Parametric Study of Additive Manufacturing Process in FDM Technology

Jay S. Pinara[a], Chandrakant V. Bhatia[b],Dhaval H. Panchal[c]

[a, b, c]*Mechanical Engineering, Gandhinagar Institute of Technology, Moti Bhoyan, Gujarat-382721, India*

Abstract

Additive manufacturing has got wide applications in different industries. Fused Deposition Modelling (FDM) is one of the most widely used additive manufacturing processes in which the part is manufactured by depositing the material layer-by-layer. Additive manufacturing (AM) is capable of producing complex geometries and components using metal, ceramic, and polymer-based materials. FDM Process uses a continuous filament of a thermoplastic polymer to 3D print layer of products. The benefits of this method are that it has low cost and high speed. It is obvious that a select few applications have claimed greater popularity than the rest. These popular areas are biomaterials, aerospace, buildings, and protective structures. In this study, Poly lactic acid (PLA), Polybutylene terephthalate Glycol (PETG), Acrylonitrile butadiene styrene (ABS) are printed in standard specimen at different angles. Input parameters like temperature, speed and raster patterns are varied for different angles of specimen. At the later stage, different material is compared based on mechanical properties and parameters achieved by testing to finalize the material to be used for printing of commercial products.

Keywords: Additive manufacturing, 3D Printing, FDM technology, Parametric Study, 3D printing materials, study of process parameters.

1. Introduction

1.1. Additive manufacturing or with its more popular name 3D printing is a process of creating physical objects from a digital model by fusing materials layer by layer successively with light, heat or chemicals. These digital models can be formed via computer aided design (CAD) programs or 3D scanners. Then, digital model is sliced into layers by software and sent to the 3D printer for execution.[1]. There are a number of different 3D printing methods, yet 3D printers mainly form layers by either squirting the raw material through nozzles onto a build area or selectively fuse liquid, solid or powdered material. While traditional manufacturing techniques like cutting, machining, punching, and grinding are subtractive since they produce final parts by removing some portion of the mass raw material, 3D printing is an additive process as it produces the parts by bonding raw material as needed.[1].

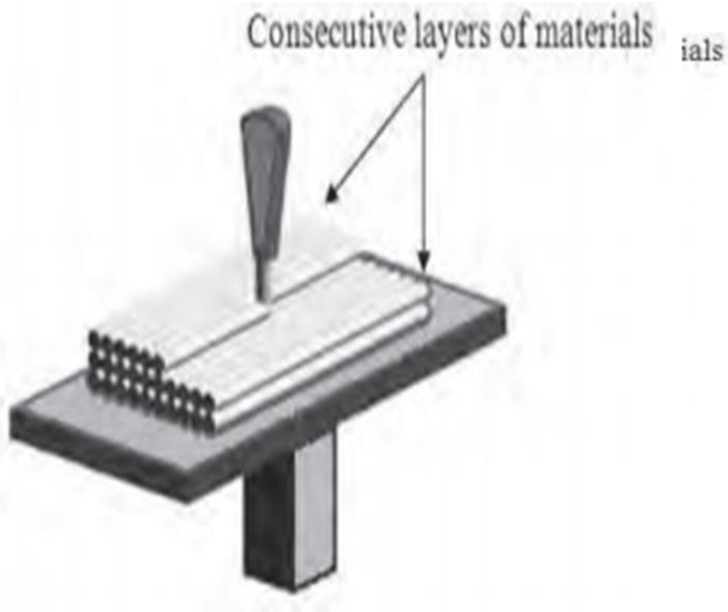


Fig. 1. 3D Printing Process Layer by Layer [1]

1.2. Types of 3D printing process

Solid-based 3D printing: 3D printers that use fused deposition modeling (FDM) produces objects by extruding heated material, usually thermoplastic or metal wire, from a nozzle layer by layer.[1]

Liquid-based 3D printing: in stereolithography (SLA) method, a tank filled with liquid plastic (photopolymer) is used. There is a perforated platform on the top of the tank, and it leaves a thin layer of photopolymer on the surface. [1]

Powder-based 3D printing: selective laser sintering (SLS) works very similarly to SLA except using polymer, metal or ceramic powder instead of liquid plastic. In SLS, laser selectively sinters powdered raw material which is spread as a thin layer on the powder bed. At the end of each cycle, powder bed is lowered incrementally, and a fresh layer of powder is added.[1]

1.3. 3D Printing Applications

1. Desktop 3D printers provide an enormous opportunity for individuals to produce whatever they wish and at their own places, within the dimensions allowed by a desktop 3D printer and raw material possibilities. Hobby items, toys, utensils, ornamental objects are just some of the first examples coming to mind.[1]
2. One of the most amazing examples of 3D printing applications comes from construction sector. Although it is in a very early phase, there have been multiple successful efforts to construct buildings by using gigantic 3D printers. Most popular materials for building printing are plastic, concrete, and sand. If it measures up, building printing may bring about improvements in terms of quality, speed, costs - especially labor costs, flexibility, modularity, work safety, and environmental effects.[1]
3. 3D printing can also be used for other educational purposes, especially regarding science, technology, engineering, and mathematics (STEMS) skills. By utilizing 3D printers, students can design and produce objects in classroom environment and, thus, find a valuable opportunity for testing ideas and learning by doing. This increases fun, teamwork, and interactivity in class as well as supporting creativity, computer skills and three- dimensional thinking ability of students. Thanks to 3D printing, students can see engineering concepts prior to higher education, and university students can comprehend the content of technical courses better.[1]
4. Electronics industry is one of the early adapters of 3D printing technology. 3D printers have been used for production of complex special parts from different materials as well as styling work in this industry. 3D printing is also perfectly suited to the fashion industry, where personalization is critically important. 3D printed custom jewelry and clothes are becoming popular.[1]
5. Aerospace industry is another eager customer of 3D printing technology. Increasing number of aircraft parts, especially those with complex shapes or assembled from different parts, have been produced by 3D printers. This brings about significant advantages regarding tooling, inspection, maintenance, assembly, and inventory. [1]

2. Literature Review

M. Manoj Prabhakar's work investigates the effect of input parameters like filament diameter, extruder temperature, feed rate, raster angle, characteristic of working material, nozzle angle, and distance between parallel faces on output parameters. Some approaches are suggested to maximize these parameters. It is believed a summary of the approaches produced would help compare their major characteristics and their benefits and limitations to help choose one of the most acceptable approaches for a specific application.[3]

Diego bermudez's work, the former 'gold standard', pla grade 4043d, is compared to the newer grade, 3d870. Mechanical properties, rheological characteristics, chemical qualities, and the ability to manipulate the crystallinity of the material were compared between the two. A detailed fracture surface analysis of tensile specimens was also performed that revealed distinct differences in crack propagation behavior between the two materials in the annealed and non-annealed conditions.[4]

Amanuel diriba tura's work presents an experimental examination into the quality analysis of parameters on printed components utilizing fdm. By adjusting process factors such as layer height, raster width, raster angle, and orientation angle, the experiment was carried out utilizing Taguchi's l18 mixed orthogonal array approach. The unitek-94100 universal testing equipment was used to evaluate the flexural strength of acrylonitrile butadiene styrene (abs) specimens that had been conditioned as per astm d790 standard. The impacts of parameters on experimental results were examined and optimized using the hybrid genetic algorithm with response surface methods, response surface approach, and Taguchi method. When the optimal solutions of each technique were studied, the response surface approach and Taguchi methods were determined to be less promising than the genetic algorithm method.[5]

João Francisco’s paper aims to determine the influence that some 3D printing parameters (Filling Density, Extrusion Temperature, Raster Angle and Layer Thickness) have in some of the mechanical properties (Ultimate Tensile Strength, Yield Tensile Strength, Modulus of Elasticity, Elongation at Break and Toughness) of PLA, after it goes through the printing process. It is also the aim to find the scale of the amount of water that it’s absorbed by the PLA and find a way to reduce this absorption. It was also found o3ut that for each parameter value, each mechanical property reacts differently.[6]

Mohammed Hikmat’s paper experimentally and statistically studied the effect of various printing parameters namely build orientation, raster orientation, nozzle diameter, extruder temperature, infill density, shell number, and extruding speed on tensile strength using Polylactic acid (PLA) filament. the specimens of PLA are printed on an FDM 3D printer and tested for tensile strength using the universal testing machine. the confirmation test showed that there is a good agreement between the experimental and statistical data.[7]

3.Design and development of 3D printed sample

3.1. Design

For Testing the material according to 3D Printing process parameters one design is required. Following design is as per the ASTM D-638 Standard. Also, the dimension of design is 165 x 10 x 3.2 mm which can easily print on small size of printer which is easily available in market. The test specimens were designed to conform to ASTM D-638, standard test method for tensile testing of plastics, as illustrated in figure 2. [2]

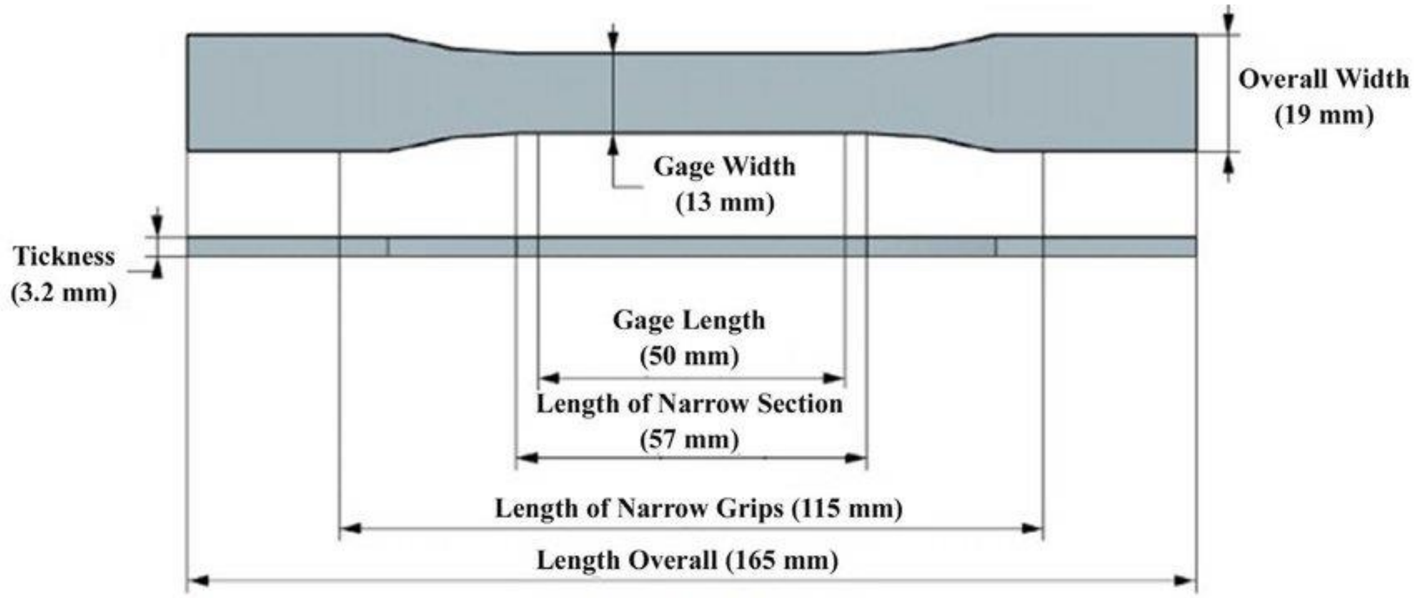


Fig. 2. Design of specimen as per ASTM D638[2]

3.2. Inputs for Sample printing varying process parameters

To test more precisely, total 18 number of samples is taken with 5 parameters which is material, raster pattern, infill geometry, extruder temperature & layer Hight. These parameters can be affected directly on the results.

Table 1. Process Parameters

Sample No.	Material	Raster Pattern	Infill Geometry (%)	Extruder Temperature (°C)	Layer Hight (mm)
1	ABS	(Line)	60	230	0.2
2			80	220	0.3
3		(Triangle)	60	230	0.2

4			80	220	0.3
5		(Grid)	60	230	0.2
6			80	220	0.3
7	PLA+	(Line)	60	190	0.2
8			80	220	0.3
9		(Triangle)	60	190	0.2
10			80	220	0.3
11		(Grid)	60	190	0.2
12			80	220	0.3
13	PETG	(Line)	60	220	0.2
14			80	240	0.3
15		(Triangle)	60	220	0.2
16			80	240	0.3
17		(Grid)	60	220	0.2
18			80	240	0.3

4.Results & Discussions

4.1. Result of Tensile Test

Tensile test is done on UTS machine at Hertz Testing and Training Center, Vatva GIDC. 6 sample is tested on UTS Machine by applying tensile load on it.

Table 2. Result of actual tensile test of sample

Sample No.	Material	Load (KN)	CHT (mm/min)
1	ABS	0.616	3
2	ABS	0.727	3
7	PLA+	1.025	3
8	PLA+	1.331	3
13	PETG	0.925	3
14	PETG	1.284	3

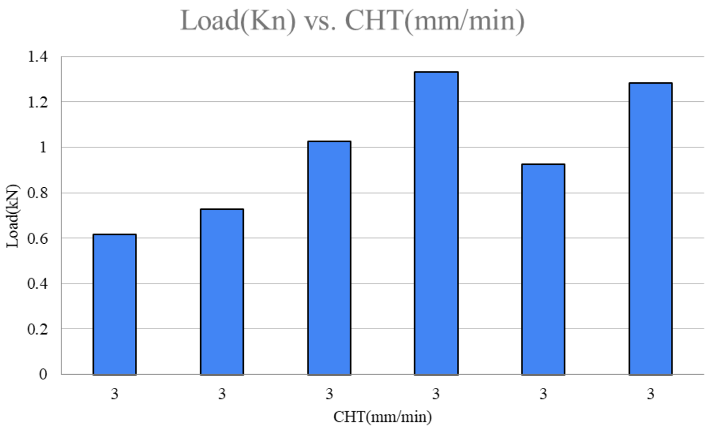


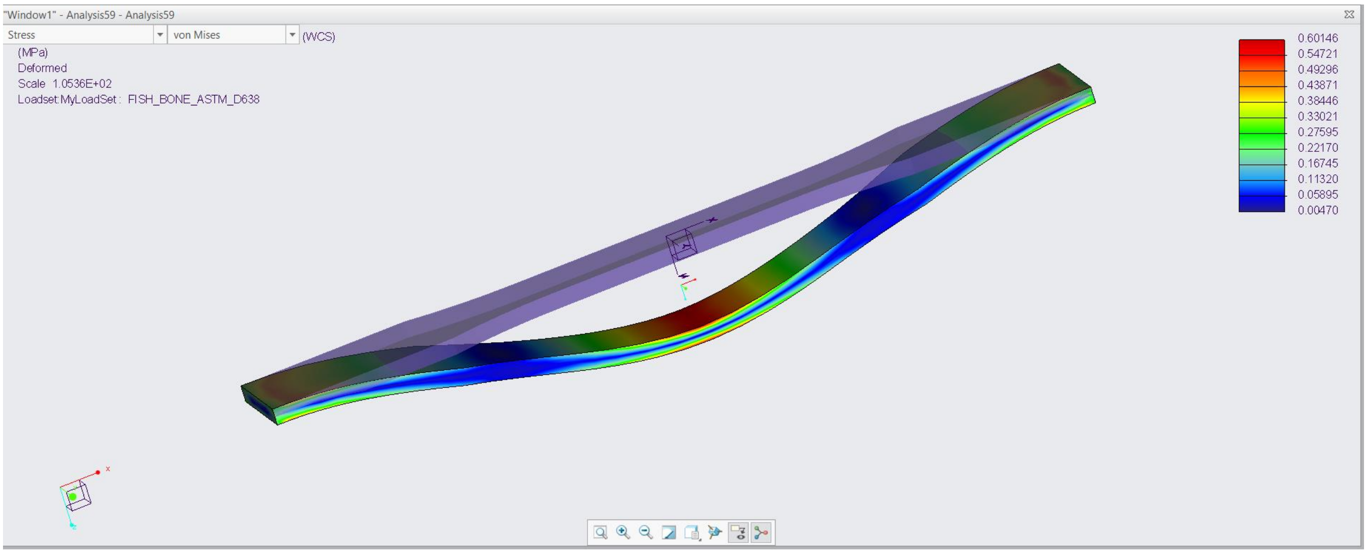
Fig. 3. Graph of Load vs. CHT rate

4.2. Result of Bending Test

UTS machine has limited load applying capacity. It is hard to perform bending test of plastic on UTS Machine.so, to do bending test of specimen CAD software is used to get proper precise results. Line and point loads are applied in software called Creo parametric 4.0 by which the following result is obtained.

Table 3. Result of graphical bending test of smaples

Sr. No	Material	Location of load	Load (KN)	Point Load (Mpa)	Line Load (Mpa)
1	ABS	Centre	0.00071383	0.58525	0.60146
2	ABS	Griping Part	0.00071383	0.50017	0.50160
3	ABS	Side	0.00071383	3.70895	3.70895
4	PLA+	Centre	0.00087545	0.71862	0.74038
5	PLA+	Griping Part	0.00087545	0.60320	0.60479
6	PLA+	Side	0.00087545	4.55420	4.55420

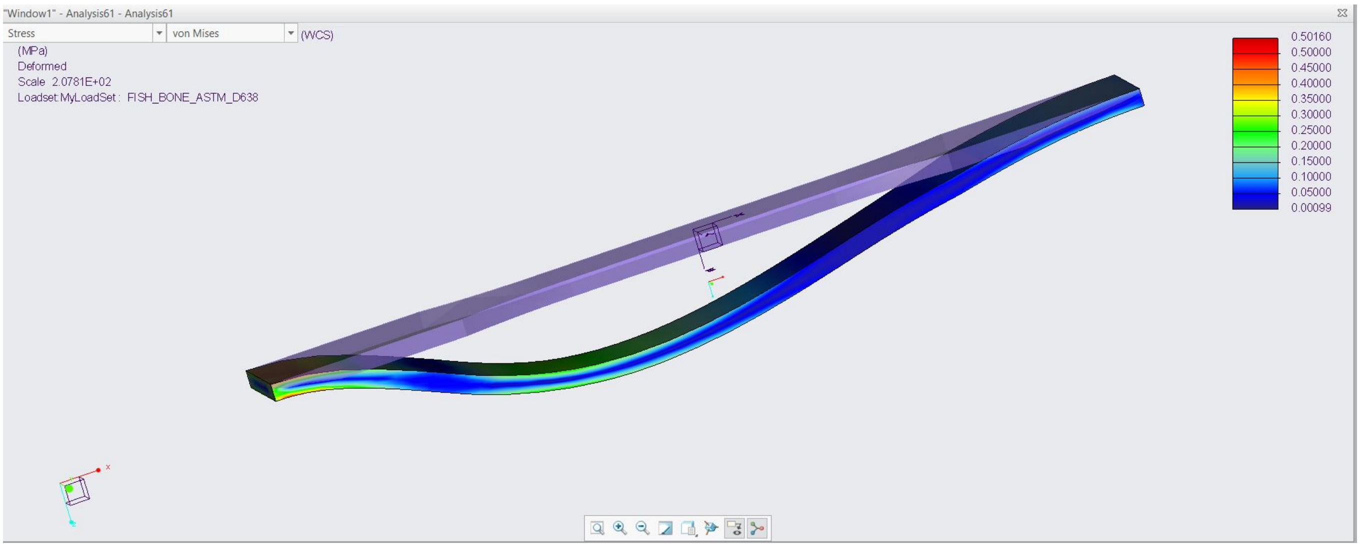


"Window1" - Analysis59 - Analysis59

Stress ▾ von Mises ▾ (WCS)

(MPa)
Deformed
Scale 1.0536E+02
Loadset:MyLoadSet : FISH_BONE_ASTM_D638

Fig. 4. Sample no.1

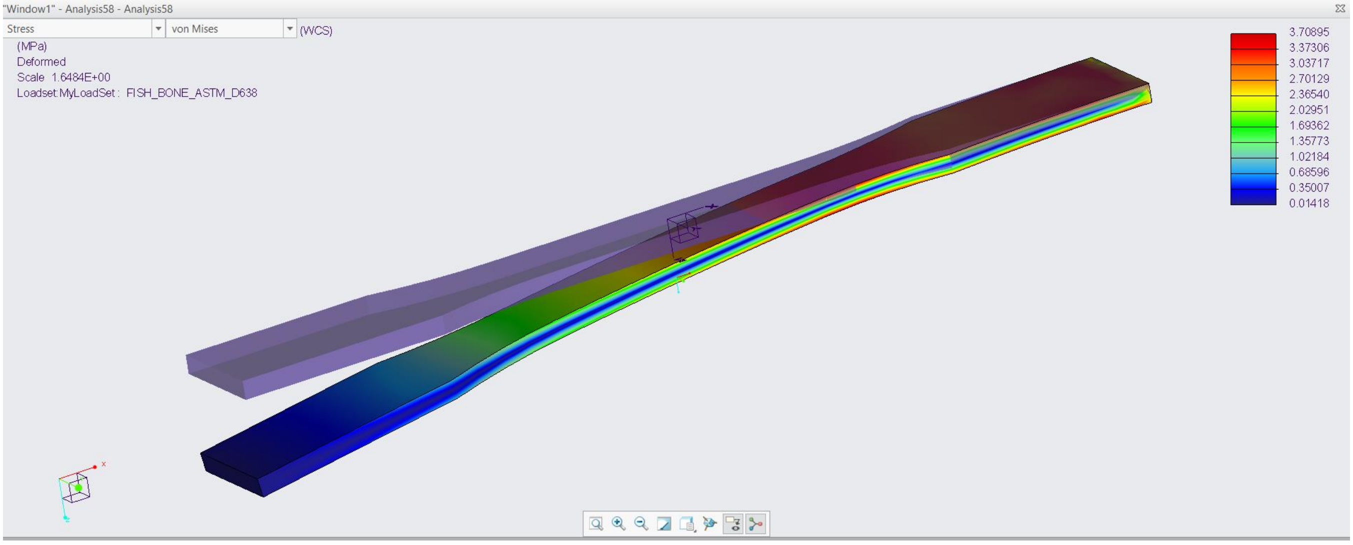


"Window1" - Analysis61 - Analysis61

Stress ▾ von Mises ▾ (WCS)

(MPa)
Deformed
Scale 2.0781E+02
Loadset:MyLoadSet : FISH_BONE_ASTM_D638

Fig. 5. Sample no.2

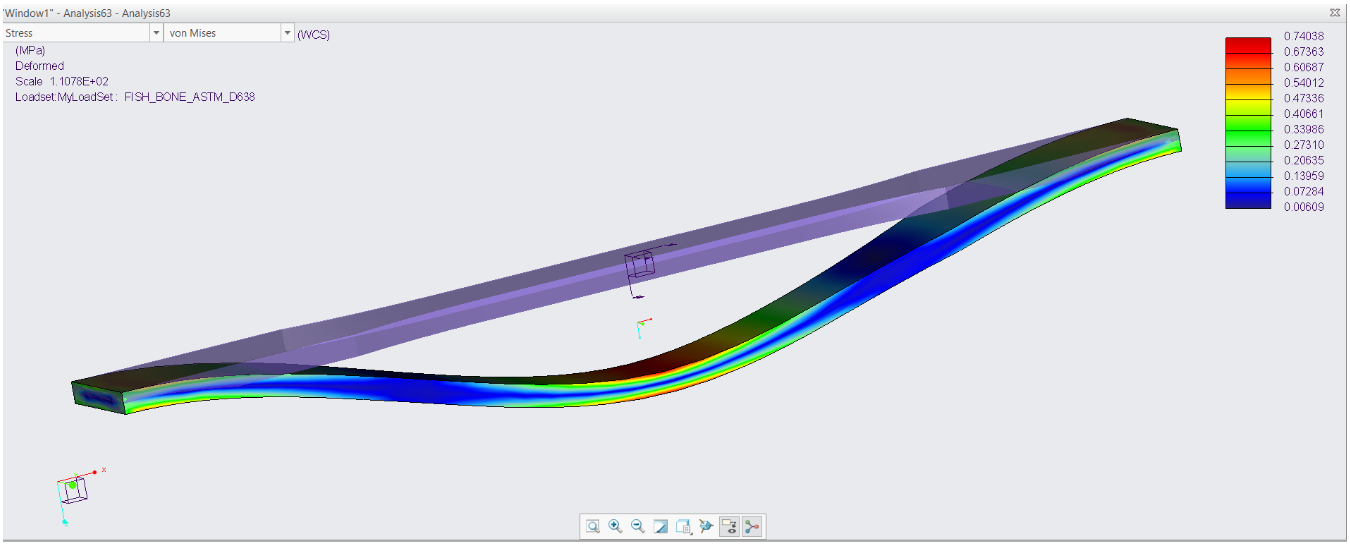


"Window1" - Analysis58 - Analysis58

Stress: von Mises (WCS)

(MPa)
Deformed
Scale 1.6484E+00
Loadset:MyLoadSet : FISH_BONE_ASTM_D638

Fig. 6. Sample no.3

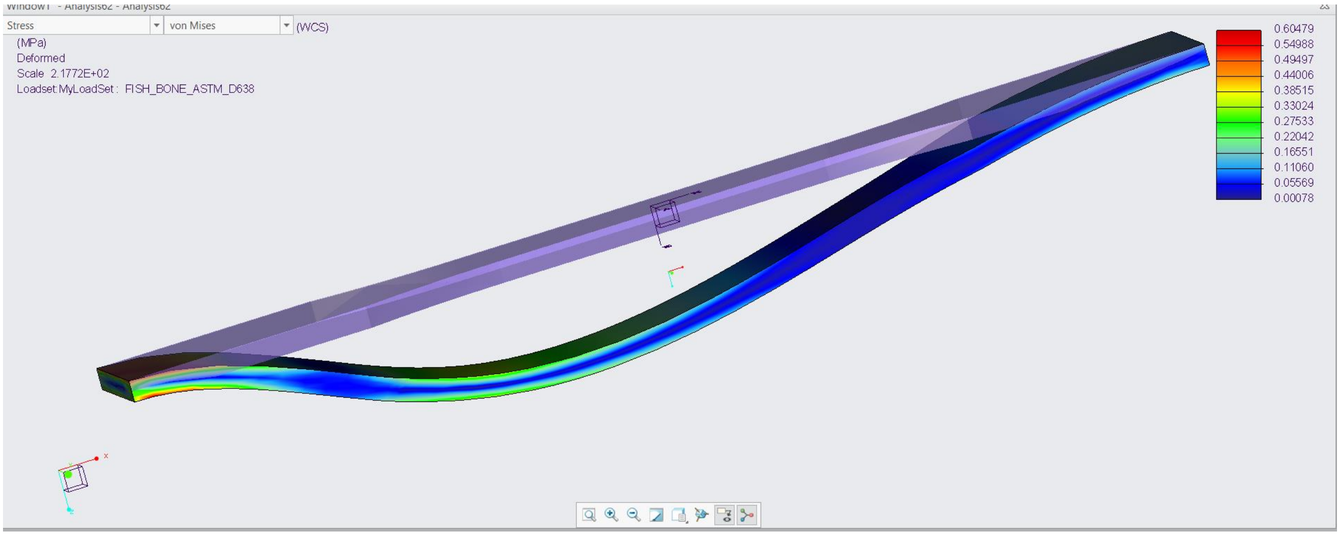


"Window1" - Analysis63 - Analysis63

Stress: von Mises (WCS)

(MPa)
Deformed
Scale 1.1078E+02
Loadset:MyLoadSet : FISH_BONE_ASTM_D638

Fig. 7. Sample no.4

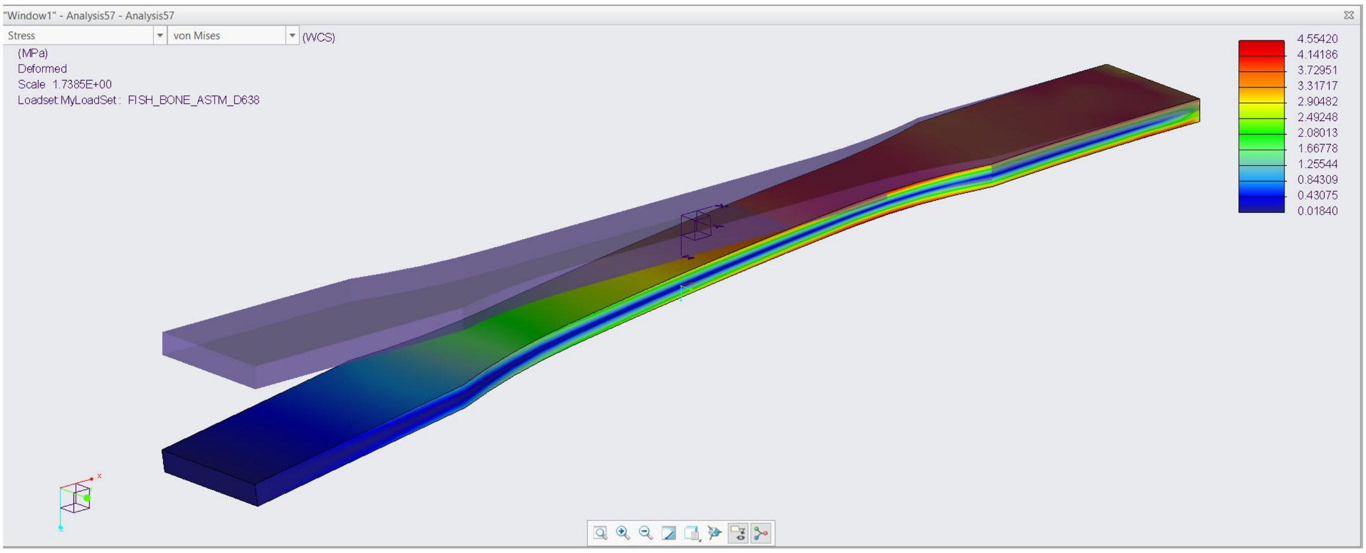


Window1 - Analysis62 - Analysis62

Stress: von Mises (WCS)

(MPa)
Deformed
Scale 2.1772E+02
Loadset:MyLoadSet : FISH_BONE_ASTM_D638

Fig. 8. Sample no.5



"Window1" - Analysis57 - Analysis57

Stress ▾ von Mises ▾ (WCS)

(MPa)
Deformed
Scale 1.7385E+00
Loadset:MyLoadSet : FISH_BONE_ASTM_D638

Fig. 9. Sample no.6

4.3. Summary of Results

As per the results PLA+ material has higher stress sustain capacity showed in Figure 9. in that figure side load has applied on the sample and one end is fixed. The same method is applied on figure 6 and material is ABS. the different between stress sustaining capacity of both the material is very less. But by considering the other properties of material, ABS is Better than PLA+.

4.4. Problem Definition

Now day's technology needs smart gadgets and smart gadgets needs proper handling. Router is one of the known smart gadgets. And it needs proper stand to mount it on wall. But the router stands which is available in market has not suitable material. Which is wooden, fiber & plastic. Also, the material which used in market has lower mechanical properties. Like lower strength & load caring capacity. Design is also not that much effective; all the router stands are wall mounted which can be mounted by screw. Screw halls can damage walls. Which is also not suitable for wall. Also, all the router stand are consuming space of 5-8 inch in room. Design of router stand is also not suitable in aesthetic and agronomical way.

4.5. Design of Router Stand

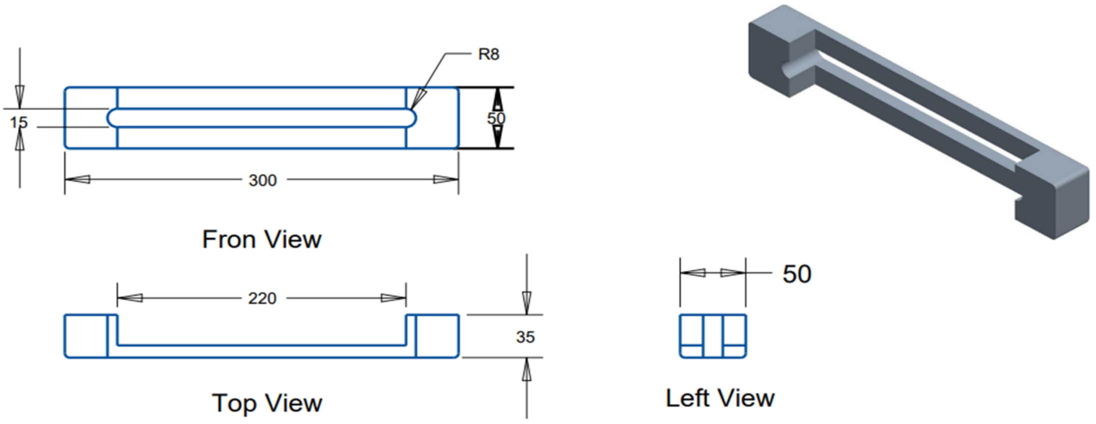


Fig. 10. Fixed Router Stand

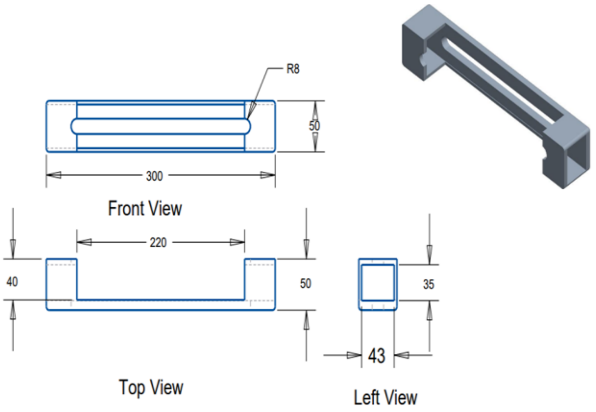


Fig. 11. Fixed Part of Assemble Router

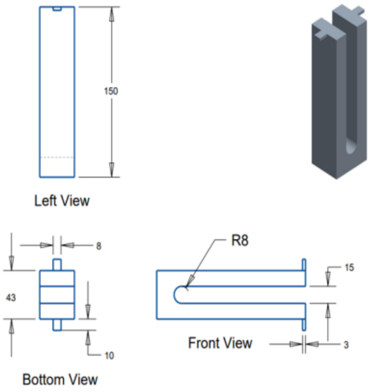


Fig. 12. Moving Part of Assemble Router

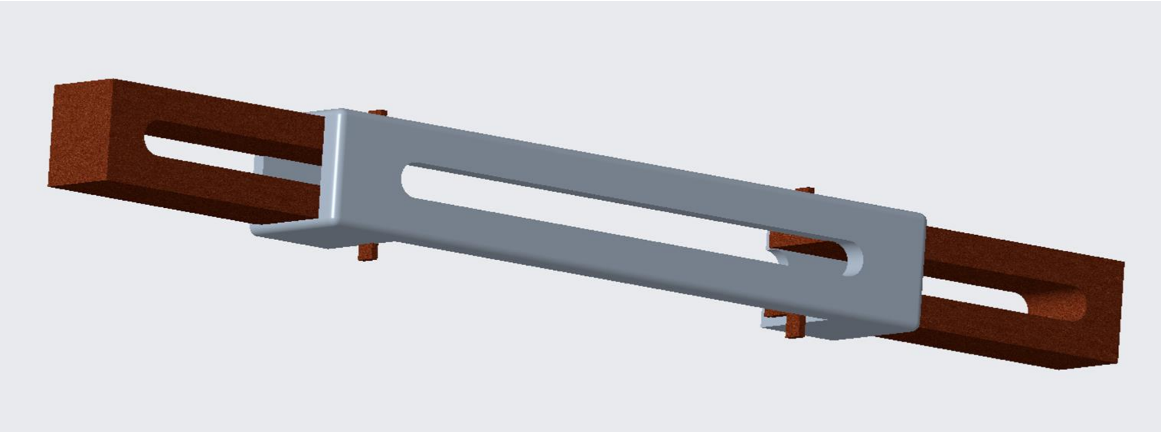


Fig. 13. Assembled Router

4.6. Conclusion

In this work, research demonstrates that the strength of parts manufactured through FDM is significantly affected by important printing parameters. An effort has been made in the present work to assess the effect of mentioned parameters on the mechanical properties of the printed parts. changing in mentioned parameters can be directly affect the mechanical properties of 3D printing materials. Also, it’s observed that Abs has better mechanical properties than Pla. Which can be good effective material for printing of router stand & other commercial products. type of load and location of load is affecting the stress of 3D printed material.

Layer hight is playing good role in increasing of strength of material. After that raster pattern and infill geometry is also affecting the strength of material. Changing in infill geometry, extruder temperature, layer height, raster pattern, type of load and location of load can optimize the final 3D printed product.

References

1. Burak karagöl, (2019) 3D printing: what does it offer and for whom? Science and technology policies research center
2. Kemar Hibbert, Open Journal of Organic Polymer Materials, 2019, The Effects of Build Parameters and Strain Rate on the Mechanical Properties of FDM 3D-Printed Acrylonitrile Butadiene Styrene
3. M. Manoj prabhakar a, A. S. (2020). A short review on 3D printing methods, process parameters and materials. Materials today: proceedings.
4. Diego bermudez, p. A. (2021). A comparison of the physical properties of two commercial 3D printing PLA grades. Virtual and physical prototyping.
5. Amanuel Diriba Tura, Heliyon 8 (2022), Characterization and parametric optimization of additive manufacturing process for enhancing mechanical properties.
6. João Francisco, Instituto Superior Técnico (2020), Study of the Influence of 3D Printing Parameters on the Mechanical Properties of PLA
7. Mohammed hikmat, s. R. (2021). Investigation of tensile property-based Taguchi method of PLA parts fabricated by FDM 3D printing technology. results in engineering 11.
8. Fernandes, j. F. (N.D.). Study of the influence of 3D printing parameters on the mechanical properties of pla. instituto superior técnico, universidade de lisboa, portugal.
9. J.D. Kechagias, K. N. (2021). An investigation of surface quality characteristics of 3D printed PLA plates cut by CO2 laser using experimental design. Materials and manufacturing processes.
10. Joel john, d. D. (2022). Optimization of 3D printed polylactic acid structures with different infill patterns using Taguchi-grey relational analysis. Advanced industrial and engineering polymer research.
11. L. Bergonzi, A. P. (2021). A study on additive manufacturing build parameters as bonded joint design factors. The journal of adhesion.
12. Limtasiria, r. M. (2019). Optimization of stereolithographic 3D printing parameters using Taguchi method for improvement in mechanical properties. Materials today: proceedings.
13. Mamo, A. D. (2022). Characterization and parametric optimization of additive manufacturing process for enhancing mechanical properties. Heliyon.
14. Namsoo peter kima, d. (2018). Optimization of 3D printing parameters of screw type extrusion (STE) for ceramics using the Taguchi method. A department of metallurgical, materials and biomedical engineering, the university of texas at El paso, USA.
15. Ranvijay kumar, r. S. (2021). Polymer- ceramic composites: A state of art review and future applications. Advances in materials and processing technologies.
16. Vinay kumar, r. S. (N.D.). On correlation of rheological, thermal, mechanical and morphological properties of chemical assisted mechanically blended abs-graphene composite as tertiary recycling for 3D printing applications. Advances in materials and processing technologies,2021.
17. Vishwas m, a. C. (2018). Experimental investigation using Taguchi method to optimize process parameters of fused deposition modeling for ABS and nylon materials. materials today: proceedings.
18. Yusuf samed, i. (2020). The breakthrough innovation 3D printing as additive manufacturing. PHYS 374 experimental methods of physics project supervised by prof. Onur tokel.
19. Sunil kumar, (2019.) Influence of inhomogeneous deformation on tensile behavior of sheets processed through constrained groove pressing. Journal of engineering materials and technology, transactions of the ASME.
20. C. P. Khunt, M. A. (2021). Investigations on the influence of printing parameters during processing of biocompatible polymer in fused deposition modelling (FDM). Advances in materials and processing technologies.
21. Jyoti Sekhar Banerjee (2018), An in-depth Study of Implementation Issues of 3D Printer, 1 Department of Electronics & Communication Engineering, Bengal Institute of Technology Kolkata, West Bengal, India
22. F. M. Mwema, Springer Nature Switzerland AG 2020, Basics of Fused Deposition Modelling