Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 12, December-2021

An Overview of The Effects of Process Parameters on The Characteristics of FDM Additively Manufactured Specimens

Mr. Yousuf Pasha Shaik
Applied Logistics and Polymer Sciences
Hochschule Kaiserslautern
Pirmasens, Germany

Mr. Rajashekar Reddy Palle
Applied Logistics and Polymer Sciences
Hochschule Kaiserslautern
Pirmasens, Germany

***Abstract*— Rapid Prototyping (RP) is a technology that involves fused deposition modeling (FDM). Fabrication of 3D products is carried out with the help of 3D printers. Achieving quality in final printed parts has been one of the main challenges. The purpose of this study is to assess the effects of nozzle diameter, nozzle material, and layer thickness on the mechanical properties of 3D printed parts and to suggest possible ways to improve their performance. Results show that nozzle diameter and pressure drop are correlated, and nozzle material depends on the type of filament being used. A layer's thickness determines the roughness of the surface. The greater the layer height, the rougher the surface. Similarly, the printing time varies inversely with the degree of surface roughness. Raster orientation and infill speed are also the most important parameters for the 3D printing process and they have a vital role in specimen strength, printing quality, and surface finish. The samples can be printed more efficiently with materials with high mechanical properties, such as tensile strength, Young's modulus, and melting temperatures.**

Keywords*— Raster orientation; surface roughness; FDM 3D printing; nozzle diameter; nozzle material; pressure drop; layer's thickness; printing time; mechanical properties

I. INTRODUCTION

Manufacturing technology has greatly improved over the years, with much innovation to meet demand. Rapid prototyping (RP) is one of the fastest-growing technologies since the 1960s [1]. There are several types of RP technology, including Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA) [2,3,4]. RP typically begins with importing CAD data, converting it to STL format, and then sending the STL data into the machine, which builds up layers of material until the final layer is created [5]. FDM has an advantage over the other processes because the use of filament forms offers flexibility and reduces the time in the melting chamber. The FDM process is quite simple since the filament is pushed by the roller to be extruded through the nozzle layer-by-layer with complex geometries as the filament is pushed into the melting chamber. FDM is one of the most advantageous technologies for fabricating 3D models, but its cost is an issue. In terms of processes and other components, research has been conducted to minimize the cost. As a result, an open-source 3D printer, commonly referred to as RepRep (replicating rapid prototype) has been introduced at a low price [8]. Availability of the software and design online makes it suitable for home fabrication and research [9]. In RepRep 3D printing, one of the designs is referred to as delta, and it uses three stepper motors to move the shaft [10]. In a recent study, RepRep 3D printing has been modified to be a versatile application of materials and processes and costs less than $1000 (US dollars), which indicates that 3D printing is becoming much cheaper thanks to the availability and accessibility of the technology [11]. It is very important to choose the optimum nozzle diameter, not only to maximize accuracy but also to reduce the extrusion time. Using open-source 3D printing developed for research purposes, it was determined that using an open-source 3D printer with a diameter of 0.3 mm was the best range for extruding PLA material [12]. Typical desktop 3D printers have 0.4mm nozzles. The nozzles are likely to be brass. The softness of brass is fine for printing common materials such as PLA and ABS but becomes problematic when printing exotic materials such as glow-in-the-dark PLA or metal-enriched filaments. A 3D printer's nozzle gradually erodes as a result of the continuous extrusion of filaments containing hard particles. With time, this distorts the opening and inner dimensions of the nozzle, reducing the consistency of what is extruding out of the nozzle at any given moment and affecting the quality of prints. Due to this, 3D printer nozzles made of harder materials are preferred for such applications. Brass nozzles are easily machined, cheap, and widely available, which makes them ideal stock nozzles. Because it has excellent thermal conductivity, it is also used for exotic nozzles where the tip is made from a harder material. PLA, ABS, and PETG are the best options for "Soft" plastic filaments. Metals and carbon fiber are non-particle additives that can be used in 3D printers. Steel is less thermally efficient than brass as a 3D printer nozzle. In particular, this can lead to inconsistent flow performance. Filaments with metal, carbon fiber, and glass additives are the best use of filaments. This is why Olsson created the Olsson Ruby. When combined with a ruby tip, a brass nozzle has the thermal conductivity of brass and the abrasion resistance of ruby (specifically aluminum oxide). A nozzle like the Ruby is ideal for highly abrasive filaments, as with steel. Unlike most printers, this one was specifically designed to print the third hardest material on earth, without giving up after a few hundred grams of material. Tungsten Carbide 3D printer nozzles are relatively new to the market. It was inspired by the heavy mining industries and their use of ceramic for cutting metals and drilling rocks, made by Canadian manufacturer Dyze Design. Tungsten Carbide is hard, abrasion-resistant, and thermally conductive. Tungsten

Carbide 3D printer nozzles are billed as the best "all-rounder", as they could handle abrasive filaments that require a tough nozzle [14]. During this study, two parameters were observed: surface roughness and production duration. Based on the results of the analysis, it can be concluded that layer height affects surface roughness. Surface roughness is lowest on the 0.25 mm layer height, whereas it is smallest on the 0.05 mm layer height. Furthermore, the optimized printing parameters occur for layer heights of 0.15 mm and 0.2 mm [13]. Despite its high tensile strength (75 MPa), nanocarbon has one of the smallest moduli of elasticity (0.62 GPa). In PC-IN polycarbonate, similar to nanocarbon, the tensile strength is 64 MPa, and the modulus of elasticity is 0.52 GPa, the smallest of the tested materials. Both materials are suitable for building high-strength machine parts. PLA and PETG materials have similar tensile strengths -58 MPa and 56 MPa, respectively. PETG, on the other hand, should be used in applications that require greater elasticity, since it has nearly 3.4 times more modulus of elasticity than PLA, which is 19 GPa. A common support material when printing with ABS is HIPS, which has a tensile strength of 10 MPa. All materials tested have a modulus of elasticity larger than 31 GPa. The results obtained were in line with expectations, and they are useful for selecting materials for the construction of machine parts (where tensile strength is an important parameter), as well as a basis for further research. These materials have better mechanical properties than other materials printed at the highest temperatures of the print head and the work table [15]. Slicers work by converting digital 3D models into instructions for a 3D printer to follow to produce an object. Furthermore, the instructions include user-entered 3D printing parameters, such as layer height, speed, and support structure settings. The slicer relies on two inputs to prepare a model for 3D printing: the 3D model itself and a set of printing parameters that tell the machine how to do the actual printing [16]. The concentric pattern yields the most desirable tensile, impact, and flexural strength due to the alignment of deposited rasters and better consolidation of layers with the loading direction. The pressure and temperature of the autoclave have a positive effect on the PLA samples, which helped them to reorganize the structure, hence strength properties were enhanced. The test results were also compared with injection-molded samples for better understating [17]. Research shows that a raster angle of 45* * 45* produces stronger parts than a raster angle of 0* 90*. This study indicates that a slow infill speed improves tensile properties by improving the inner connection between two contiguous roasters. As a result, the detailed analysis of microstructural defects correlated with tensile test results gives insight into the optimization of raster angle and infill speed, as well as opportunities to improve mechanical properties [18]

II. METHODOLOGY

An object is manufactured by fused deposition modeling (FDM) by fusing layers of material in a pattern. Extrusion is usually performed just above the glass transition temperature, then successive layers are added to create the object. FDM 3D printers utilize plastic filament pushed through a hot end, melted, and then deposited in layers on the print bed. Throughout the print, layers are fused, and eventually, they will form the finished part. In 1991, Stratasys trademarked "Fused Deposition Modeling" and the abbreviation "FDM" to brand the technology. FDM and FFF are the same things. With FDM techniques, a wide range of materials may be used, from thermoplastics to chocolates to pastes, as well as "exotic" materials like metal- or wood-infused thermoplastics [16]

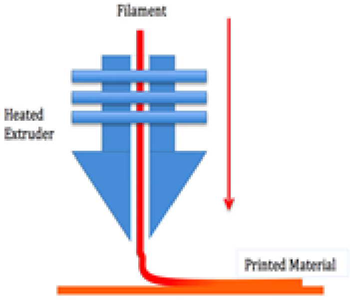


Fig. 1. The basic mechanism of the FDM process

FEA was used to investigate the flow behavior of PLA materials considering all boundary conditions. The flow of material inside the liquefier allowed us to observe the effect of varying nozzle diameter on pressure drop. Different nozzle diameters also affect printing time. A calculation and an experiment were conducted to analyze these issues and suggest the optimal nozzle diameter based on accuracy and printing time [12]. The flow chart in Figure 2 illustrates the overall research method. To begin, CAD software was used to design a specimen. Stereolithography (.STL) files are exported from the 3D model. They are used to generate 3D models for 3D printing. Creality Slicer was used in this research. Before being transferred to the 3D printer machine, it is used to simulate the nozzle movement process. Table 1 gives an overview of the parameters that are set in the 3D printing software. A G-Code file is also exported that contains the coordinates for nozzle movements. The 3D printer machine uses it to guide the movement of the nozzle when building a physical 3D object [13]

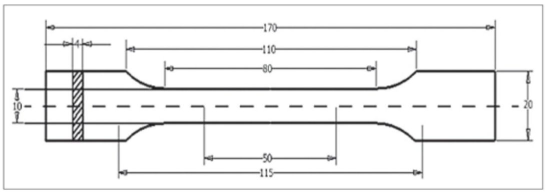


Fig. 2. Sample for strength tests

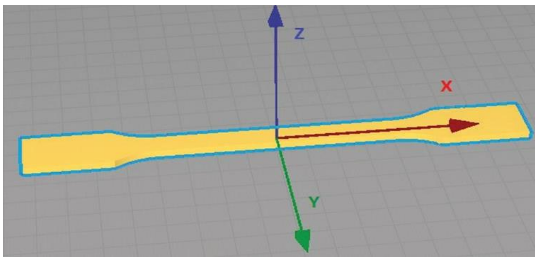


Fig. 3. Setting the sample on 3d printer table- orientation relative to the X-axis

Parameter	Value
Printing speed (mm s-1)	50
Layer Height Variation (mm)	0.05; 0.1; 0.15; 0.2; 0.25
Nozzle temperature (°C)	205
Bed temperature (°C)	60

Table 1 Parameter set on the 3D printing software

The samples for the strength tests were prepared according to PN-EN ISO 527-2. Inventor 2018 files were created in stl format and saved in Autodesk Inventor 2018. Figure 3 illustrates the sample shape with its characteristic dimensions. Figure 4 shows the model of each printed sample oriented along the X-axis. Table 2 summarizes the filament data used for the sample [15]. Using two combinations of raster angles, (45* * 45*) and (0* 90*), along with three different infill speeds, parts were fabricated in three dimensions. Two types of 3D printing materials were used in this study - Polylactic Acid (PLA) and tough-PLA. To identify the best combination of these parameters, each 3D part was investigated for its material properties. Figure 5 shows a scanning-electron-microscopy (SEM) analysis of the outer and inner surfaces, as well as the fracture interface, which was also performed to explain failure modes and reasons in the materials [18].

Filament	**PLA Devil Design**	**PLA PRO Spectrum**	**SmartABS Spectrum**	**PETG Devil Design**	**ASA Devil Design**	**HIPS ArtFlex**	**PC-IN F3D**	**NANO CARBON F3D**	**NYLON FIBERLOGY**
Head temperature	190ºC	205ºC	235ºC	230ºC	240ºC	245ºC	260ºC	250ºC	260ºC
Table temperature	50ºC	50ºC	95ºC	75ºC	95ºC	95ºC	110ºC	115ºC	120ºC
Material feed speed	35 mm/s	35 mm/s	30 mm/s	35 mm/s	35 mm/s	35 mm/s	25 mm/s	25 mm/s	25 mm/s
Cooling	First layer 20% next 100%	First layer 20% next 100%	No cooling	First layer 0% kolejne 20%	No cooling	No cooling	No cooling	No cooling	No cooling

Table 2: List of print parameters for the materials used

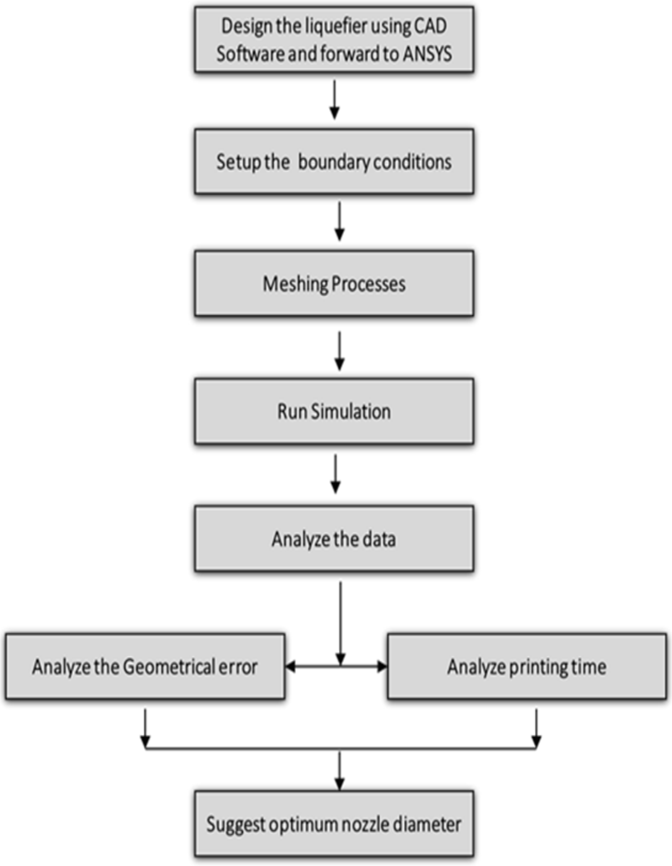
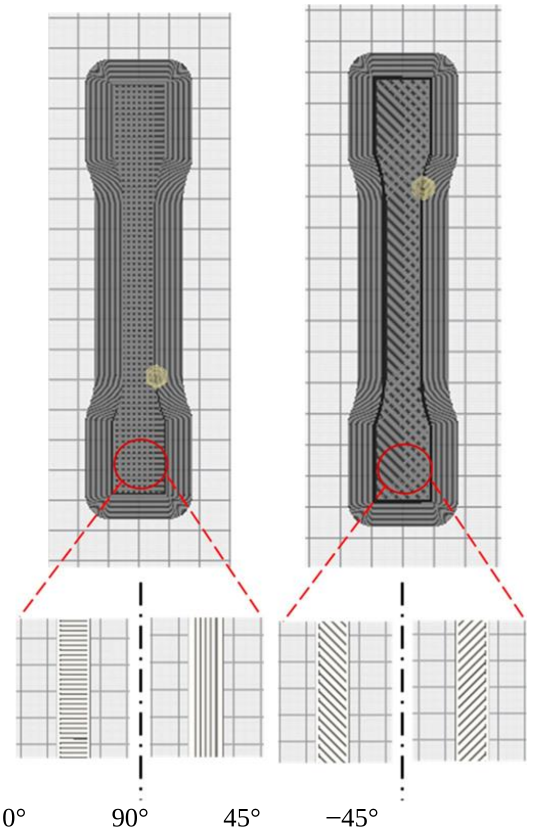


Fig. 4. The general procedure for the research



(a) Roaster angle [0° 90°] (b) Roaster angle [45° −45°]

Fig. 5. (a) Images for the roaster angle (0◦ 90◦). (b) Images for the roaster angle (45◦ −45◦). All images were captured from Ultimaker 3D printer software Cura 4.3.0.

III. RESULTS AND DISCUSSION

As the nozzle diameter varies from 0.2 mm to 0.25 mm, 0.3 mm to 0.35 mm, and 0.4 mm to 0.4 mm, the pressure drop can be seen in Figure 6. The pressure drop increases as the outlet nozzle diameter narrows. In comparison to the 0.2 mm and 0.4 mm nozzle diameters, the 0.2 mm nozzle produces a pressure drop that is almost three times greater. There is a strong relationship between nozzle diameter and pressure drop.

Material	Breaking force value [N]	Tensile strength[MPa]	Relative elongation atbreak [mm]	Yield point [N]	Relative elongation at yieldpoint [mm]	Modulus of elasticity [GPa]
HIPS	391,58	9,79	4,88	127,16	0,19	31,25
NYLON	1420,66	35,52	13,12	1384,08	4,94	23,31
Smart ABS	1875,64	46,89	3,65	0	0	8,59
PLA PRO	1889	47,23	5,52	43,98	0,15	10,29
ASA	1903,28	47,58	4,8	0	0	4,97
PETG	2222,54	55,56	5,325	70,1	0,28	18,83
PLA	2303,56	57,59	6,485	42,72	0,19	5,59
Polycarbonate	2572,12	64,30	6,04	0	0	0,52
NANOCARBON	3002,68	75,07	5,49	2970,4	5,04	0,62

Table 4 List of optimal print parameters for each material

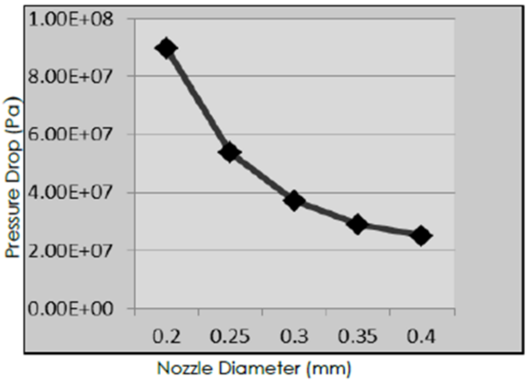


Fig. 6. Decreasing pressure drop as the nozzle angle becomes larger

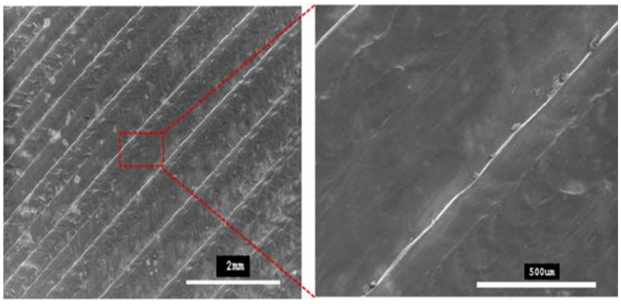
To determine the surface quality of 3D printed parts, layer heights are tested. Therefore, Table 3 shows the average roughness (Ra) as an indicator of surface quality.

	Layer height (mm)				
	0.05	0.1	0.15	0.2	0.25
Roughness Ra (µm)	9.04	9.16	9.11	10.48	12.41
Time Consume (min)	465	235	158	120	97

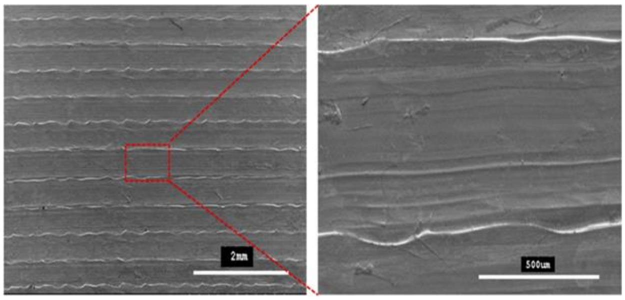
Table 3 Surface roughness of the specimen

In table.4, the test results for different materials are given. The maximum braking force, relative elongation at break, yield point, relative elongation at yield, and modulus of elasticity are given for each material. Since all samples had the same initial cross-sectional area, it was possible to determine the breaking strength for each material. It was also possible to determine the maximum breaking stress

For both materials—PLA and tough PLA, the 45°, -45° raster orientation with a 35-mm/s infill speed produced strong specimens with average ultimate tensile strengths of 64.57 MPa and 53.60 MPa, and highest elongations of 6.6% and 6.8%, respectively. The 0°, 90° raster orientations with the same 35-mm/s infill speed produced specimens with average ultimate tensile strengths of 59.17 MPa and 46.93 MPa (8% and 12% less than the strength of the specimens produced with the 45°, -45° raster orientation with the same speed). Overall, the 45°, -45° raster orientation produced the strongest specimen for both materials and all three infill speeds. The infill speed of 35 mm/s produced the strongest specimen. The value of the ultimate strength decreases as the infill speed increases. A possible reason for this is that the increase in infill speed reduces the deposition time, which results in less interaction and lower inner-connection for the creation of a bond between two contiguous roasters and causes a decrease in tensile properties. This is clearly shown in the figures below

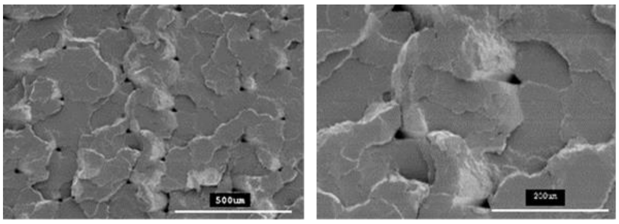


(7a) Raster orientation [45° −45°]

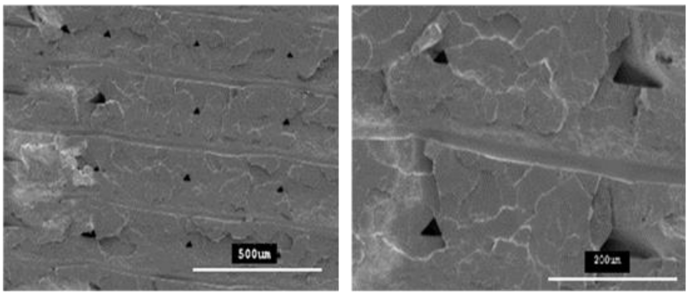


(7b) Raster orientation [0 90°]

Fig. 7. SEM micrographs showing printing patterns on specimens fabricated with (7a) raster orientations (45° −45°) and (7b) raster orientations (0 90°).

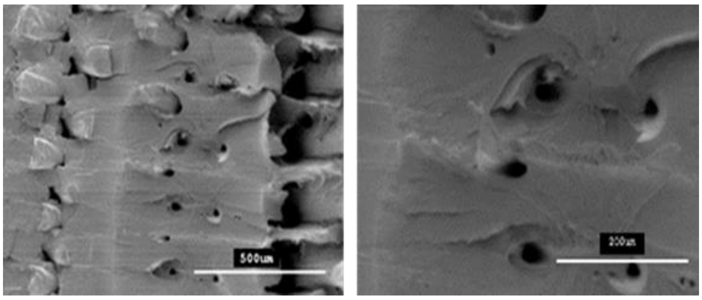


(8a) Sample ID: 7, Raster angles = [45° −45°], Infill speed = 35 mm/s

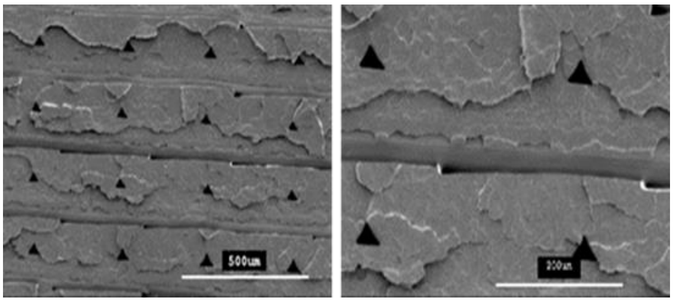


(8b) Sample ID: 8, Raster angles = [0° 90°], Infill speed = 35 mm/s

Fig. 8. SEM images of the fractured interface of tensile specimens fabricated with two different raster orientations (45° −45°and 0° 90°) with 35mm/s infill speed for the PLA material



(9a) Sample ID: 1, Raster angles = [45° −45°], Infill speed = 35 mm/s



(9b) Sample ID: 2, Raster angles = [0° 90°], Infill speed = 35 mm/s

Fig. 9. SEM images of the fractured interface of tensile specimens fabricated with two different raster orientations (45° −45°) and (0° 90°) with 35 mm/s infill speed for the tough PLA material type

CONCLUSIONS

According to the above information, the parameters that affect the mechanical properties and overall quality of 3D printed parts are the nozzle diameter, the nozzle material, layer thickness, and the printed material.

1. Pressure drop is affected by factors such as the nozzle diameter. Not only in terms of accuracy but also in terms of extrusion time, choosing the right nozzle diameter is very important. Because the nozzle diameters of 0.2 mm and 0.25 mm contribute to the highest pressure drop, they are not selected to be in the optimum range. According to one study, using an open-source 3D printer with a 0.3 mm nozzle size is the most efficient way to extrude PLA material.

It is important to match the nozzle material to the filament you want to print with because some filaments are abrasive and will wear down certain types of metal.

2. Surface roughness and printing time are affected by the layer thickness of the nozzle. For a part to print at the 0.05cm layer thickness, it will take approximately 2 hours, and for the 0.07cm layer thickness, it will take approximately 1 hour. To obtain optimal printing parameters, the layer thickness should be a minimum of 0.05cm for detailed parts and 0.10cm for larger parts. For 3D printing, raster orientation and infill speed are the most critical parameters, since they have a direct impact on specimen strength, printing quality, and surface finish. Regular PLA produced stronger specimens than tough PLA. Tough PLA, however, gave better elongation than standard PLA. The raster orientation of 45°, -45° with a low infill speed exhibited higher tensile strength and elongation at break than the raster orientation of 0°, 90° Low infill speeds increase a specimen's strength and toughness by allowing for long deposition times, which allows a bond to form between two contiguous roasters

3. As a combination of nylon and carbon fiber, nanocarbon has the highest breaking strength. PC-IN polycarbonate is another very durable material. Its strength is 14% lower than nanocarbon. Further, there are two materials with very similar strengths: PLA and PETG with 23-26% less strength than nanocarbon, smart ABS, ASA, and PLA PRO with 37% less strength than nanocarbon. When compared to nanocarbon, PA12 nylon is twice as strong. When subjected to tensile testing, nylon showed the most elongation. Compared to other materials, this material showed more than twice the elongation. Smart ABS, however, showed the least elongation. Only 27% of smart ABS elongated as much as nylon. The yield strength of Smart ABS, ASA, and PC-IN polycarbonate materials could not be determined because these materials are brittle. Material made from PLA PRO is twice as elastic and 18% weaker than PLA. To test this, we printed material samples at the highest temperature possible.

ACKNOWLEDGMENT

This research was sponsored by IKW and the University of Applied Sciences Kaiserslautern. I must thank Prof Jens Schuster for the supervision. This work would not be possible without a significant contribution from Mr. Rajashekar.

REFERENCES

[1] Pandey, P. M. 2010. Rapid Prototyping Technologies, Applications, and Part Deposition Planning. Retrieved Oct. 2010, 15.

[2] Chua, C. K., Leong K. F. and Lim C. S. 2003. Rapid Prototyping, Principles, and Applications.2nd edition. Singapore: World Scientific Publishing Co. Pte Ltd.

[3] Hull, C. W. 1986. Apparatus for Production of Three-Dimensional Objects by Stereolithography.US 4575330 A. Washington, DC: U.S. Patent and Trademark Office.

[4] Crump, S. S. 1992.Apparatus and Method for Creating Three-Dimensional Objects. U.S. Patent No. 5,121,329. Washington, DC: U.S. Patent and Trademark Office.

[5] Wohlers, T. T. 2000. Rapid Prototyping & Tooling: State of the Industry: Annual Worldwide Progress Report.USA: Wohlers Associates.

[6] Zein, I., Hutmacher, D. W., Tan, K. C. and Teoh, S. H. 2002. Fused Deposition Modeling Of Novel Scaffold Architectures For Tissue Engineering Applications. Biomaterials. 23(4): 1169-1185.

[7] Roberson, D. A., Espalin, D. and Wicker, R. B. 2013. 3D Printer Selection: A Decision-Making Evaluation and Ranking Model.Virtual and Physical Prototyping.8(3): 201-212

[8] Jones, R., Haufe, P., Sells, E., Iravani, P., Olliver, V., Palmer, C., and Bowyer, A. 2011. RepRap–the Replicating Rapid Prototyper. Robotica. 29(1): 177-191.

[9] Wittbrodt, B. T., Glover, A. G., Laureto, J., Anzalone, G. C., Oppliger, D., Irwin, J. L., and Pearce, J. M. 2013. Life-Cycle Economic Analysis of Distributed Manufacturing with Open-Source 3-D Printers. Mechatronics. 23(6): 713-726.

[10] Rocholl, J. C. 2012. Rostock.

[11] Anzalone, G. C., Wijnen, B. and Pearce, J. M. 2015. Multi-Material Additive and Subtractive Prosumer Digital Fabrication with A Free and Open-Source Convertible Delta Reprap 3-D Printer.Rapid Prototyping Journal.21(5): 506-519

[12] Nor Aiman Sukindara, M. K. A. Ariffinb, B.T. Hang Tuah Baharudinb, Che Nor Aiza Jaafarb, Mohd Idris Shah Ismail, "Analyzing the effect of nozzle diameter in fused deposition modeling for extruding polylactic acid using open-source 3D printing," Jurnal Teknologi, p. 78(10), September 2016.

[13] Redyarsa, D. B, Didin Zakariya, L., and Yanuar Rohmat, A. P, "The effect of layer height on the surface roughness in 3D Printed Polylactic Acid (PLA) using FDM 3D printing," in IOP Conference Series Materials Science and Engineering 1034(1):012096, February 2021.

[14] M. Mensley, "3D Printer Extruder – The Ultimate Guide," ALL3DP, Aug 21, 2019.

[15] M. Snopczynski, "Testing of mechanical properties of materials used in FDM technology," in Mechanik 92(4), April 2019.

[16] Lucas Carolo, https://all3dp.com/, "What Is a 3D Slicer? – Simply Explained," Apr 13, 2020.

[17] Shaik, Y.P.; Schuster, J.; Shaik, A.; Mohammed, M.; Katherapalli, H.R. "Effect of Autoclave Pressure and Temperature on Consolidation of Layers and Mechanical Properties of Additively Manufactured (FDM) Products with PLA". J. Manuf. Mater. Process. 2021

[18] Naveed, N. "Investigating the Material Properties and Microstructural Changes of Fused Filament Fabricated PLA and Tough-PLA Parts". Polymers 2021