA)

Many experiments on PLA material suggest that the last word strength heavily depends on the raster angle the implications of raster angle on the mechanical properties of PLA parts reduced using FDM. The assorted layer thicknesses were 0.1 and 0.2 mm, and three samples of each layer thickness were tested **[4]**. Three distinct infill patterns were used, and thus the experimental results indicate that layer thickness significantly influenced all three pattern's load capacities. A unique mechanical model of assorted mechanical properties that will accurately predict the strength and Young's modulus of FDM PLA. The experimental data show an identical effect of layer thickness on strength while varying the raster angles.

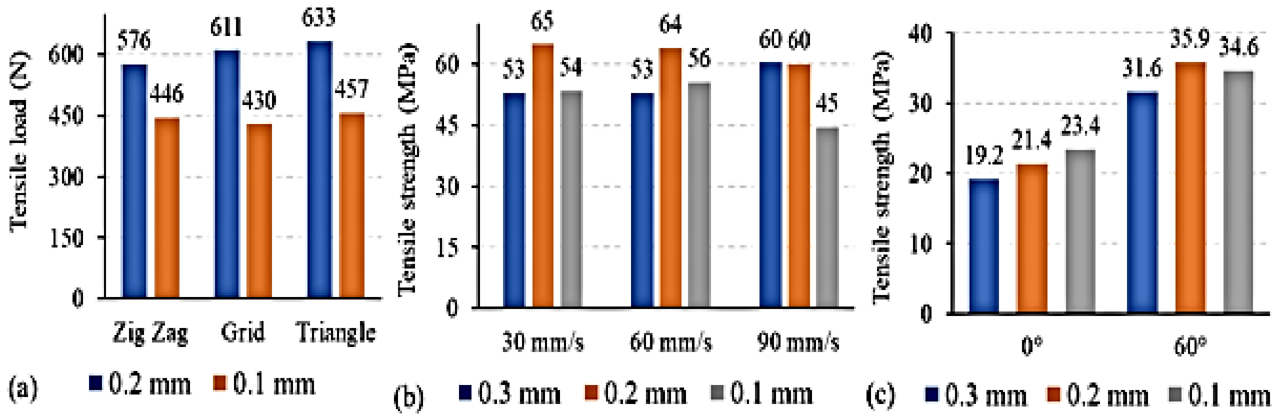

Fig. 9. (i) Influence of raster angle on PLA (a) tensile strength, (b) Young's modulus, and (c) % elongation and PLA strength sensitivity to layer thickness (mm) with different infill patterns.

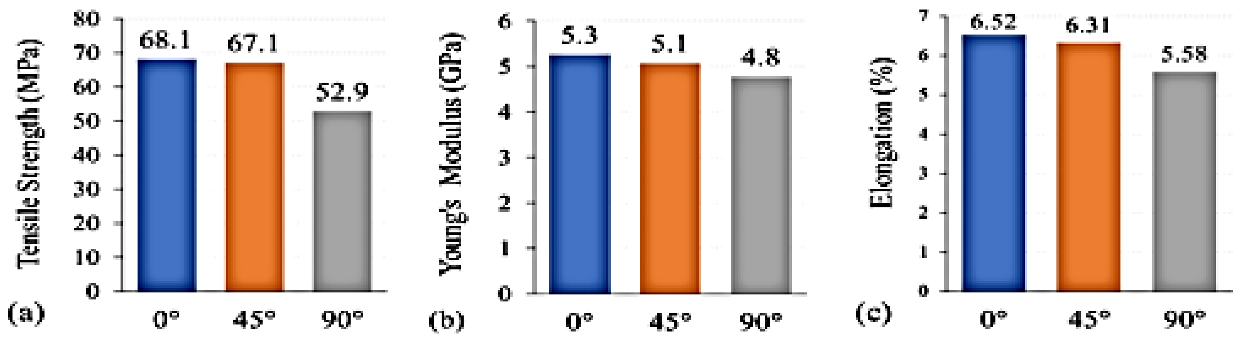

Fig. 9 (ii) Influence of raster angle on PLA (a) tensile strength, (b) Young's modulus, and (c) % elongation and PLA strength sensitivity to layer thickness (mm) with different infill patterns.

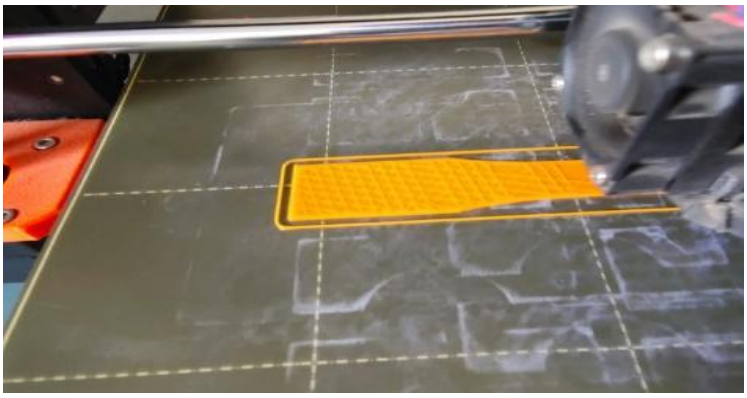

Fig. 10. Printing PLA Specimen.

The effects of varied manufacturing parameters on the mechanical behaviours of PLA parts fabricated via FDM methods. The study concluded that increasing the infill percentage from 20% to 50% improved the UTS by 27%, yield stress by 21%, Young's modulus by 34% and elongation at break by 30% **[4]**. They also concluded that infill percentage influences these characteristics over layer height and build orientation. The increasing the PLA infill percentage from 25% to 75% could enhance the last word durability, yield strength and modulus of elasticity. Different printing speeds have a giant influence on the material's spread and forming dimension. In small parts, high printing speed results in material deformations thanks to new layers being placed on top of layers that haven't yet fully solidified. Consequently, the load of the new layer deforms the previous layer **[4]**. The study shows that different printing speeds (70, 80, 90, 100, and 110 mm/s) don't change Young's modulus by quite 20%. Additionally, higher printing speeds affect how the filament melts and causes poor layer-to-layer adhesion, which ends in lower strength. Additionally, examined the influence of various printing speeds (30, 40, and 50 mm/min) on the PLA's compressive strength.

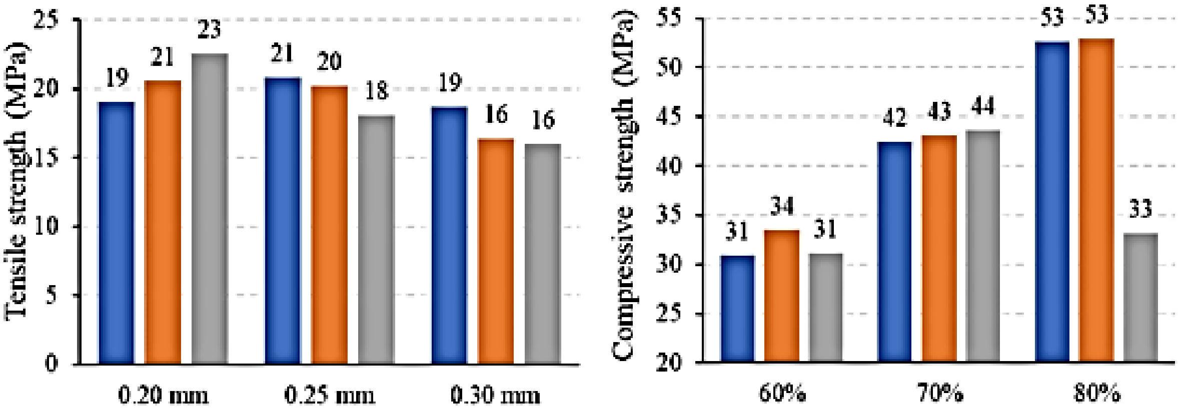

Fig. 11. (a) PLA tensile strength sensitivity to printing speed with different layer thicknesses (in mm) and (b) Compressive strength sensitivity to printing speed with different infill percentages.

Table 2. Process parameters range used for PLA.

PROCESS PARAMETER	RANGE SELECTED	LOW	MIDDLE	HIGH
Raster angle	0◦–90◦	0◦	45◦	90◦
Layer thickness	0.1–0.3 mm	0.1 mm	0.2 mm	0.3 mm
Infill density	20-100%	20%	50%	100%
Printing speed	35-65 mm/s	35 mm/s	50 mm/s	65 mm/s

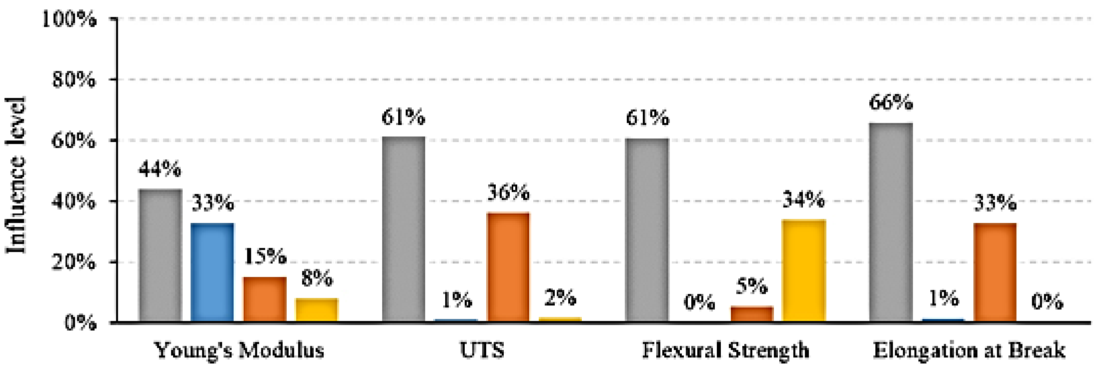

Fig. 12. Process Parameter's relative influence on PLA Mechanical Properties.

3.3 Polyether Ether Ketone (PEEK)

PEEK is a thermoplastic biomaterial that has superior thermal resistance, good dimensional stability, superior creep resistance, and excellent mechanical properties. It is used in compressor seals, aerospace components, and bearings as well as to support bone healing in human bodies. The size of printed specimen has selected of ISO527-02 standardized specimen. The dimensions are mentioned as below:

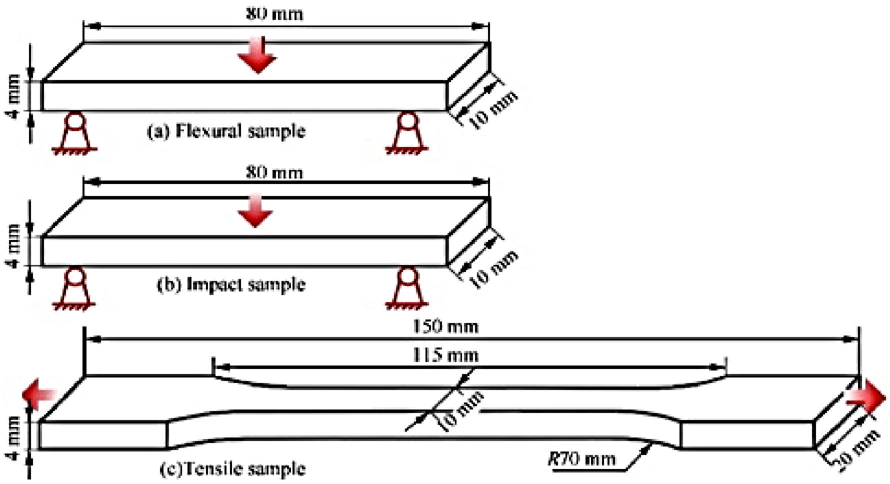

Fig. 13. Dimensions and load case of FDM-3D Printed Samples.

Effects of extruder temperature on mechanical properties including lastingness, flexural strength and impact strength of FDM-3D printed PEEK, CF/PEEK and GF/PEEK parts are illustrated that the extruder temperature can be from 360°C to 400°C, the lastingness and flexural strength of PEEK, CF/PEEK moreover as GF/PEEK increase. However, the impact property of fibre reinforced PEEK composites isn't obviously littered with nozzle temperature.

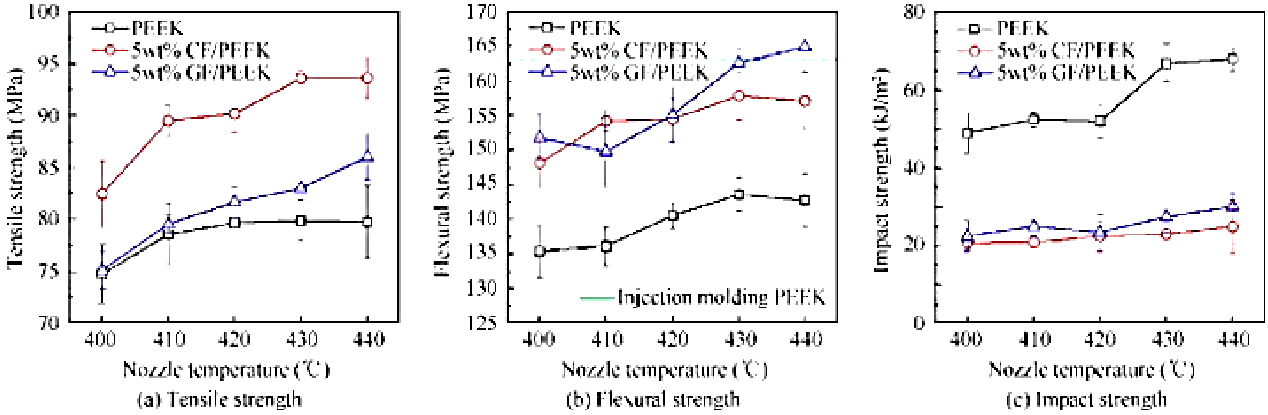

Fig. 14. Effects of Nozzle Temperature on Mechanical Properties.

The effect of platform temperature on the mechanical properties of FDM-3D printed PEEK, CF/PEEK and GF/PEEK parts. It will be seen that the influence regularity of the platform temperature on the mechanical properties is essentially according to that of the nozzle temperature: the tensile properties and flexural properties enhance because the platform temperature rising. When the platform temperature rises from 240 °C to 280 °C, the strength of CF/PEEK increases by most obviously to fifteen, and GF/PEEK has the largest improvement approximately 10% within the flexural strength.

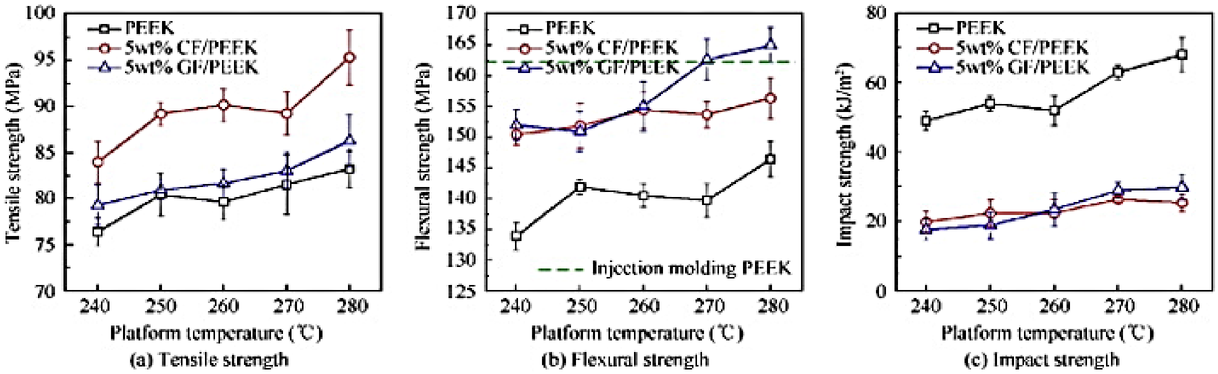

Fig. 15. Effects of Platform Temperature on Mechanical Properties.

While printing the PEEK material thing need to focus is that Control the temperature, Maintain clean nozzle, Keep the PEEK filament dry, Build platform material and Controlling the speed of print.

The effects of FDM-3D printing parameters on tensile properties, flexural properties and impact properties of printed PEEK, CF/PEEK and GF/PEEK samples were explored. So as to analyze the explanations of materials failure, the tensile fractured surfaces were observed by scanning electron microscope **[6]**.

Conclusion

The conclusions are given as follows:

The lastingness and flexural strength of CF/PEEK and GF/PEEK grow with the increase of nozzle temperature and platform temperature, respectively. However, the impact performance of fiber reinforced PEEK composites isn't obviously influenced by temperature. Extruder temperature of 440 °C and platform temperature of 280 °C lead to the largest comprehensive mechanical properties of printed CF/PEEK and GF/PEEK. Higher nozzle temperature makes better melting fluidity and formability of printed materials.
Increasing printing speed and layer thickness has negative effect on all mechanical properties of printed fiber reinforced PEEK composites. The results show that the printing speed and layer thickness are the crucial printing parameters affected the impact strength. The optimal mechanical properties are achieved when the printing speed and layer thickness are 5 mm/s and 0.1 mm respectively.

Result

By doing the various analysis of the specimen by changing the various parameter we find the different changes in the tensile strength, compatibility and the hardness of material occurs, durability as well as using taguchi method for optimization can help in to control material reduction in process. In addition, performing such research we can find out that the result shows the difference by changing some parameters so using this material in various application like aerospace industries, manufacturing in plastic polymers and different sectors of engineering to get better outcome. In future work we'll work on different specimen by using two different material at the same time.

References

1. Agnieszka Łagoda, and Rafał Gabor, 2018, Opole "Strength parameters of the ABS material used in 3D printing" , University of Technology, Faculty of Electrical Engineering, Automatic Control and Computer Science, Prószkowska 76, pp. 45-758.
2. Paweł Żur, Alicja Kołodziej, Andrzej Baier and Grzegorz Kokot, 2020, "Optimization of Abs 3D-Printing Method and Parameters", Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland.
3. Pl. Gwarków, 2019, "Static and Dynamic Mechanical Properties of 3D Printed ABS as a Function of Raster Angle", Department of Material Engineering, Central Mining Institute, Katowice, Poland, 1, pp. 40-166.
4. King Abdulaziz, 2021, "Comparative Study of the Sensitivity of PLA, ABS, PEEK, and PETG's Mechanical Properties to FDM Printing Process Parameters" , Mechanical Engineering Department, Faculty of Engineering, University, P.O. Box 344, Rabigh 21911, Saudi Arabia.
5. Xi'an Jiaotong, Xin Wang, Xiaoyong Tian, Dichen Li, 2021, "Dual mechanisms of fiber dispersion of CF/Sn50Pb50 composites fabricated by double-layer Printing head 3D printing process", State Key Laboratory of Manufacturing Systems Engineering, University, Xi'an 710049, China.
6. Peng WANG, Bin ZOU, Shouling DING, Lei LI, Chuanzhen HUANG, 2020, "Effects of FDM-3D printing parameters on mechanical properties and microstructure of CF/PEEK and GF/PEEK", Centre for Advanced Jet Engineering Technologies (CaJET), School of Mechanical Engineering, Shandong University, Jinan 250061, China.
7. Nesma T. Aboulkhair, Marco Simonelli, Luke Parry, Ian Ashcroft, Christopher Tuck, Richard Hague, 2019, "3D printing of Aluminum alloys: Additive Manufacturing of Aluminum alloys using selective laser melting" , Centre for Additive Manufacturing, Faculty of Engineering, University of Nottingham, Nottingham NG8 1BB, United Kingdom.
8. Zhanghao Hou, Xiaoyong Tian Junkang, Zhang Lu Zhe Ziqi Zheng Dichen Li Andrei V. Malakhov, 2020, "Design and 3D printing of continuous fiber reinforced heterogeneous composites" State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, 28 Xian Ning West Road, Xi'an 710049, China, Mechanical Engineering Research Institute of the Russian Academy of Sciences, Maly Kharitonyevsky Pereulok 4, Russia.
9. Archimede Forcellesea, Valerio di Pompeoa, Michela Simoncinia, Alessio Vitaa, 2020, "Manufacturing of Iso-grid Composite Structures by 3D Printing" , Università Politecnica delle Marche, Via Brecce Bianche 12, 60131 Ancona, Italy bUniversità eCampus, Via Isimbardi 10, 22060 Novedrate (CO), Italy.

10. Dileep Bonthu, H.S. Bharath, Suhasini Gururaja, Pavana Prabhakar, Mrityunjay Doddamani, 2020, "3D printing of syntactic foam cored sandwich composite" Advanced Manufacturing Laboratory, Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal 575025, India, Aerospace Engineering, Indian Institute of Science, Bengaluru 560012, India, Department of Civil and Environmental Engineering, University of Wisconsin-Madison, Madison 53706, WI, USA.
11. Seong Je Park, Ji Eun Lee, Jiyong Park, Nak-Kyu Lee, Yong Son, Suk-Hee Park, 2019, "High-temperature 3D printing of polyetheretherketone products: Perspective on industrial manufacturing applications of super Engineering plastics" Advanced Joining and Additive Manufacturing R&D Department, Korea Institute of Industrial Technology, Advanced Textile R&D Department, Korea Institute of Industrial Technology, 143 Hanggaul-ro, Sangnok-gu, Ansan-si, Gyeonggi-do 15588, South Korea.
12. Tuan Noraihan Azila Tuan Rahim, Abdul Manaf Abdullah, Hazizan Md Aki, Dasmawati Mohamad and Zainul Ahmad Rajion, 2015, "Preparation and characterization of a newly developed polyamide composite utilising an affordable 3D printer", journal of Reinforced Plastics and Composites, Vol. 34(19), pp. 1628–1638.
13. Uday Kiran Roopavath, Sara Malferrari, Annemieke Van Haver, Frederik Verstreken, Subha Narayan Rath, Deepak M. Kalaskar, 2018, "Optimization of extrusion based ceramic 3D printing process for complex bony designs" , Institute of Musculoskeletal sciences (IOMS), UCL Division of Surgery and Interventional Science, Royal National Orthopaedic Hospital-NHS Trust, HA7 4LP, United Kingdom of Great Britain and Northern Ireland Monica Hospital, Monica Orthopedic Research (MORE) Institute & University Hospital Antwerp.
14. Wodesenbet E, Kidane S, Pang S., 2003, "Optimization for buckling loads of grid stiffened composite panels", Orlando JI. Isogrid design handbook, 60, pp. 159–69.
15. Salonitis K, Tsoukantas G, Stavropoulos P, Stournaras A, 2003, A critical review of stereolithography process modeling, (VRAP 03),3rd International Conference on Advanced Research in Virtual and Rapid Prototyping, Leiria, pp. 377–384.
16. Wohlers TT Wohlers report 2012: additive manufacturing and 3D printing state of the industry: annual worldwide progress report. Fort Collins, Wohlers Associates.
17. Wohlers TT Wohlers report 2013: additive manufacturing and 3D printing state of the industry: annual worldwide progress report. Fort Collins, Wohlers Associates.
18. ASTM Standard. Standard terminology for additive manufacturing technologies, 2014, vol. 10.04
19. Wohlers TT Wohlers report 2014: additive manufacturing and 3D printing state of the industry: annual worldwide progress report. Fort Collins, Wohlers Associates.
20. Zheng Q, Jiang D, Huang C, Shang X, Ju S., 2015, Analysis of failure loads and optimal design of composite lattice cylinder under axial compression. Compos Struct, 131, pp. 885–94.
21. Jadhav P, Mantena PR., 2007, Parametric optimization of grid-stiffened composite panels for maximizing their performance under transverse loading.
22. Mack J, Mcgregor O, Mitschang P., 2014, Prepreg lay-up technology for manufacturing of lattice structure fuselage sections.

Acknowledgement

The authors would like to acknowledge Department of Mechanical Engineering, Gandhinagar Institute of Technology for their kind support for the above discussed project work.